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The Effect of Augmented Reality in Building Structure Learning on Civil Engineering Students' Conceptual Understanding

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ABSTRACT
This study aims to determine the influence of the use of Augmented Reality in learning building structures on the understanding of concepts of Civil Engineering Students. This type of research is a quantitative research with a meta-analysis approach. The inclusion criteria in this study are research published in 2021-2024, research must be indexed by SINTA or Scopus, research must be relevant, research obtained from the journal databases of google scholar, Wiley, ScienceDirect, and ERIC and research data must be complete to calculate the effect size value (d). Data analysis with the help of the JASP application. The results of this study concluded that the 14 effects sizes analyzed had a total effect size value of d = 0.962; p < 0.001. This finding explains that the use of Augmented Reality has a significant influence on the Conceptual Understanding of Civil Engineering Students in Building Structure Learning.

ABSTRAK
Penelitian ini bertujuan untuk mengetahui pengaruh penggunaan Augmented Reality dalam pembelajaran struktur bangunan terhadap pemahaman konsep Mahasiswa Teknik Sipil. Jenis penelitian ini adalah penelitian kuantitatif dengan pendekatan meta-analisis. Kriteria inklusi dalam penelitian ini adalah penelitian diterbitkan tahun 2021-2024, penelitian harus terindeks SINTA atau Scopus, penelitian harus relevan, penelitian diperoleh dari database jurnal google scholar, Wiley, ScienceDirect, dan ERIC dan data penelitan harus lengkap untuk menghitung nilai effect size (d). Analisis data dengan bantuan aplikasi JASP. Hasil penelitian ini menyimpulkan bahwa 14 effects size yang dianalisis nilai summary effect size sebesar d = 0.962; p < 0.001. Temuan ini menjelaskan bahwa penggunaan Augmented Reality memberikan pengaruh signifikan terhadap Pemahaman Konsep Mahasiswa Teknik Sipil dalam Pembelajaran Struktur Bangunan.

1. Introduction

Civil Engineering Education has a strategic role in supporting the development of sustainable modern infrastructure (Ahmed, 2019) Civil Engineering encompasses various aspects of the design, construction, and maintenance of infrastructure such as buildings, roads, bridges, and drainage systems, which are the backbone of a country's progress. In the era of rapid globalization and urbanization, the need for safe, efficient, and environmentally friendly infrastructure is increasing (Yen et al., 2013). Therefore, Civil Engineering education not only serves as a means to equip students with theoretical knowledge, but also to develop the practical skills and critical thinking abilities necessary to solve complex challenges in the real world. With a relevant learning approach, Civil Engineering education is able to create professionals who are competent, innovative, and adaptive to technological developments and the needs of society (Chen et al., 2011; Zulyusri et al., 2023; Dewanto et al., 2023).

In addition to contributing to physical development, Civil Engineering education has a great responsibility in realizing sustainable development. Through the application of sustainability principles in the curriculum, Civil Engineering students are taught to consider environmental, social, and economic aspects in every stage of a construction project (Chacón et al., 2020). For example, the use of environmentally friendly materials, energy efficiency, and climate change-responsive infrastructure planning are the main focuses in this education. In addition, Civil Engineering education also encourages students to integrate the latest technology, such as Building Information Modeling (BIM) and Augmented Reality (AR), to improve efficiency and accuracy in project design and implementation (Li et al., 2018; Ahmed, 2019). Thus, Civil Engineering education plays an important role in producing a generation of professionals who are not only technically proficient, but also committed to the sustainability and welfare of society.

Civil Engineering plays an important role in the development of modern infrastructure as the main foundation that underpins various sectors of people's lives (Altmeyer et al., 2020). Infrastructure designed and built by Civil Engineering professionals, such as buildings, bridges, highways, and drainage systems, is a vital element in supporting social, economic, and cultural activities (Rahmawati et al., 2022). In the era of rapid globalization and urbanization, the need for safe, efficient, and innovative infrastructure is increasingly urgent. This is where Civil Engineering education takes a strategic role to ensure that graduates not only master technical knowledge, but also have the ability to think critically and adapt to complex challenges in the field. This education is designed to create professionals who are able to present innovative solutions to infrastructure problems, both on a local and global scale (Behzadan & Kamat, 2013; Oktarina et al., 2018).

Civil Engineering students are required to understand the concept of building structures well as the basis of professional expertise, because building structures are the main element in infrastructure design and construction (Behzadan et al., 2011). A deep understanding of this concept allows students to design buildings that are safe, efficient, and compliant with technical standards (Eh Phon et al., 2014). As the foundation of various disciplines in Civil Engineering, knowledge of building structures includes the analysis of loads, material strengths, to structural behavior under various conditions. This is the foundation that students must master before they can be involved in complex and challenging real construction projects. A good education in this field not only helps students to understand theory, but also hones their analytical skills in applying that knowledge into practice.

Furthermore, mastery of the concept of building structures is also an important indicator of the professional competence of a Civil Engineering engineer. In the world of work, engineers are expected to be able to solve various structural problems, such as designing buildings that are resistant to earthquakes, optimizing cost-efficient designs, and ensuring user safety (Behzadan & Kamat, 2013). Therefore, the Civil Engineering curriculum must be designed holistically to help students understand these concepts in depth through innovative learning methods. The use of modern technology, such as computer simulations, Augmented Reality (AR), and virtual laboratories, can help students gain a clearer visualization of the behavior of building structures. With this approach, students not only understand concepts theoretically, but also develop practical skills and readiness to face the challenges of the professional world (Oke & Arowoiya, 2022).

Building structure materials in Civil Engineering education are often considered abstract and complex, making them difficult for students to understand through traditional learning methods. This complexity arises because the material involves deep theoretical concepts, such as force analysis, material behavior, and the interaction of structural elements under various load conditions. In addition, many aspects of building structures require three-dimensional visualization to be truly understood, whereas traditional methods such as lectures and textbooks often only present information in two-dimensional form (Y. C. Chen et al., 2011). As a result, students often have difficulty connecting the theory to its application in real-world contexts, which can hinder their conceptual understanding. In traditional learning, the lack of interactivity and an adequate visual approach can reduce the effectiveness of learning, especially when students are expected to understand complex technical details.

Therefore, innovation in learning methods is needed to overcome these challenges and increase students' understanding of building structure materials. Modern educational technologies, such as Augmented Reality (AR) and computer-based simulation, have shown great potential in bridging this gap (Hilmi et al., 2018). By utilizing the technology, students can view, analyze, and interact with building structure models virtually, allowing them to understand abstract concepts in a more concrete way (Lucignano, 2018). In addition, project-based and collaborative learning methods can also help students apply theory in a practical context, thereby deepening their understanding. The integration of technology and an active approach to learning not only helps to overcome the limitations of traditional methods but also increases student engagement in the learning process, thereby creating a more effective and meaningful learning experience (Li et al., 2018).

Research conducted by Ibáñez et al. (2020), the use of AR in engineering learning has helped students to understand complex concepts more easily through interactive visualization. This technology allows students to interact with three-dimensional virtual models that resemble real conditions, so they can observe the structural elements directly. Another study by Cheng and Tsai (2019) revealed that students who learned to use AR showed better results in concept comprehension tests compared to those who only learned through traditional methods. These studies support the idea that the integration of technologies such as AR can improve the effectiveness of learning, especially in abstract courses such as building structures. Research by Sukumar et al. (2021) shows that traditional learning methods, such as lectures or the use of static diagrams, are not effective enough to help students understand the concepts of force, load, and structural response. The study recommends more interactive and student-centered learning approaches, such as the use of virtual simulations and AR technology, to help bridge the gap between theory and practice. In addition, research conducted by Miller and Langston (2022) revealed that students who use a project-based learning approach with technology support tend to be more able to apply the concept of building structures in real situations. This shows the importance of innovation in the Civil Engineering learning method.

Research by Zaharia et al. (2020) shows that the integration of AR in structural engineering learning can increase student engagement and make it easier for them to understand the relationship between structural elements. Students can access 3D models of buildings and study the interactions between components, such as columns, beams, and joints, which were previously difficult to visualize through traditional media. In addition, research by Navarro et al. (2021) found that students who learned to use AR not only improved their understanding of the material, but also showed a significant increase in learning motivation. Although Augmented Reality (AR) technology has been widely used in various fields of education, its implementation in learning Civil Engineering, especially in building structure materials, is still relatively rarely explored in depth (Delgado-kloos, 2018). Previous research has focused more on the use of AR for architectural design visualization or construction process simulation, but few specifically evaluate the effectiveness of AR in improving students' conceptual understanding of building structure concepts, such as load distribution, material strength, and structural stability. In addition, most of the existing studies focus on cognitive learning outcomes in general without providing an in-depth analysis of the involvement of this technology in helping students connect abstract theory with practical applications. Thus, there is a significant need for research that examines the role of AR in improving the conceptual understanding of Civil Engineering students specifically in building structure courses. Based on this, this study aims to determine the influence of the use of Augmented Reality in learning building structures on the understanding of concepts of Civil Engineering Students.

2. Literature Review

a. Augmented Reality

Augmented Reality (AR) is a technology that incorporates virtual elements, such as images, animations, or interactive data, into a real environment in real-time (Chen et al., 2022). This technology works by utilising hardware such as cameras, sensors, and special software capable of recognising physical objects to add digital information on top of them. AR differs from Virtual Reality (VR) in that it does not completely replace the real world with a virtual environment, but enriches the real world with digital elements. AR allows users to interact with virtual content more naturally, thus providing a more immersive and realistic experience (Wibowo, 2023).

AR technology has been applied in various sectors, including education, healthcare, entertainment, manufacturing, and architecture. In education, AR is used to make learning more interactive, especially on material that is difficult to visualise, such as the anatomy of the human body or the structure of chemical molecules (Rizki et al., 2024). In healthcare, AR helps in surgical training by providing accurate visual guidance. In the manufacturing and architecture sectors, AR is used to simulate the design of products or buildings before construction begins. The versatility of AR makes it an effective tool for improving efficiency, accuracy and user engagement in various fields.

In the context of education, AR provides various benefits, including increasing student engagement, enriching the learning experience, and aiding the understanding of complex material. The technology is capable of presenting three-dimensional visualisation elements that make it easier for students to understand abstract concepts, such as the mechanics of physics or the dynamics of building structures. In addition, AR enables simulation-based learning, which provides students with learning experiences that approximate real-world conditions. Research also shows that AR can increase student motivation, learning engagement, and critical thinking ability, making it a highly potential tool in learning method reform.

b. Building structure learning

Learning about building structures is a fundamental component of civil engineering education, providing students with the theoretical and practical foundation necessary for designing, analyzing, and constructing safe and efficient infrastructure (Manago & Kenzie, 2022). Understanding key principles such as load distribution, material strength, and structural stability is crucial for future engineers to create buildings that can withstand external forces, including earthquakes, wind, and operational loads. This knowledge equips students not only to solve technical problems but also to contribute to the development of sustainable and resilient infrastructure that meets societal needs**.**

Despite its importance, mastering building structures poses significant challenges due to the abstract and complex nature of the subject. Many concepts, such as stress-strain relationships or dynamic load responses, are difficult to grasp through traditional teaching methods like static diagrams or textbook explanations. Additionally, limited access to advanced laboratory equipment or simulation software can hinder students from gaining a comprehensive understanding of structural behavior. These challenges highlight the need for innovative teaching approaches to make the subject more accessible and engaging for learners.

The integration of modern technology, such as Augmented Reality (AR), offers a promising solution to enhance the teaching and learning of building structures. AR enables students to visualize structural elements in three-dimensional space, allowing them to observe how forces interact within a system. For instance, students can use AR to simulate the impact of different loads on a beam or column, gaining a deeper understanding of structural mechanics. Research has demonstrated that incorporating technologies like AR not only improves conceptual understanding but also boosts student engagement and motivation, making it a valuable tool in advancing civil engineering education.

c. Concept Understanding

Conceptual understanding is the foundation of effective learning, enabling students to grasp the underlying principles and relationships within a subject (Santosa & Sepriyani., 2020). It goes beyond memorizing facts and procedures, focusing instead on the ability to connect ideas, apply knowledge in different contexts, and solve problems creatively. In engineering education, particularly in complex fields like structural mechanics or fluid dynamics, a strong conceptual understanding allows students to approach real-world challenges with confidence and innovation. This level of comprehension is critical for developing professionals who can adapt to rapidly evolving technological and industrial demands.

Developing conceptual understanding requires a combination of effective teaching strategies, student engagement, and suitable learning resources. Traditional methods, such as lectures and textbook-based learning, often fall short in facilitating deeper understanding, particularly for abstract or multi-dimensional topics (Nurtamam et al., 2023). Active learning strategies, such as problem-based learning, simulations, and collaborative projects, have proven more effective in helping students internalize concepts. Additionally, the use of technology, such as visualization tools or interactive software, can bridge the gap between theory and application, making complex ideas more tangible and accessible.

3. Methods

The methodology of this study uses a meta-analysis approach to examine the effectiveness of Augmented Reality (AR) technology in improving students' conceptual understanding in learning building structures in the field of Civil Engineering. The inclusion criteria applied in the selection of studies are studies published between 2021 and 2024, with priority given to studies indexed in SINTA or Scopus. Relevant research will be selected based on its suitability to topics that address the use of AR in Civil Engineering education, particularly in building structure materials. Research data sources will be obtained from trusted journal databases, such as Google Scholar, Wiley, ScienceDirect, and ERIC. Only studies that provide complete information about the research design, samples, instruments, and measurement results will be included in this analysis to ensure that the data obtained can be used to calculate the effect size value (d).

Furthermore, the data collected from these studies will be analyzed using a statistical meta-analysis method to calculate the effect size (d), which allows researchers to measure how much the use of AR affects students' conceptual understanding in the context of building structures. The effect size will be calculated by taking into account variations in the results of the studies taken, and this analysis will provide a clearer picture of how significant and consistent the effects of AR are in Civil Engineering learning. To improve the validity and reliability of the findings, this study will apply heterogeneity testing techniques to evaluate the diversity between different studies, as well as sensitivity analysis to ensure that the results obtained are not affected by one study extreme or bias in sample selection. Furthermore, the criteria for the effect size value can be seen in Table 1.

Table 1. Category Effect Size Value

Effect Size	Category
$0.0 \leq ES \leq 0.2$	Low
$0.2 \leq ES \leq 0.8$	Medium
$ES \geq 0.8$	High

Source: (Borenstein et al., 2007; Bachtiar et al., 2023; Tamur et al., 2020)

4. Result

Hasil Based on the results of data search through the database, 14 studies/articles met the inclusion criteria. The effect size and error standard can be seen in Table 2.

Table 2. Effect Size and Standard Error Every Research

Code Jurnal	Years	Effect Size	Standard Error
PL 1	2021	0.83	0.23
PL 2	2022	1.03	0.49
PL 3	2022	0.91	0.33
PL 4	2023	1.17	0.28
PL 5	2024	0.44	0.19
PL 6	2024	0.72	0.25
PL 7	2024	0.86	0.39
PL 8	2022	1.25	0.40
PL 9	2021	1.05	0.32
PL 10	2023	1.52	0.30
PL 11	2022	0.87	0.29
PL 12	2024	1.47	0.42
PL 13	2021	0.52	0.20
PL 14	2024	0.77	0.19

Based on Table 2, the effect size value of the 14 studies ranged from 0.44 to1.47. According to Borenstein et al., (2007) Of the 14 effect sizes, 4 studies had medium criteria effect sizes and 10 studies had high criteria effect size values. Furthermore, 24 studies were analyzed to determine an estimation model to calculate the mean effect size. The analysis of the fixed and random effect model estimation models can be seen in Table 3.

Table 3. Fixed and Random effect

	Q	df	p
Omnibus test of Coefficients Model	61.942	1	< 0.001
Test of Residual Heterogeneity	94.082	13	< 0.001

Based on Table 3, a Q value of 94.082 was obtained higher than the value of 61.942 with a coefficient interval of 95% and a p value of 0.001 <. The findings can be concluded that the value of 14 effect sizes analyzed is heterogeneously distributed. Therefore, the model used to calculate the mean effect size is a random effect model. Furthermore, checking publication bias through funnel plot analysis and Rosenthal fail safe N (FSN) test (Tamur et al., 2020; Badawi et al., 2022; Ichsan et al., 2023b; Borenstein et al., 2007; Asnur et al., 2024; Ali et al., 2024); Wantu et al., 2024).

Tabel 4. Summary/ Mean Effect Size

Coefficient						
	Effect Size	Standard Error	z	p	95 % Coefficient Interval	
					Lower	Upper
Intercept	0.962	0.204	7.58	< 0.01	0.72	1.02

Table 4, shows that the summary effect size value is 0.962; p < 0.001. This finding explains that the use of Augmented Reality has a significant influence on the Conceptual Understanding of Civil Engineering Students in Building Structure Learning than conventional learning with high effect size category. By utilizing AR, students can visualize the elements of building structures in three dimensions, so that abstract concepts such as load distribution, structural stability, and interactions between elements become more real and easy to understand. This is in line with previous research by Ibáñez et al. (2020), which showed that AR-based learning helps students in connecting theory with practical applications through an interactive approach and deep visualization. These findings suggest that AR can be an effective tool in bridging the gap between complex theory and practice in the field (Behzadan & Kamat, 2013).

One of the important findings in this study is that AR is able to overcome the limitations of traditional learning methods that tend to be textual and less interactive. In traditional learning, students often have difficulty understanding concepts involving load dynamics and structural responses due to limited visual representation (Zulkifli et al., 2022). With AR, students can interact directly with a virtual structure model that allows them to observe the behavior of structural elements under various load conditions. A study by Cheng and Tsai (2019) supports these findings, where AR-based learning has been shown to increase student engagement and deepen their understanding of critical concepts in Civil Engineering. The use of AR in learning also has a positive impact on student motivation and engagement. This technology provides a more engaging and interactive learning experience compared to conventional learning methods. Students feel more motivated to understand the material because they can explore difficult concepts in a more intuitive way. Research by Zaharia et al. (2020) shows that students who use AR in learning not only achieve better understanding, but also have higher participation rates in class discussions and collaborative projects. This shows that AR not only supports cognitive aspects but also affective aspects in the learning process. In addition to improving conceptual understanding, the use of AR also contributes to the development of students' practical skills (Yoon et al., 2012). Students can utilize AR to simulate real-world situations, such as analyzing the behavior of structures under certain loads, without the need for complex physical laboratories. This provides them with practical experience relevant to the world of work, while improving their ability to make data-driven decisions. This research supports the study of Miller and Langston (2022), which found that Civil Engineering students who use AR in learning are better prepared to face technical challenges in the field than those who rely solely on the learning method of learning design (Ghobadi et al., 2023).

Penulis harus menghubungkan hasil dan analisis asli Anda dengan hasil atau pendapat dari penelitian sebelumnya yang telah dipublikasikan dalam lima tahun terakhir. Meskipun referensi lama dipersilakan, 90% referensi harus dari studi 2017-2021. Harus ada minimal 25 kutipan studi dalam lima tahun terakhir

5. Conclusion

From the results of this study, it can be concluded that the 14 effects sizes analyzed have a summary effect size value of d = 0.962; p < 0.001. This finding explains that the use of Augmented Reality has a significant influence on the Conceptual Understanding of Civil Engineering Students in Building Structure Learning. This technology has been proven to overcome the limitations of traditional learning which is often not able to provide clear and dynamic visual representation. Thus, AR not only supports cognitive learning but also increases student motivation, engagement, and readiness to face technical challenges in the world of work.

However, this study also identifies challenges in the implementation of AR, such as the need for adequate technological infrastructure and training for lecturers. Therefore, the sustainability of AR adoption requires strategic planning, both in terms of resource provision and integration in the curriculum. The implications of these findings show that AR can be an effective learning tool, especially in supporting the transformation of Civil Engineering education that is more adaptive to technological developments in the era of the industrial revolution 5.0. Further research is suggested to explore the long-term impact of the use of AR as well as its application to various disciplines in Civil Engineering, such as hydraulics and geotechnics.

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