International Journal of Electrical and Computer Engineering (IJECE)
Vol. 15, No. 2, April 2025, pp. 1889~1899
ISSN: 2088-8708, DOI: 10.11591/ijece.v15i2.pp1889-1899

Enhancing engineering education through virtual reality: a systematic study on immersive engineering education practices

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Article Info

Article history:

Received Apr 2, 2024
Revised Oct 9, 2024
Accepted Oct 23, 2024

Keywords:

Engineering education
Immersive engineering education
Immersive technologies
Learning experiences
Problem-solving skills
Virtual reality

ABSTRACT

This article explores the integration of virtual reality (VR) and associated technologies in engineering education, focusing on the pedagogical approaches adopted in this integration, which we refer to as immersive engineering education. This study considers the application possibilities and the transformative impact of VR on engineering education. The article addresses the critical collection and analysis of VR applications in engineering education. It covers main VR-related papers published from 2015 to February 2024 and indexed in Scopus, Web of Sciences, or both, and discussing design, development challenges, and collaborative tools. Empirical evidence showcases improved engagement, motivation, and learning outcomes. The findings offer modern insights for educators and researchers on leveraging VR for impactful learning experiences, while also noting the need for further research in this evolving field.

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1. INTRODUCTION

The integration of emerging technologies in engineering education has revolutionized the way information is transmitted and has made the teaching and learning process more engaging and enjoyable [1]. A significant driver for analyzing these technologies is their potential benefit to engineering education. However, understanding their full impact is hindered by the rapid proliferation of diverse technologies, the speed of their development, and the variety of educational contexts in which they are applied. Increased investment in educational technology is crucial, but the key factor is not merely the usage of technology, but rather how effectively it supports teaching and learning. Both students and teachers need a deeper understanding of the educational potential of these technologies [1], [2].

Among the technologies gaining prominence, virtual reality (VR) and associated technologies have experienced a notable surge since 2015, marking a new era in educational tools and methodologies. VR is an immersive technology that recreates artificial three-dimensional environments, often interactive, to simulate realistic sensory experiences. By using devices such as VR headsets and controllers, users are immersed in virtual worlds where they can interact with objects and environments much like in reality. VR harnesses advanced graphics, tracking movements, and sometimes sound elements to create an immersive experience that can be applied across various domains, from training and education to medicine, entertainment, and design. It offers unique opportunities for lifelike simulations, secure experimentation, and interactive exploration, transforming how we interact with the digital realm and expanding the boundaries of user experience [3], [4].

The key questions addressed in this research are:

a. How feasible is the integration of virtual reality technology into engineering education, and does this integration positively impact the learning outcomes of engineering students?
b. How has the use of virtual reality and its technologies in engineering education evolved over the past decade?
c. What pedagogical approaches have been adopted for integrating virtual reality technology into engineering education?

VR technologies have undergone significant evolution over the years, marked by reductions in form factor where it has become more streamlined and suitable alongside enhancements in features and capabilities. While the technology's widespread popularity in gaming platforms is well-established today, its appeal is expanding to encompass domains like education, training, and learning. This surge of interest is attributed to the immersive experiences it offers, creating a profound sense of presence, transporting individuals into virtual environments, and momentarily disconnecting them from the physical world [5]–[8].

To address these gaps, this paper is structured as: the methods section will detail the systematic approach used to review and analyze the relevant literature. The results and discussion section will present the key findings from our review, comparing them with previous studies and highlighting the implications for engineering education. Finally, the conclusion will summarize the main contributions of this research and propose future directions for the integration of VR in engineering education.

2. METHOD

This study employs a systematic literature review approach to critically analyze the use of virtual reality technologies in engineering education. The aim is to explore how VR has been integrated into educational practices over the past decade and assess its impact on both student learning outcomes and pedagogical approaches. The systematic review method ensures a comprehensive and structured evaluation of existing literature, allowing for a robust analysis of trends, challenges, and future directions in the field. The search strategy employed in the Scopus and Web of Science databases utilized specific keywords such as "engineering education," "immersive engineering learning," "VR in education," "augmented reality in education," and "3D." The query was structured as: virtual environment or 3D or augmented reality or virtual reality and engineering education or teaching or learning or education.

The study was conducted following three distinct stages. Initially, a literature search process was undertaken concerning virtual reality research and its applications in engineering education. Subsequently, all retrieved articles were analyzed in terms of employed technologies and the application areas, and the outcomes of the study were succinctly summarized, providing an overview of future directions for VR research and its applications in engineering education.

2.1. Paper retrieval

The paper retrieval process was guided by three established search criteria. This systematic review, centered on VR in the context of engineering education, selectively included only academic journal articles given their significant impact. Excluded from this review were articles, book chapters, and conference papers from either less prominent journals. The literature search was carried out using Web of Science [9] and Scopus [10], which are among the most comprehensive academic databases. Additionally, keywords such as engineering education technology, Immersive engineering learning, VR in education, augmented reality in education, and 3D were used in the retrieval process. The search query followed this rule: (virtual environment OR 3D OR augmented reality OR virtual reality) AND (engineering education OR teaching OR learning OR education). Publications containing the specified keywords in their title, abstract, or keyword list were pinpointed. This search yielded 138 articles spanning from 2015 to February 2024, the date of this research. The year 2015 was selected as part of the search constraints because it marks a pivotal moment when the spread of virtual reality technology accelerated with the launch of several advanced devices from major companies, significantly increasing accessibility to consumers. Following this, a meticulous manual selection was undertaken to verify the relevance of each article to the objectives of this study. This selection process involved a careful and detailed reading of the articles, combined with a systematic analysis of their methodologies, findings, and relevance to the integration of VR in engineering education. Comprehensive summaries were developed for each article, ensuring a thorough understanding before inclusion. This process resulted in the identification of 49 publications for closer analysis [4], [11]-[59].

2.2. Data analysis

The analysis of the 49 selected publications involved the application of specific codes. These codes were derived from similar studies involving content analysis. The codes employed in this study are presented in Table 1.

Table 1. Codes utilized for content analysis

Code	Description
Autor	Authors of the selected publications
Country	Country of origin for the publications selected
Year	Publication year, from 2015 to February 2024
Venue	The journals hosting the selected publications
Technology	Type of employed VR technologies
Application	Categories of VR application
Prospective research	Prospective research directions suggested in the article

3. RESULTS

3.1. Overview of chosen research papers

Figure 1 illustrates the annual distribution of publications. It reveals a growing research interest in VR and its application in engineering education and the pedagogical approaches adopted, especially since 2018. Table 2 outlines the categorization of selected publications based on their publishing journals. The table identifies over 30 journals featuring articles on VR and associated technologies in engineering education. Notably, as indicated in Table 2, the Computer Applications in Engineering Education [60], International Journal of Engineering Education [61], and Applied Sciences [62] emerge as the top three journals frequently publishing on VR in Engineering Education, and the pedagogical approaches adopted.

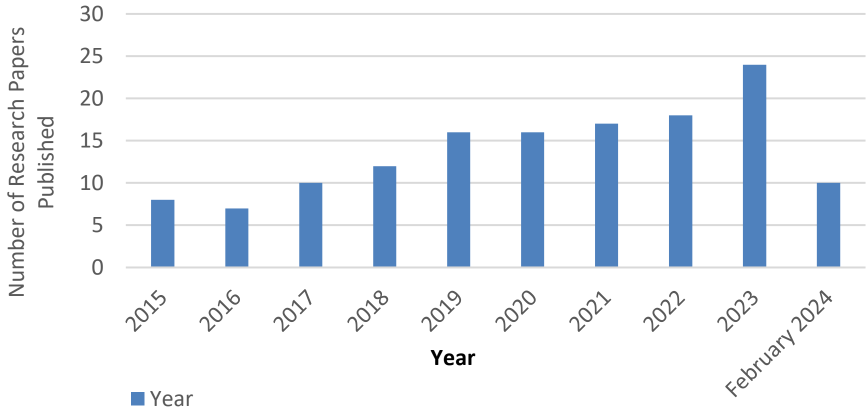

Figure 1. Publication on VR implementation in engineering education from 2015 to February 2024

3.2. Technologies

In engineering education, VR and associated technologies can be classified into five principal categories: head-mounted display (HMD), 360-degree cameras and videos, augmented reality (AR) and mixed reality (MR) systems, 3D modeling and design software, and interactive simulators. The study is organized based on the varied applications of visualization media and display platforms. Its primary focus lies in examining the advancements and assessments of VR technology within engineering education programs. It is should be highlighted that while the categorization is detailed, it remains open-ended, encompassing all aspects of VR including hardware, software, visualization, and interaction.

Table 3 outlines the distribution of the chosen publications, highlighting the technologies implemented. According to Table 3, the most frequently utilized VR systems in the literature are HMD and 3D modeling and design software, representing 42.8% and 18.4% of the usage, respectively. Although the development of AR and MR systems has been relatively consistent, the growth in collaborative VR platforms, along with 360-degree cameras and videos has garnered significant interest lately, evidenced by 8 and 4 publications, respectively.

Table 2. Categorization of the selected publications based on journals

Journal title	Number of selected papers
Computer Applications in Engineering Education	7
International Journal of Engineering Education	5
Applied Sciences	4
IEEE Global Engineering Education Conference (IEEE EDUCON)	2
International Conference on Interactive Collaborative Learning (ICL)	2
Journal of Civil Engineering Education	2
Journal of Higher Education Outreach and Engagement	2
Smart Learning Environments	2
International Conference of Education, Research and Innovation (ICERI2019)	1
Computers & Education	1
Journal of Computers in Education	1
Australian Computer-Human Interaction Conference, OzCHI 2016	1
ASEE Annual Conference and Exposition, Conference Proceedings	1
Bibliothek Forschung Und Praxis	1
Engineering, Construction and Architectural Management	1
Eurasia Journal of Mathematics Science and Technology Education	1
Journal of Computing and Information Science in Engineering	1
International Conference on Robotics in Education (RIE)	1
International Congress on Educational and Technology in Sciences, CISETC 2019	1
International Journal of Computer Applications in Technology	1
Journal of Biomechanical Engineering-Transactions of The ASME	1
Journal of Computer Assisted Learning	1
European Conference on e-Learning, ECEL 2021	1
European Journal of Dentistry	1
Journal of Experiential Education	1
Journal of Pre-College Engineering Education Research	1
Journal of Visualized Experiments	1
MRS ADVANCES	1
Proceedings of 2015 International Conference on Interactive Collaborative Learning	1
Springer Briefs in Education	1
Telematics and Informatics	1
Total	49

Table 3. Breakdown of publications by technology and year of publication

Research theme	Period			Total	Percentage
	2015-2017	2018-2021	2022-February 2024		
3D modeling and design software	4	2	3	9	18.4%
Interactive simulators	1	3	3	7	14.3%
HMD	1	10	10	21	42.8%
Augmented reality and mixed reality systems	1	2	5	8	16.3%
360-degree cameras and videos	1	2	1	4	8.2%
Total	8	19	22	49	100%

3.2.1. 3D modeling and design software

In the initial stages, 3D modeling and design software emerged as the most prevalent VR technology. Table 3 indicates that, from 2015 to 2017, half of the studies (4 out of 8) involved 3D modeling and design software. This technology operates using a standard computer monitor as the interface for virtual activities, rendering a three-dimensional virtual environment on a desktop screen without the need for specialized tracking equipment. It depends on the user's spatial awareness and perceptual skills to navigate and interact within the virtual space. Most interactions are facilitated through a mouse and a keyboard. Given its reliance solely on standard computing equipment, this technology is considered as cost-effective compared to other VR technologies.

In 2017, Huang and Lin conducted a study aimed at integrating the conceive, design, implement, operate (CDIO) educational framework with tangible 3D modeling teaching materials for students [15]. This investigation was centered on assessing the impact of diverse teaching resources, specifically three-view diagrams and 3D printed solid models, on the development of students' spatial abilities. The experimental outcomes of the study provided significant insights, demonstrating that the use of different instructional materials leads to the development of varied spatial skills, including mental rotation and spatial visualization. Furthermore, these differences in teaching methodologies and materials were also reflected in the learning outcomes, suggesting a direct correlation between the nature of the teaching aids and the enhancement of specific cognitive skills in students.

In order to leverage the advantages of contextualized learning and address socially pertinent issues in real-world contexts, the print 3D project, a service-learning initiative in engineering, was developed, as presented by Lozano [16]. This project is primarily focused on fostering empathy towards individuals with visual impairments, understanding their accessibility needs, and devising and prototyping viable solutions. As a collaborative effort, the project emphasizes the 3D design and 3D printing of various objects. These include subway line maps, facility layouts, signage, and artistic creations, all tailored to be accessible to those with visual impairments. The outcomes of print 3D have been notably positive, leading to increased motivation, heightened social awareness, and enhanced technical skills. This impact was particularly significant among engineering students at a higher risk of discontinuing their education, underscoring the project's role in engaging and retaining these students through meaningful, applied learning experiences.

3.2.2. Interactive simulators

Moussa *et al.* [14] conducted a comprehensive review of 73 publications focusing on the application of VR and interactive digital simulations in dental education for student training. The systematic review uncovered that a substantial 71% of the studies examined showed a marked enhancement in educational results. Additionally, all participants involved unanimously viewed virtual technologies favorably. This observation is made within the confines and constraints of this analysis, it becomes evident that virtual technology holds substantial potential in enhancing educational outcomes for dental students.

At the 2023 ASEE Annual Conference and Exposition, Conference Proceedings, Fidan Ismail presented enhancements implemented in an engineering technology course through the application of the engineering service-learning approach [13]. This course focuses on instructing students in the complex process of manufacturing intricate machined parts using G-code simulators. Student feedback from this project underscored a range of advancements and developments in achieving the Accreditation Board for Engineering and Technology (ABET) student outcomes. These improvements demonstrate the effective integration of practical, hands-on experience with theoretical knowledge This method exemplifies the dynamic evolution of engineering education, wherein innovative teaching methodologies are increasingly being adopted to enhance student learning and competency.

3.2.3. HMD

HMD is the most recognizable form of VR technology. They provide immersive visual and auditory experiences, often used in gaming, training, and simulation. To highlight the significance of adopting disruptive technologies, especially virtual reality VR via HMD, and to evaluate its effectiveness against conventional teaching approaches, a study was carried out by Al-Khiami *et al.* [17]. This research examined the effects of VR HMD on engineering students' motivation, performance, and workload relative to traditional 2D drawings. The findings of the study indicate that incorporating VR, specifically VR HMD, into an undergraduate concrete structures course, markedly improves student performance and motivation. Additionally, it was noted that enhancing the user-friendliness of the employed methods could further boost both performance and motivation.

The integration of VR and immersive technologies into project-based learning initiatives presents a compelling opportunity for the evolution of joint narratives. This is exemplified by the collaborative service-learning experiences involving communication students and faculty from Ecuador and Ohio, United States. They interacted with local communities in the varied settings of Manabí’s coastal rural areas and the Andean highlands of Chugchilán, these projects were significantly enhanced through the application of state-of-the-art VR via HMD and immersive technologies. The results of these collaborations highlighted the synergistic potential of combining service-learning projects with VR and their positive impact in energizing the nonfiction storytelling abilities of students in practical settings. Furthermore, the incorporation of immersive technologies in international service-learning partnerships reveals a complex array of challenges, encompassing ontological, technological, narrative, and professional dimensions [20].

3.2.4. Augmented reality and mixed reality systems

AR is increasingly acknowledged as an innovative interactive interface, transcending traditional device screens like those of smartphones, tablets, and laptops. It offers a more intuitive interface, facilitating interactions within a VR that seamlessly blends with the real environment. AR is characterized by the enhancement of the real-world setting with computer-generated graphics and digital objects. One of its primary objectives is to reduce the risk of social isolation and the erosion of social abilities and skills among its users. MR, which encompasses AR, represents an intermediary realm that merges real and virtual environments, creating a hybrid space where digital and physical elements coexist and interact [18].

In a comprehensive study conducted in the eastern part of India [63], 392 engineering students from a prominent engineering college were selected for a comparative educational experiment. These students were split evenly into two groups. The first group, consisting of 196 students, engaged in learning technical drawing through traditional methods. In contrast, the experimental group, also comprising 196 students, utilized an AR-based technical drawing application named EDINAR to facilitate their learning process. A one-way

ANOVA was utilized to analyze and contrast the performance outcomes of the two groups. The findings of the study were quite revealing. Students who used the EDINAR application to study technical drawing significantly outperformed those who adhered to conventional learning techniques. Additionally, the experimental group provided favorable feedback about the AR application, particularly highlighting the enhanced learning experience it offered. Based on these compelling results, the study strongly recommends the integration of AR technology into engineering education curricula. This integration aims to not only improve learning performance but also to enrich the overall educational experience of engineering students [11].

At the Hong Kong Baptist University, within the global and Chinese studies program, a group initiated the development of a virtual teaching and learning initiative, "metaverse sojourn" [12]. This initiative sought to furnish students at the University of Hong Kong with virtual excursions in China and Europe, utilizing cutting-edge metaverse technology. The results reveal that the notion of a "metaverse sojourn" can provide students with a novel exchange experience in augmented reality (AR) and also has considerable promise for fostering interactive, learning educational activities among students, and educators on the metaverse platform.

3.2.5. 360-degree cameras and videos

360° models represent a unique aspect of VR and are generated through software from multiple pictures of a space taken by 360-degree cameras. this technology enables viewers to examine and navigate a photorealistic object from various locations within the model. Consequently, these models provide a versatile means to conduct virtual field trips (VFT), offering the advantage of being independent of time and location constraints.

In a research project at the University of Auckland, New Zealand, Kavanagh *et al.* [21] undertook a case study to examine an alternative approach for producing educational content in VR. Deviating from the conventional reliance on computer graphics and programming for VR content creation, the team explored the practicality of employing a 360° camera to develop educational courses designed for HMD. This method notably reduces both the cost and training requirements associated with utilizing VR HMD for educational purposes and in the creation of corresponding educational materials. Despite facing several challenges throughout the research, they successfully demonstrated an innovative means of generating VR educational content, effectively lowering the entry barriers. While solutions were found for most of the encountered issues, some unresolved challenges, such as the recording quality of 360° cameras and the display quality of HMD, are anticipated to be addressed with the advancement and release of future technologies.

In the Bauhaus-Institute for infrastructure solutions at Bauhaus-Universität Weimar, a research initiative was undertaken to establish the efficacy of 360-degree models as pedagogical tools in environmental engineering education. This exploratory study focused on the 360-degree model of an innovative engineering project named P-Bank, specifically designed for wastewater treatment systems. Methodologically, the study involved a sample size of 17 participants who interacted with the P-Bank 360-degree model for knowledge acquisition, followed by an evaluative post-test. The results were consistently promising: the 360-degree model's applicability and usability in the context of engineering education were rated as good, while motivational and emotional responses were evaluated as excellent. Furthermore, the learning outcomes achieved through this model were positive. The obtained data from the conducted interviews provided substantial and valid insights for the further enhancement and development of the 360-degree model's functionality. Overall, this study contributes significantly to the scientific discourse on the integration of 360-degree models in engineering education [23].

4. DISCUSSION

4.1. Categories of VR applications in engineering education

In order to broaden this review perspective, VR applications are methodically classified into three key groups, each emphasizing specific aspects of immersive technology within the domain of engineering education. These aspects are:

a. Integration and substitution potential: assessment of the scope and extent to which immersive technology can be systematically incorporated into the curriculum of engineering education, evaluation of the capability of immersive technology to act as a substitute for traditional pedagogical methods in engineering education, and examination of its applicability.
b. Educational impact: analysis of the influence of immersive technology on the pedagogical processes in engineering, focus on how it shapes and enhances the learning experience.
c. Pedagogical approaches synergy: investigation of the effects of embedding immersive technology within a specific learning approach, exploration of its contributions to both the educational outcomes and the learning methodology.

Table 4 presents a statistical analysis of papers classified based on the categories of VR applications they addressed. It is important to note that several articles have addressed more than one of these categories, reflecting a comprehensive and interconnected approach to the application of VR within the realm of engineering education.

Table 4. Breakdown of publications by categories of VR applications they addressed

Categories of VR applications	Total	Percentage
Integration and substitution potential	17	35%
Educational impact	32	65%
Pedagogical approaches synergy	19	39%

4.1.1. Integration and substitution potential

The consensus among the reviewed papers is that integrating immersive technology into engineering education is highly feasible. However, only 5 papers, representing 10% of the studies, confirm the potential of immersive technology to fully replace traditional teaching-learning methods in engineering education. 62% of the studies suggest that such technologies should be considered as supplementary tools, serving as alternatives in situations where physical attendance is impractical or impossible, such as during the coronavirus disease 2019 (COVID-19) pandemic. This indicates a recognition of the adaptability of immersive technologies in enhancing the educational experience, albeit with varying opinions on their capacity to serve as a complete substitute for conventional instructional approaches.

The remaining papers did not address the feasibility of integration, considering it as a foregone conclusion. Instead, they directly explored the impact of immersive technologies on the development and enhancement of engineering education. These studies highlight the immediate benefits and practical applications of immersive technologies, focusing on their role in enriching the educational landscape. By bypassing the discussion on integration feasibility, these papers implicitly endorse the adoption of such technologies as a valuable component of contemporary engineering education, emphasizing their effectiveness in fostering a more engaging and effective learning environment [14], [18], [19], [22], [28], [29], [33]–[35], [37], [38], [42], [45], [55].

4.1.2. Educational impact

All research and studies reviewed confirmed that learning objectives were achieved despite various challenges, including the unavailability or high cost of VR equipment, the absence of an interactive environment customized for each project, limited familiarity with this advanced technology among some engineering students or some professors, and the lack of a specific pedagogical approach for employing immersive technology. These findings highlight the potential of immersive technologies in engineering educational settings, underscoring their effectiveness in meeting learning goals even when faced with significant obstacles.

In addition to achieving learning objectives, numerous studies within this review, explicitly (9 papers) or implicitly (26 papers), stated that immersive technology facilitates the engineering education process by stimulating students' senses and immersing them in experiences that mimic reality, particularly when using VR or augmented and mixed reality (AR/MR) HMD. This immersive approach not only enhances the learning experience by providing a realistic context but also significantly improves the engagement and understanding of complex engineering concepts. The integration of immersive technologies into engineering education represents a forward-thinking method to bridge the gap between theoretical knowledge and practical application, offering students an unparalleled opportunity to explore and interact with engineering principles in a virtual environment that closely resembles real-world scenarios. To enhance innovation adoption, it is crucial to provide in-house content creation support for educators. Developing and delivering VR training and educational frameworks will ensure that high-quality content is produced and effectively utilized [64].

4.1.3. Pedagogical approaches synergy

A total of 19 papers addressing the adoption of a specific pedagogical approach in immersive engineering education were reviewed. Out of these, 18 emphasized students' satisfaction with engaging in immersive experiences. However, the immersive experience did not resonate well with students at the University of Auckland in New Zealand. Kavanagh *et al.* [21] confirmed that although they achieved their goal of providing an alternative means of creating VR content for education, they encountered numerous challenges in implementing 360-degree video technology via HMD, such as difficulty in selecting camera position to achieve comprehensive spatial vision and the poor quality of obtained video.

All 19 papers highlighted the potential for adopting immersive technology in conjunction with pedagogical approaches and methods. Most of them considered immersive technology to provide a simulated environment that facilitates the learning process and places students at the center of the learning experience. Additionally, it reduces the risks and costs associated with traveling to and from project locations, ensuring sustainable and effective solutions that have been previously tested under realistic conditions. This guarantees satisfaction with the obtained results.

Based on these 19 reviewed papers, it is evident that the most suitable teaching-learning approach for integrating virtual reality technology in engineering education is project-based learning. Specifically, the service-learning approach in engineering, which combines project-based learning with community service, stands out. Adopting these approaches facilitates the achievement of better, more effective, beneficial, and sustainable outcomes.

4.2. Limitations

This study is limited by its scope, focusing only on publications available between 2015, the year that saw a revolution in VR technology, and February 2024. It targets articles published in journals or conferences indexed in Scopus or Web of Science, or both. The variability in educational contexts, instructor proficiency, and student engagement, which were not comprehensively addressed, may affect the generalizability of the findings. Additionally, the rapid evolution of VR technologies requires continuous updates to the conclusions drawn. Future research should include empirical studies to validate the proposed benefits and identify best practices for VR integration in engineering education.

This review, while comprehensive, presents certain limitations. Its scope is primarily confined to technologies pertinent to engineering education. Consequently, it does not encompass the entire breadth of technological advancements in this field. The review further delineates potential avenues for future research. Notably, the efficacy and adaptability of these VR technologies have not been exhaustively evaluated in the context of contemporary engineering education paradigms, such as the flipped classroom model. Moreover, the compatibility of these VR solutions with other nascent educational tools in VR and alternative visualization techniques warrants further exploration.

5. CONCLUSION

In this study, an extensive examination of VR in engineering education and the learning approaches and methods was undertaken, identifying the technologies, application areas, and future research directions. Drawing from an analysis of 49 research papers, the VR technologies implemented in engineering education encompass HMD, 360-degree cameras and videos, augmented reality and mixed reality systems, 3D modeling and design software, and interactive simulators. The development of VR technologies is transitioning from 3D Modeling and Design Software to mobile ones with enhanced immersion and interaction abilities.

VR plays a pivotal role in enhancing engineering education by enabling students to develop visual engineering projects that closely simulate real-world scenarios. This technology facilitates skill development and knowledge acquisition through a comprehensive and continuously accessible virtual environment. One of the key advantages of VR in this context is its ability to mitigate the high costs associated with large-scale engineering projects. Moreover, VR provides a safe, risk-free platform where students can experiment and learn without the potential hazards associated with physical project execution. Consequently, VR offers immersive experiences that bridge the gap between theoretical knowledge and practical application in engineering.

In the realm of educational methodologies, the evolution of VR-based pedagogical strategies is anticipated to transform learning paradigms from a traditional, teacher-centered approach to a more dynamic, student-centered model within virtual or hybrid virtual-reality environments. VR serves as a powerful instrument for exploring and understanding the environments under study, eliminating the necessity for physical travel. This aspect of VR allows learners to simultaneously engage with multiple issues or projects, enhancing the scope and efficiency of their educational experience. Furthermore, VR offers the capability to devise, test, and refine practical solutions in a virtual setting before their real-world implementation. This approach not only ensures the feasibility of solutions but also significantly reduces the risks and costs associated with trial-and-error in actual environments. Consequently, VR emerges as a valuable tool in engineering learning, providing students with a realistic yet controlled platform for problem-solving and community engagement.

The most suitable teaching-learning approach for integrating virtual reality technology in engineering education is project-based learning. Specifically, the engineering service-learning approach stands out. Adopting these approaches facilitates the achievement of better, more effective, beneficial, and sustainable outcomes. The advancements in HMD and the concept of smart cities are highlighted as valuable resources, offering tangible elements that facilitate the design of virtual environments for engineering project-based learning. The insights garnered from this study are poised to significantly contribute to both future scholarly inquiries and practical applications in implementing VR within the spheres of engineering education and the engineering learning methodologies.

This paper confirms the necessity and feasibility of implementing specific engineering pedagogical approaches through virtual reality technologies, in conjunction with the conventional methodologies typically adopted for this purpose. In addition, the paper recognizes an unaddressed area found via a thorough examination of existing studies. It concludes that when designing VR applications, learning theories are frequently overlooked. Additionally, it argues that VR presents a powerful and effective tool for engineering education when applied within a service-learning approach, which combines project-based learning and community service. Hence, focused efforts and research are essential to assess VR technology in harmony with evolving teaching and learning methodologies. The insights garnered from this study are poised to significantly contribute to both future scholarly inquiries and practical applications in implementing VR within the spheres of engineering education and the engineering learning methodologies.

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