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A systematic review on innovations in computer aided design in engineering education

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ABSTRACT

The study addresses the pressing need to keep engineering education curricula up-to-date with advanced computer-aided design (CAD) technologies to understand their practical application in various industrial and research contexts. Given this need, a systematic review was proposed following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) method to evaluate the most recent innovations in CAD systems and their effective application in engineering education. The results reveal that emerging technologies such as real-time virtual collaboration, 3D design, and virtual reality are being incorporated into educational environments, significantly enhancing students' technical and collaborative skills. The research concludes that these technologies not only reconfigure engineering education, emphasizing a practical and updated approach, but also facilitate a more interactive and effective learning experience. This study highlights the urgent need to adapt educational programs to incorporate these innovations, thus ensuring that future engineers are better prepared to face the challenges of modern industry.

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1. INTRODUCTION

Computer-aided design (CAD) has established itself as an essential resource in the field of engineering, exerting a significant influence on the educational process of this discipline [1]–[4]. This innovation has revolutionized traditional project creation and development methods, providing specialists with tools to develop detailed renderings and conduct evaluations through simulations before production [5]–[9]. Its role in academic training is decisive; granting future professionals superior capabilities for the optimal conceptualization and examination of ideas [10]–[12] of technical disciplines with teaching in exact and applied sciences has become essential, evidencing the inseparability between technical advance and specialized training within the science, technology, engineering, and mathematics (STEM) spectrum [13]–[17]. The improvement of spatial perception, driven by this resource, is recognized as essential for success in analysis and problem-solving tasks [11], [16]–[19]. Specialized texts highlight the need for constant renewal in the management of these tools to guarantee cutting-edge education.

Curriculums must evolve at the pace of the latest advances and developments, such as augmented reality, that have changed the professional environment [11], [20]–[23]. It is suggested that the most beneficial educational environments could be those that implement cutting-edge teaching strategies, emphasizing the importance of integrating emerging technologies, including this specific software, into curricula [24]–[27]. However, a detailed examination of the latest CAD technologies is essential to effectively integrating the newest and most efficient tools into the academic program. The rapid evolution of these technologies and their incorporation into the industry demands constant and agile updating of academic programs to ensure that graduates have relevant and up-to-date skills. Contrary to what is indicated in specialized writings, which highlight the relevance of addressing this requirement through research, it is equally vital to update study plans to integrate advances such as augmented reality and interactive design methods. It is essential to adjust this version to meet the needs of the market and the constant innovative advances in this area [28]–[31]. On the other hand, the adoption of these developments is presented as key to the increasing relevance of digital skills in technical fields, particularly in the face of the challenges presented by industry 4.0 [32], [33]. However, the global crisis has highlighted the need to review and adjust teaching methodologies, including digital design instruction, to ensure the continuity and effectiveness of learning in non-face-to-face modalities [29], [34], [35].

The objective of our systematic review seeks to investigate the integration of the most recent innovations in assisted design software in technical training. These include studies focused on the implementation of current technological developments, such as augmented reality and interactive design approaches, within educational curricula [36]–[38]. Another aspect is the exploration of how adapting teaching methodologies to these technological advances can improve teaching and learning in virtual and non-face-to-face contexts, a need that has become particularly urgent in response to recent global challenges [39]–[43]. Specifically, we propose to determine the latest trends and technological innovations in the field of CAD systems and their application in the educational context, and the questions that guided this review were:

i) What are the most recent trends and technological innovations in the field of CAD systems?
ii) How are these new CAD technologies being applied in engineering educational environments?
iii) What benefits do they offer in terms of learning experience and skill acquisition?
iv) What limitations and challenges does the integration of these emerging CAD technologies imply in teaching?
v) What recommendations are proposed for an effective implementation of these innovations?

2. METHOD

The study in question used the preferred reporting items for systematic reviews and meta-analyses (PRISMA) method to conduct a systematic review [44], [45]. The PRISMA method is internationally recognized and provides a rigorous and transparent framework for conducting systematic reviews [46]. Following PRISMA guidelines, the study involved several stages, including identification of the research question, search and selection of relevant studies, data extraction and analysis, and synthesis of results [47]. As a search strategy, the following combinations of terms were used: (CAD and engineering), CAD, university and software AND engineering AND education; keyword: "Computer-aided design".

Articles published without distinction in languages in 2019 and 2023 were reviewed. The inclusion criteria included peer-reviewed studies published in scientific journals. Studies should address the use of CAD software in engineering-level educational programs. Study participants must be students or faculty in engineering programs, and studies must describe or evaluate interventions that use CAD technologies for educational purposes. Results related to the impact of CAD innovations in education will be considered, such as improvements in learning, design skills, or teaching efficiency. In this review, studies published before 2019 are excluded to focus on recent and relevant research. Duplicates and multiple versions of the same study will be discarded, and conferences, non-academic resources such as technical reports or blogs will not be considered. Studies that lack relevant information on methodology, results, or conclusions will be excluded from the review. The sources of information were an electronic search of articles published between 2019 and 2023 in the Scopus, Wiley, and Science Direct database.

3. RESULTS

The search strategies yielded 3,110 references. During the selection process, 3,041 references that did not meet the inclusion criteria were eliminated after reviewing the title and abstract (first step). The 69 selected references were read to confirm eligibility (second step), which can be seen in Figure 1. Once the selection process was completed, 11 studies were included. Review of the 69 selected full-text references resulted in the exclusion of 58 studies that did not meet our inclusion criteria. The results of the remaining 11 studies are presented below in a descriptive manner, since the nature of these studies does not allow any other type of analysis. Likewise, Table 1 (see Appendix) presents the results in a concise manner.

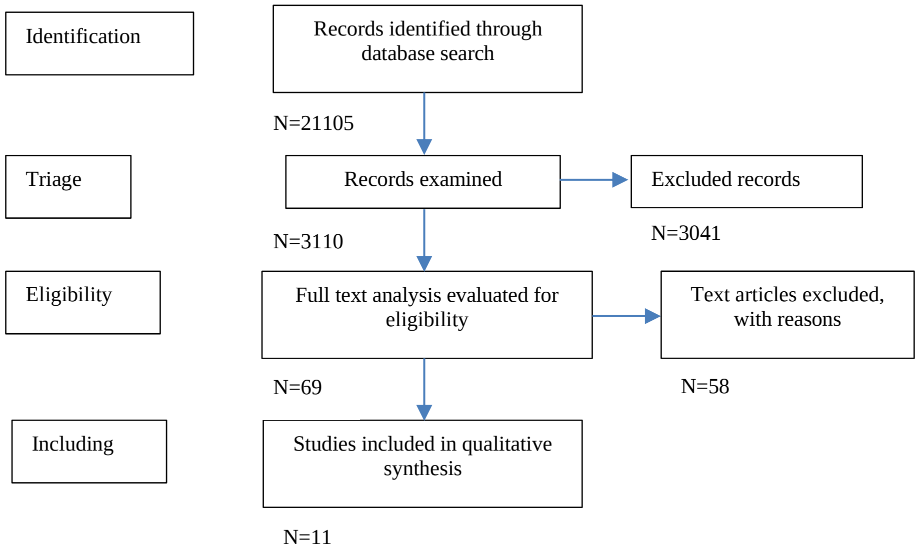

Figure 1. PRISMA flowchart [24]

3.1. Characteristics of the included studies

The eleven studies included in this review were published between 2019 and 2023, focusing on the teaching of CAD in the field of engineering. These studies encompass a variety of approaches and methodologies, such as the implementation of interactive tools, the application of problem-based learning (PBL) techniques, and the integration of advanced technologies such as virtual reality. The results of the systematic review on technological trends and innovations in the field of CAD systems and their application in the educational context are presented, answering the five research questions formulated in the introduction.

3.1.1. What are the latest technological trends and innovations in the field of CAD systems?

Recent technological trends and innovations in the field of CAD systems have seen significant evolution, ranging from virtual collaboration to the integration of advanced technologies. According to Deng *et al*. [48], one of the notable trends is real-time virtual collaboration within multi-user environments for CAD, underscoring the growing importance of interaction and teamwork in CAD. In a similar vein, Ramatsetse *et al*. [49] emphasize the transition to more advanced techniques, such as 3D CAD, which represents a step toward improved complexity and capability in CAD tools. Singh *et al*. [50] have investigated the use of machine learning to enrich the educational experience in CAD design, indicating a growing integration of artificial intelligence into these systems. For their part, Wang *et al*. [51] have applied CAD-based multivalued color image segmentation for smart classroom optimization, demonstrating how CAD is used to improve educational infrastructure.

Cerra *et al*. [30] introduce interactive self-assessment tools into CAD learning using AutoCAD, demonstrating an evolution towards more interactive and student-centered teaching methods. Ramonell and Chacón [52] described the use of low-cost terrestrial laser scanners for the virtualization of geometric entities in AEC classrooms, evidencing the expansion of CAD technology to new fields and applications. Assaf and Vacca [53] present a virtual reality trainer for the fluid power curriculum, replicating physical laboratory experiences on a virtual platform, indicating a movement toward immersive and digital learning environments. Wong and Shih [54] propose to integrate product design and CAD into STEM education, representing a holistic approach that unites design, engineering and CAD technology.

Gadola *et al*. [55] introduce an integrated design tool for teaching automotive suspension design, covering everything from early kinematics to CAD vehicle dynamics simulations and FEM modeling. Alves and Putnik [56] add the importance of interoperability of CAD systems and education based on social networks, using an experiential learning model to teach interoperability in industry 4.0 environments. Finally, Berselli *et al*. [57] highlight the use of integrated CAD/computer-aided engineering (CAE) software for the analysis of mechanical devices in a single parametric environment, which is becoming an industry standard. These innovations and trends reflect a clear direction toward simplification of modeling procedures and a reduction in associated time and cost. The integration of advanced technologies, real-time collaboration, and a focus on interactive, student-centered teaching methods are transforming the field of CAD systems, preparing it to meet the challenges of the future with greater effectiveness and efficiency.

3.1.2. How are these new CAD technologies being applied in engineering educational environments?

In the field of engineering education, the application of new CAD technologies is marking a before and after in the teaching and learning methodology. Deng *et al*. [48] introduce the innovative MUCAD-CLF collaborative learning framework, applied in a collaborative design challenge with students, demonstrating the potential of these tools to foster teamwork and creativity in design projects. Ramatsetse *et al*. [49] highlight the role of engineering graphic design (EGD) in enhancing creativity and innovative product design, underscoring the importance of fusing art and technique in engineering education. Singh *et al*. [50] for their part, focus on the personalization of CAD learning through machine learning algorithms, allowing teaching to be more adapted to the needs and learning rates of each student.

Wang *et al*. [51] highlight how CAD can be used to improve the efficiency and functionality of smart classrooms, representing a significant advance in the integration of cutting-edge technologies in the educational space. Cerra *et al*. [30] combine PBL with self-assessment tools in CAD, offering a richer and more autonomous learning experience. Ramonell and Chacón [52] using terrestrial laser scanning (TLS) in the classroom to teach measurement principles and real-time point cloud visualization brings a practical, applied dimension to engineering education. Likewise, Assaf and Vacca [53] apply virtual reality to overcome logistical and safety challenges, providing a safe and flexible way to experiment with complex engineering concepts.

Wong and Shih [54] suggest the integration of CAD and product design approaches into STEM education, thus encouraging more holistic and multidisciplinary learning. Gadola *et al*. [55] describe the application of an integrated design tool in teaching automotive suspension design, underscoring the importance of practical experience in engineering education. Alves and Putnik [56] implement an experiential learning model for the interoperability of CAD systems in an industrial engineering course, using a project-based approach and just-in-time learning. This approach highlights the importance of collaboration and autonomous learning in a social network environment, preparing students for the challenges of industry 4.0.

Finally, Berselli *et al*. [57] detailed a CAD/CAE-based learning project at the University of Genoa, which involves working in small groups on an industrial design. This project highlights the importance of collaboration and active learning, preparing students for real-world collaborative and creative challenges. In short, the integration of these CAD technologies into engineering education is transforming not only how students learn and apply their knowledge but also how they prepare for the demands and challenges of the professional world.

3.1.3. What benefits do they offer in terms of learning experience and skills acquisition?

The incorporation of new CAD technologies in engineering education is providing significant benefits in terms of learning experience and skill acquisition. According to Deng *et al*. [48], the transition towards multi-user CAD environments, which actively promote real-time virtual collaboration, is significantly boosting the development of teamwork skills and communicative effectiveness among students, thus facilitating deeper and more efficient collaborative learning in the educational field of engineering. Ramatsetse *et al*. [49] highlight the transition from traditional drawing methods to more advanced techniques such as 3D CAD, which implies a development in the understanding and application of cutting-edge technologies.

Singh *et al*. [50] highlight that the integration of machine learning with CAD design is profoundly transforming engineering education, facilitating a highly personalized teaching approach that dynamically adapts to the individual needs and learning pace of each student, thereby improving conceptual understanding and performance in design. Wang *et al*. [51] developed a CAD-based multi-valued color image segmentation algorithm to improve the efficiency of smart classrooms, achieving a more interactive and effective educational environment. The implementation of this algorithm has been shown to significantly increase the functionality of the smart classroom, reducing teacher workload by 20% and raising student learning efficiency by 20% as well. Through this innovation, smart classrooms benefit from greater computerization and improved capabilities, facilitating classroom communication and classroom efficiency.

Cerra *et al*. [30] stand out in the field of engineering education by introducing interactive self-assessment tools in CAD systems, such as TrainCAD for AutoCAD, offering significant benefits in the learning experience and acquisition of skills. In their study with 191 first-year mechanical engineering students, the integration of these tools in a PBL approach resulted in notable improvements in academic performance and motivation, compared to using PBL alone. This method promotes students' autonomy and critical reflection, allowing them to receive immediate and personalized feedback, crucial for effective and autonomous learning. Additionally, it makes it easier for instructors to monitor learning progress in real time, optimizing CAD teaching. This approach not only improves educational efficiency, but also prepares students for real-world design challenges, evidencing a positive impact on engineering education. Previous research [52], [53] expand the benefits of engineering education by integrating virtual and practical environments, significantly enriching experiential learning and the understanding of complex concepts, and validating this improvement through implementation and direct feedback from students in their respective studies. Assaf and Vacca [53] developed a virtual reality tool for the fluid power curriculum, allowing students to interact with hydraulic circuits realistically in a virtual environment, where the evaluation of its effectiveness is based on the students' self-reported satisfaction and learning, showing positive acceptance and recognition of acquired skills. On the other hand, Ramonell and Chacón [52] present an open-source terrestrial laser scanner for the virtualization of geometric entities in AEC classrooms, making it easier for students to understand complex geometries through the visualization and interactive manipulation of data in real time. The active involvement of students and the discussion generated during the scanner demonstrations validate the positive impact of this technology on learning, demonstrating how these technological approaches not only make learning more interactive, but also deepen theoretical understanding through practical application.

Wong and Shih [54] emphasize improving creativity and learning performance by integrating product design and CAD into STEM education. This holistic approach not only increases technical skills but also encourages innovative thinking among students. Gadola *et al*. [55] offer a practical and detailed approach to suspension design, providing students with a realistic and comprehensive experience in mechanical design. Finally, other research [56], [57] expand these benefits by encouraging self-organization, hands-on learning, and the development of advanced skills in the use of integrated CAD/CAE tools. Research by Alves and Putnik [56] highlight the importance of the interoperability of CAD systems in an industry 4.0 environment, while Berselli *et al.* [57] emphasize the acquisition of strategic knowledge and specific skills in industrial design. Together, these innovations and applications of CAD systems in engineering education are revolutionizing the way students acquire technical skills and develop critical competencies for their professional future, effectively preparing them for the challenges and demands of modern industry.

3.1.4. What limitations and challenges does the integration of these emerging CAD technologies into teaching entail?

The integration of emerging CAD technologies into engineering education comes with a number of challenges and limitations that require attention. Although Deng *et al*. [48] do not specifically detail limitations in their study, it is possible to infer challenges such as the skills gap and the need for advanced technological resources for the effective implementation of these technologies. Ramatsetse *et al*. [49] point out the need to improve spatial and visual skills in both students and teachers to adapt to new design tools. Singh *et al*. [50] recognize significant challenges related to the collection and processing of large amounts of data, as well as the adaptation of machine learning systems in the educational context. For their part, Wang *et al*. [51] identify specific challenges related to the high investment cost, system design complexity, and maintenance costs associated with smart classrooms.

Cerra *et al*. [30] although they do not mention specific limitations, suggest that challenges include the need to adapt teaching methodologies to the new technologies and tools available. This adaptation is crucial to ensuring that pedagogical methods are aligned with the capabilities and potentials of emerging technologies. Several researches [52], [53] mention the cost and logistics challenges associated with advanced technologies, which may be an impediment to their widespread adoption in educational settings. Wong and Shih [54] highlight the need for appropriate learning materials and accessible CAD software, underscoring the importance of effective and affordable teaching resources.

Gadola *et al*. [55] highlight the need for a specific interface for the effective integration of CAD software in teaching, which involves careful consideration of interface design and user experience. Alves and Putnik [56] emphasize the challenges in teaching CAD system interoperability and the need to adapt teaching methodology to incorporate project-based and social media approaches. Finally, Berselli *et al*. [57] emphasize the importance of adapting engineering curricula to include training in advanced virtual prototyping technologies, aligning with current industrial trends. This approach ensures that students are prepared for the challenges and demands of the modern world of work.

3.1.5. What recommendations are proposed for an effective implementation of these innovations?

For an effective implementation of innovations in CAD systems in engineering educational environments, various studies have proposed a series of recommendations. Deng *et al*. [48] recommend actively promoting collaboration between students with different levels of CAD skill, emphasizing that this strategy has the potential to deepen the educational process by facilitating a rich exchange of knowledge and experiences. This collaboration not only allows less experienced students to learn effectively through direct guidance from their more advanced peers but also gives more experienced students the opportunity to consolidate their own knowledge by teaching others, thus reinforcing your understanding and skills in CAD. This mutual exchange not only accelerates the learning of newbies, providing them with practical insights and applicable advice, but also prepares more experienced participants for leadership roles and improves their communication skills, aspects crucial for their professional future. Ramatsetse *et al*. [49] emphasize the importance of adapting teaching to technological advances and market demands, ensuring that students are prepared for current professional challenges.

Singh *et al*. [50] propose careful integration of machine learning into CAD systems, focused on the individual needs of students, to personalize and optimize their learning experience. Wang *et al*. [51] recommend optimizing image segmentation algorithms in CAD to improve the operability and adjustment of smart classrooms, which implies a multifaceted approach that combines virtual and augmented reality in education. Cerra *et al*. [30] advocate the integration of innovative teaching methodologies such as PBL along with self-assessment tools and advanced CAD technologies. This combination is proposed to improve the effectiveness of teaching and learning in CAD. Ramonell and Chacón [52] suggest that low-cost terrestrial laser scanners can be used in a variety of ways in the classroom, such as interactive demonstrations and hands-on exercises, providing students with valuable skills in computational geometry and digitization.

Assaf and Vacca [53] recommend the use of virtual simulators to complement traditional laboratory experiences, offering a safe and controlled environment to experiment and learn. Wong and Shih [54] propose the adoption of innovative learning tools and online learning systems, which would facilitate access and flexibility in engineering education. Gadola *et al*. [55] suggest a step-by-step educational process for complex projects and design competitions, allowing students to develop design and problem-solving skills in a realistic context. Alves and Putnik [56] recommend an experiential learning model that combines education based on social networks and learning platforms to teach the interoperability of CAD systems, encouraging self-organization, collaborative learning, and innovation.

Finally, Berselli *et al*. [57] emphasize the importance of a project-based learning approach that integrates design and simulation using a single CAD/CAE software package. This approach promotes students' ability to solve real problems and work as a team, effectively preparing them for the challenges of the world of work. Together, these recommendations point towards CAD teaching that is more collaborative, interactive, and aligned with current industry trends, ensuring that students acquire the skills necessary for their professional development.

4. DISCUSSION

The current study provides a comprehensive systematic analysis of the latest developments in the application of CAD technologies in engineering education. The integration of novel technologies, such as live virtual interaction, three-dimensional modeling, and simulated reality, in educational environments is highlighted, underscoring their role in the significant progress of students' technical and teamwork skills. These tools not only renew educational strategies in the field of engineering but also foster a highly interactive and successful learning experience.

The results show that the incorporation of advanced CAD technologies drives an updated and modern educational approach. These technological advances allow students to effectively address and solve complex challenges, providing solid preparation for the demands of today's work environment. They encourage interaction and cooperation between students, enhancing essential skills for today's world of work.

The latest developments in the field of CAD systems highlight an important technological advance, characterized by the implementation of virtual collaboration in real time and the inclusion of artificial intelligence in design contexts. Deng *et al*. [48] highlight the importance of virtualization and collaboration in contemporary CAD education, demonstrating how multi-user software can enhance pedagogy in this area. In their study, Ramatsetse *et al*. [49] investigate the use of engineering and design graphics with the purpose of enhancing the creation of innovative products, which represents a step forward towards more effective and sophisticated design methods. Finally, Singh *et al*. [50] examine the ability of machine learning to anticipate student performance in design activities with CAD software, highlighting the relevance of incorporating artificial intelligence to provide automated support to students. These trends indicate a movement toward more complex and efficient design practices, enabled by advanced technologies that promote greater interaction and teamwork. However, it is essential to conduct more research to fill these gaps and discover new ways to safely and efficiently incorporate artificial intelligence into design to fully realize its potential in CAD systems.

The inclusion of CAD technologies in engineering education has transformed approaches to teaching and knowledge acquisition. The MUCAD collaborative teaching model presented by Deng *et al.* [48] highlights the relevance of cooperation and digitalization in CAD teaching, highlighting how these tools stimulate inventiveness and group collaboration. In their study, Ramatsetse *et al*. [49] analyze the relevance of EGD in optimizing the creation of novel products, demonstrating how CAD tools promote inventiveness and productivity in the development of designs. In another vein, Singh *et al*. [50] investigate how adapting the teaching process using machine learning algorithms can enhance education in the field of engineering, providing a more adjusted and effective method for personalized teaching.

The integration of modern CAD technologies significantly enhances the teaching process and the development of relevant skills. Online cooperation and individualized teaching, highlighted by Deng *et al.* in their MUCAD collaborative learning model [48], promote the growth of communication skills and provide a more detailed understanding of CAD. On the other hand, Singh *et al.* [50] highlight the importance of personalizing the teaching process through machine learning algorithms, which favors the creation of more adapted and effective learning. Likewise, the introduction of interactive tools and immersive learning environments, as evidenced in the research of Cerra *et al.* [30] enriches the educational experience by promoting more independent and effective learning. These progresses indicate an improvement in teaching through the use of advanced technologies that promote participation and autonomy in the learning process.

When introducing novel technologies in engineering education, challenges arise such as updating technological resources, disparity in competencies, and related expenses. It is essential to adjust educational strategies so that they are in tune with the possibilities offered by these technologies. Ramatsetse *et al.* [49] discuss the importance of engineering graphics and layout in improving innovative product design through a systematic review, underscoring the critical role of emerging technologies in engineering education. On the other hand, Berselli *et al.* [57] highlight the benefits of incorporating advanced technologies into curricula to promote creativity and collaboration in engineering education through project-based teaching with cutting-edge CAD/CAE tools. The importance of overcoming logistical and economic challenges is raised to promote greater integration of these technologies in the educational field.

To achieve adequate incorporation of new CAD technologies in engineering education, it is essential to promote interaction between students with different skills or abilities, as mentioned in the collaborative learning approach [48] which highlights the relevance of working together to enhance the understanding and use of CAD. Singh *et al.* [50] highlight the importance of incorporating the use of artificial intelligence to individualize the educational process. They recommend that the modification of study plans incorporate these technological tools in order to promote learning that is more adjusted to the particularities of each student. Likewise, the improvement of pedagogical resources and approaches is crucial [30], [54], as the application of interactive resources and the inclusion of CAD instruction in STEM education with the purpose of fostering the technical and practical skills required by students to meet the challenges of contemporary industry. Implementing these advanced tactics ensures that students not only gain relevant CAD skills but also cultivate teamwork and problem-solving skills critical to their future careers.

The findings have fundamental implications for engineering education professionals and those responsible for designing curricula. They highlight the importance of updating and adjusting curricula to incorporate CAD technologies not only as additional resources but as fundamental elements of teaching. Additionally, they support investment in technology and teacher training to maximize the benefits of CAD in educational settings. In this analysis, various restrictions are identified, such as the constant required updating of technologies and the possible difficulty in the learning process for teachers and students.

This study offers a solid foundation about the effectiveness of CAD tools in engineering education. To expand this knowledge, it would be wise to include in future research an analysis of technologies that are becoming obsolete in the field of engineering in response to changing market demands. The analysis should examine how current technological trends, such as artificial intelligence, three-dimensional printing, and the incorporation of sophisticated CAD systems, are replacing tools and approaches that used to be common.

5. CONCLUSION

It is essential to highlight the relevance of integrating the latest CAD and CAE tools into university engineering education. The project-based pedagogical tactic turns out to be an effective approach to stimulating experiential learning, allowing students to practically apply the theoretical concepts acquired in the classroom. This method not only improves technical understanding but also promotes critical and problem-solving skills, essential in the professional practice of engineering. By implementing these pedagogical strategies, it is possible to significantly raise the quality of teaching in the field of engineering, preparing students more effectively to face today's technological challenges with skill and confidence.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

INFORMED CONSENT

The authors declare that the study did not involve human participants.

ETHICAL APPROVAL

The authors declare that the study did not involve human or animal participants.

DATA AVAILABILITY

The data supporting the findings of this study are available upon request from the corresponding author [MFMM].

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APPENDIX

Table 1. Studies selected for systematic review

Study	Type of study	Methods	Results	Critical analysis	Study contribution
[48]	Applied research and development of a framework.	Use of MUCAD-CLF applied to a collaborative design challenge with 31 participants, analyzing more than 20,000 CAD actions.	Observation of differences in CAD behavior between novice and experienced teams, and educational benefits of collaboration.	The study highlights the need to better understand and visualize student performance in CAD learning processes.	It proposes an analytical framework for evaluating CAD collaboration and potentially improves CAD education.
[30]	Experimental study on CAD teaching.	Research with 191 mechanical engineering students using PBL and the TrainCAD self-assessment tool.	Significant improvement in academic performance and increased motivation in the group that used TrainCAD.	The study demonstrates the effectiveness of interactive and self-assessment tools in teaching CAD.	Contributes to the field of CAD pedagogy, highlighting the importance of self-assessment and interactive tools in improving learning
[51]	Applied research on smart classroom optimization	Use of CAD software to improve software design and product technology; smart classroom core technology improvement	Increase smart classroom efficiency by 20%, reduce teaching pressure by 20%, improve student learning efficiency by 20%	High investment and maintenance costs, complex system design	Improving efficiency and effectiveness in smart classrooms, contributing to the evolution of teaching methods
[49]	Systematic review	Literature review in academic databases on applications of engineering and design graphics (EGD) in product design.	Identification of the evolution of EGD from traditional drawing to three-dimensional methods such as CAD. They highlight the importance of EGD in the creativity of innovative product design.	Challenges are noted such as the complexity of EGD tools and the need for specific skills for their effective use.	Provides insight into the application of EGD in practice with the aim of improving product design, highlighting the importance of EGD in vocational education and training.
[50]	Applied research	Analysis of student data using Aladdin CAD software and application of machine learning techniques to predict success in design tasks.	Predicting success in designing a net-zero energy home with over 60% accuracy using logistic regression models based on sequences of design actions.	Limitations in understanding why certain sequences of design actions lead to success and the disconnect between design performance and understanding of energy concepts.	Development of an algorithm to improve student learning in CAD design and provide real-time feedback, supporting education in hybrid and online environments.
[52]	Technology development	Construction of an open-source terrestrial laser scanner for educational use in AEC classrooms.	Successful demonstration of virtualization of simple geometric entities in the classroom using low-cost technology.	Challenges related to precision and complexity in the implementation of this type of technologies in educational environments.	It contributes to the integration of innovative technologies in AEC education, fostering a better understanding and practical application of geometric concepts.

Table 1. Studies selected for systematic review (*continued*)

Study	Type of study	Methods	Results	Critical analysis	Study contribution
[53]	Development and implementation of educational tools	Development of a virtual reality tool to support the fluid power curriculum, using Unity3D software and CAD models.	Successful creation of an interactive virtual reality environment that replicates the physical laboratory experience, enhancing remote learning.	Limitations in exact replication of physical hands-on experience and adoption by students.	Innovation in teaching fluid power, offering a practical solution for distance education and improving understanding of theoretical concepts.
[55]	Automotive engineering education	Development of an integrated approach for teaching automotive suspension design, combining CAD and CAE tools.	Successful implementation of the approach in a university course, improving students' understanding and practical skills.	The need for a balance between theory and practice in engineering education is emphasized.	Provides an effective model for teaching automotive suspension design, integrating theory and practice through the use of CAD and CAE tools.
[56]	Teaching CAD in social media-based education	Application of an experiential learning model for teaching the interoperability of CAD systems using social networks and the Learning Factory platform.	Successful development of an educational model to teach the interoperability of CAD systems, integrating experiential learning practices and social media technologies.	The need for greater integration and fluidity in interoperability between different CAD systems and adaptation to educational needs is highlighted.	Advances CAD teaching methodology, providing a more interactive and applied approach to improve students' skills in CAD system interoperability.
[54]	Improving STEM education	Integration of product design and CAD approaches in STEM education; analysis of existing problems and proposals for innovative solutions.	Development of a more effective and attractive educational framework for students, focused on the practical application of STEM knowledge.	Emphasizes the need for more interactive and applied educational approaches to improve students' skills in STEM.	It proposes a new approach to STEM education that combines theory and practice, improving student motivation and learning.
[57]	Teaching CAD/CAE in engineering	Implementation of project-based learning (PjBL) to teach advanced CAD/CAE tools, using the PTC Creo platform in automatic machine design courses.	Successful development of practical and theoretical skills in CAD/CAE among students, through projects that replicate industrial design problems.	Challenges in adapting CAD/CAE tools to educational needs and student participation.	Significant contribution to engineering education, providing a practical and applied approach to learning advanced CAD/CAE tools.

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