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Conceptual Framework for Utilizing Augmented Reality/Virtual Reality in Creating a Smart Education Ecosystem in Construction Management Learning

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ABSTRACT

Along with the development of information technology, the metaverse appears to facilitate the interaction of its users in the digital space. Various new technologies, such as Building Information Modeling (BIM), augmented reality/virtual reality (AR/VR), and digital twins, have begun to be applied in the construction industry. However, the use of these technologies has not been widely applied in education, such as in the construction management learning process in universities. This paper aims to explore the potential use of AR/VR technology in learning various courses related to construction management. It employed a qualitative approach through a focused literature review. The findings are eleven potential applications of AR/VR in construction management education, including utilization for construction occupational health and safety, construction method, and construction surveying courses. This is important considering that construction management courses need full understanding of the construction project environment, both in actual site visits and through digital representations. This paper also contributes by developing a conceptual framework for the use of AR/VR technology to create a smart education ecosystem, especially in the field of construction management. It serves as a starting point for higher education institutions to begin integrating immersive technology into a more adaptive, collaborative, and data-driven learning process.

1. Introduction

The term metaverse was first introduced by Neal Stephenson in his 1992 novel "Snow Crash" [1]. The term refers to a concept that integrates various new technologies to form a digital space [2]. Similarly, Zhou [1] sees the metaverse as a future world that integrates various information technologies. The emergence of the metaverse will transform human life through virtual science and technology, including the learning process [2]. Therefore, the metaverse has the potential to create a positive impact on the learning process through a smart education ecosystem.

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Along with the development of information technology, the metaverse also supports the development of digital technologies such as Building Information Modeling (BIM), augmented reality/virtual reality (AR/VR), and digital twins. The metaverse enables multisensory interactions between users and virtual environments, digital objects, and the real world [3]. This technology is particularly beneficial during the COVID-19 (corona virus disease 2019) pandemic, which has limited physical interaction, including in the learning process [4,5]. This was also stated by Khaira et al. [6], who saw this as a positive impact of COVID-19 on the application of new technologies in education. Metaverse technology provides a digital platform to provide students with experience before they enter the actual field or real-world environment [7]. This is especially important for construction study programs such as Civil Engineering, Architecture, and Construction Management, which frequently implement experiential learning.

Several previous studies have examined the use of metaverse technology to support the learning process [8]. A study by Haryo and Makmur [9] examined how to incorporate the metaverse into their learning system. Zonaphan *et al*., [10] argued that the metaverse could become a new space for students to proactively socialize. Muthmainnah et al. [11] saw the potential of 3D (3-dimensional) digital spaces to enhance interaction and communication through the use of avatars. Judijanto *et al*., [12] developed a metaverse using AR to teach mathematics. Siyaev and Jo [13] investigated the use of mixed reality (MR) technology in aircraft maintenance learning. Li *et al*., [14] examined the implementation of metaverse technology as a strategy to improve the quality of soccer learning. Guo and Gao [7] and Lee and Hwang [15] utilized metaverses in English language learning in China and South Korea. Barráez-Herrera [16] concluded that distance education based on virtual reality and blockchain technology can produce metaverse educational standards that encourage blended learning in a 3D virtual world.

Augmented Reality (AR) and Virtual Reality (VR) are two terms often used interchangeably. Both are digital technologies that utilize metaverse environments. However, there are slight differences based on the scope of their digitalization. AR is a technology that applies virtual elements to a real-world environment. VR is a virtual three-dimensional technology that creates a completely digital environment. According to Loijens *et al*., [17], AR technology is interactive and reality-based, enhancing users' real-world experiences. VR technology, on the other hand, provides a complete digital environment where users can interact with each other through computer-generated digital systems.

Although the use of AR/VR technology in the context of the metaverse has begun to be implemented in the construction industry [18], this technology has not yet been implemented in the construction education sector [19], such as in the construction management learning process at universities ("metaversity"). Learning with AR/VR technology can take place anywhere and anytime, providing flexibility for students [20]. During the COVID-19 pandemic, this technology offers a new learning approach that does not require students to be physically present on campus.

In Indonesia, there are few studies related to the use of metaverse technology in education. Endarto and Martadi [21] emphasize the importance of educators moving towards an education system 4.0 by implementing digital technology-based educational media. This paper aims to explore the potential of utilizing AR/VR technology for teaching various courses related to Construction Management. This is important considering that many Construction Management courses require an understanding of the construction project environment, both in actual terms.

Despite the growing global interest in the metaverse and AR/VR applications in education, their integration into construction management learning, particularly within Indonesian higher education, remains underdeveloped. Most prior research focuses on general education, language learning, or training in other industries, leaving a gap in how immersive technologies can be systematically applied to create an innovative education ecosystem in construction-related disciplines. Addressing this gap, this study aims to develop a conceptual framework for utilizing AR/VR technologies within a metaverse-based environment to enhance Construction Management education in Indonesia. The framework is expected to provide a structured approach for delivering realistic, interactive, and flexible experiential learning that simulates real-world construction environments. The outcomes will contribute to the advancement of technology-driven pedagogy, support the transition toward Education 4.0, and prepare future construction professionals with the competencies required in the Construction Industry 4.0 era.

2. Methodology

This study employed a qualitative approach through a focused literature review to explore the potential applications of Augmented Reality (AR) and Virtual Reality (VR) technologies in the context of the Civil Engineering program, particularly Construction Management education. The focused literature review method was selected to allow for an in-depth examination of scholarly publications, conference proceedings, and relevant industry reports that discuss the integration of AR/VR in educational settings, particularly within construction and engineering disciplines.

The review process involved identifying, selecting, and analyzing literature from reputable academic databases such as Scopus, Web of Science, and Google Scholar, using keywords including “AR in construction education,” “VR in construction management,” “immersive technology in learning,” and “digital tools in engineering education.” Selected accessible literature was collected and thematically analyzed to extract insights on the pedagogical benefits, challenges, and practical applications of AR/VR. The findings were then synthesized to develop a conceptual framework that outlines how these technologies can be effectively utilized to enhance the learning experience in the Construction Management discipline.

3. Results

3.1 Utilization of AR/VR Technology in Construction Management Learning

3.1.1 Utilization of AR/VR technology for construction occupational health and safety course

One of the compulsory courses in Construction Management is Occupational Health, Safety, and Environment (OHSE). This is because the construction project environment is fraught with various potential risks that can affect the health and safety of construction workers and impact the surrounding environment. To identify these risks, students need to be introduced to the construction project environment. AR/VR technology can be utilized to provide an initial introduction to this project environment. Lecturers can take photos of the actual project conditions in the field, import them into the system, and present the environment virtually to students. This virtual representation of the actual conditions in the field will be very helpful in supporting interactive discussions during the learning process.

3.1.2 Utilization of AR/VR technology for construction method course

Construction projects involve many activities that require specific methods. Lecturers can utilize AR/VR technology to virtually explain the steps of these work methods to their students. For example, Ahmed *et al*., [22] explored the use of VR technology to train workers’ skills when working at heights. In education, lecturers teaching the Construction Methods course can implement similar approaches in their teaching.

3.1.3 Utilization of AR/VR technology for heavy equipment management and operations course

During fieldwork, contractors will require a variety of heavy equipment. This Heavy Equipment Management course provides students with an understanding not only of the types and functions of heavy construction equipment, but also of its efficient management and operation. Lecturers can utilize AR/VR technology to help train students in operating heavy equipment in a virtual project environment. An example of the use of VR technology for heavy equipment operators in the field has been done by Ahmed *et al*., [22].

3.1.4 Utilization of AR/VR technology for construction surveying course

The Construction Surveying course is essential for students to understand the site conditions of construction projects. It covers survey types, measurement units, scales, contour and sectional drawings, mapping, and the use of theodolites and total stations. In addition to conducting site surveys, lecturers can utilize AR/VR technology as an alternative learning tool.

3.1.5 Utilization of AR/VR technology for construction drawing course

Construction Drawing is a mandatory competency for construction management graduates. Understanding various types of construction drawings needs to be sharpened by understanding their actual appearance in the field. This is because construction objects tend to be depicted in 2D (2-dimensional). Lecturers can utilize AR/VR technology to provide students with a deeper understanding of an object's appearance in various views presented in construction drawings.

3.1.6 Utilization of AR/VR technology for construction quantification course

The ability to measure work volume and understand the scope of work is crucial for construction management graduates. Relevant instructors can utilize AR/VR technology to provide their students with a virtual understanding of the scope and volume of work in the field. This way, students can identify the scope of work and calculate volumes based not only on construction drawings but also on the project environment, as directed by their instructors.

3.1.7 Utilization of AR/VR technology for construction procurement course

Construction projects begin with the procurement and tender process. Lecturers can utilize AR/VR technology to virtually present the project's procurement and tender environment and procedures to their students. Furthermore, the negotiation process that often occurs during procurement and tendering can also be applied to train students' skills in construction contract negotiation.

3.1.8 Utilization of AR/VR technology for construction risk management course

Regarding risks and defects in construction work, lecturers can utilize AR/VR technology to introduce various types of risks and defects that affect the quality of construction projects. In traditional teaching, this is typically presented in the form of photographs of the defects. However, with AR/VR technology, lecturers can interactively discuss risks and defects with their students in a digital space.

3.1.9 Utilization of AR/VR technology for construction cost and time management course

Construction projects are constrained by time and cost. Therefore, the Construction Time and Cost Management course is a mandatory course that students must take and master. Lecturers can utilize AR/VR technology to facilitate understanding through interactive, visual discussions with students. Ahmed *et al*., [22] have shown an example of the use of VR technology in a discussion about construction costs and time.

3.1.10 Utilization of AR/VR technology for building facility maintenance course

Building facility maintenance (asset and facility management) is an elective course in the Construction Management and Engineering study program. Lecturers can utilize AR/VR technology to explain the built environment of a construction project and how to manage and maintain these facilities.

3.1.11 Utilization of AR/VR technology for MEP course

Mechanical, Electrical, and Plumbing (MEP) are utility elements that support the functioning of a building. Understanding MEP is generally obtained solely from construction MEP drawings. By utilizing AR/VR technology, lecturers can more comprehensively explain the location, shape, and size of these MEP elements in a construction project. This is expected to improve students' understanding of these MEP elements and lead to a more focused understanding.

3.2 Conceptual Framework for Utilizing AR/VR in a Smart Education Ecosystem

To enhance the effectiveness, engagement, and practical understanding of Construction Management education through the integration of AR/VR technologies within an innovative, technology-enabled learning ecosystem, a conceptual framework was developed (Figure 1). At its foundation, the framework is built upon six key components: technological infrastructure, immersive learning content, a smart learning environment, learner engagement and experience, pedagogical strategies, and assessment and feedback mechanisms (Table 1). These elements serve as the backbone for supporting a technology-driven, student-centered learning environment.

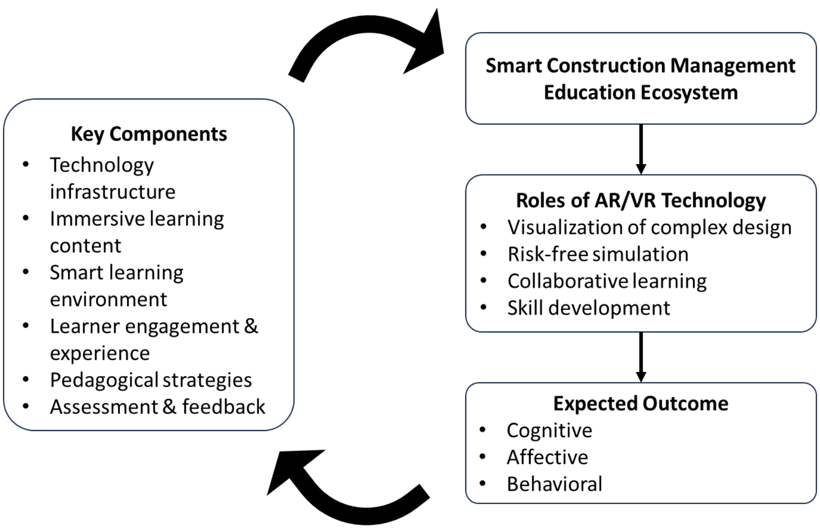

Fig. 1. Conceptual framework for utilizing AR/VR in a Smart CM Education Ecosystem

Central to the framework is the Smart Education Ecosystem, which functions as the operational platform where all components interact and are coordinated. This ecosystem enables the seamless implementation of AR/VR tools, supported by robust infrastructure and enriched content tailored for construction scenarios. The smart learning environment, integrated with adaptive learning systems and data analytics, allows for personalized and context-sensitive delivery of educational content.

Table 1
Framework components

Component	Description
Technological Infrastructure	Hardware (VR headsets, AR devices), software platforms (simulation engines, BIM integration), and stable connectivity to support AR/VR learning.
Immersive Learning Content	Interactive AR/VR modules simulating construction site operations, safety training, project management tasks, and real-time collaboration.
Smart Learning Environment	Integration of learning management systems (LMS), data analytics, AI-based feedback, and adaptive learning pathways tailored to student progress.
Learner Engagement & Experience	Enhanced motivation, spatial understanding, and retention through real-world scenario immersion, gamification, and problem-based learning.
Pedagogical Strategies	Blended learning, flipped classrooms, experiential learning, and collaborative tasks using AR/VR environments.
Assessment & Feedback	Real-time performance tracking, skill-based assessments, and analytics-driven feedback loops to improve learning outcomes.

Within this ecosystem, the roles of AR/VR are clearly defined. First, they facilitate the visualization of complex concepts, such as structural systems, project timelines (4D BIM), and cost modeling (5D BIM), which are often difficult to grasp through traditional teaching methods. Second, AR/VR offers risk-free simulation environments, enabling students to practice site management, safety procedures, and emergency responses without real-world consequences. Third, collaborative learning is fostered through shared virtual environments where students work on problem-solving tasks, enhancing teamwork and communication. Lastly, skill development is supported through interactive and scenario-based modules that strengthen decision-making and project planning abilities.

The outcomes of this framework are categorized into three domains: cognitive, affective, and behavioral. Cognitively, students are expected to gain a deeper understanding of construction management principles. Affectively, AR/VR boosts motivation and engagement by making learning more immersive and enjoyable. Behaviorally, students are likely to demonstrate improved readiness for real-world tasks, including enhanced teamwork and leadership competencies.

To ensure sustainability and relevance, the framework includes a feedback loop and a continuous improvement mechanism. This involves gathering insights from learners, educators, and performance data to update the AR/VR modules, refine pedagogical strategies, and optimize the learning environment. This iterative process ensures that the education ecosystem remains dynamic, effective, and aligned with industry needs and technological advancements.

3.3 Implications

The results of this study have important implications for curriculum development in Civil Engineering study programs, particularly in the Construction Management discipline. The integration of AR/VR necessitates the adjustment of the syllabus to incorporate immersive technology-based learning. The curriculum must support learning that is not only theoretical but also practical and interactive, by providing space for project simulations, occupational safety training, and construction planning in a virtual environment. This allows students to understand complex concepts in greater depth and application.

The implementation of AR/VR also requires lecturers to develop new pedagogical and technological skills. They act not only as presenters but also as facilitators in the interactive learning process. Lecturers need to understand how to design simulation-based learning scenarios and manage collaborative virtual classes. Therefore, higher education institutions need to provide training and technical support for instructors to adapt their teaching methods to this technology.

For institutions, implementing this framework requires investment in technological infrastructure, such as VR/AR devices, digital laboratories, and adaptive learning platforms. However, this investment is commensurate with its impact on improving the quality of learning and graduate competitiveness. Institutions also need to develop policies and operational standards that support the integration of technology into the teaching and learning process, including evaluation mechanisms based on data analytics and real-time feedback.

Externally, the implementation of AR/VR-based learning bridges the gap between academia and the construction industry. Students who are familiar with simulation technology will be better prepared to enter the workforce, which is increasingly adopting digital technologies such as BIM, drones, and AR for field projects. Therefore, this research also provides a foundation for closer collaboration between educational institutions and construction companies in designing learning content relevant to industry needs.

4. Conclusions

This research emphasizes the importance of utilizing AR/VR technology in creating an intelligent educational ecosystem capable of transforming Construction Management learning. With an interactive simulation-based approach, students gain not only theoretical understanding but also practical experience that reflects real-world conditions. The conceptual framework developed in this research can serve as a starting point for higher education institutions to begin integrating immersive technology into a more adaptive, collaborative, and data-driven learning process.

Going forward, the development and implementation of this framework need to be accompanied by further studies that empirically test its effectiveness in real-world learning contexts. Active involvement from lecturers, students, and industry stakeholders is needed to develop relevant and impactful content. With the synergy between technology, pedagogy, and the needs of the workplace, it is hoped that Construction Management education in Indonesia can move toward a more modern, competitive direction, aligned with the developments in the digital industrial revolution.

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