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StructARLearn: An Augmented Reality Platform for Enhancing Structural Engineering Pedagogy

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Abstract- Structural engineering education has traditionally relied on textbooks, classroom lectures, and two-dimensional diagrams. However, students often struggle to translate these abstract resources into an understanding of real-world structural behavior. This limitation hinders their ability to connect theory with practice. To address this challenge, this paper proposes StructARLearn, a novel software platform derived from Structure + AR (Augmented Reality) + Learning. StructARLearn is an Augmented Reality (AR)-based platform designed to provide immersive, interactive, and experiential learning opportunities in structural engineering. It integrates AR visualizations, real-time finite element simulations, and interactive modules that enable students to apply loads, visualize deformations, and observe structural responses in real-world contexts through mobile devices or AR glasses. By bridging theoretical knowledge with practice, the platform improves comprehension, retention, and engagement. This paper presents the conceptualization and development methodology of StructARLearn, reviews related literature on AR in engineering pedagogy, outlines the framework of the platform, and discusses its anticipated benefits, challenges, and implications for large-scale adoption.

Keywords – StructARLearn, Structural Engineering, Augmented Reality, Pedagogy, Simulation, Educational Technology.

I. INTRODUCTION

Structural engineering, a core branch of civil engineering, is concerned with designing and analyzing structures capable of withstanding diverse loads and environmental conditions (Blockley, 2014), (Hibbeler, 2018). Effective teaching of structural engineering requires bridging the gap between theoretical principles, mathematical formulations, and practical applications in real-world design and construction. However, traditional methods, such as classroom lectures, equations, and 2D diagrams-often fail to help students fully visualize complex structural responses like bending, shear, torsion, and deflection, (Akçayır & Akçayır, 2017).

It is evident that, Students often fail to understand structural engineering from textbooks alone, but with introduction of “AR” into civil engineering teaching and learning, the real-time visualization of bending, shear, torsion, and deflection on structural members can easily be understood. Moreover, Integration with Machine Learning (ML) and IoT-enabled smart structures further enriches pedagogy, aligning with Industry education standards, (Afshar et al., 2024).

The Platform name is a blend of "Struct" from structural engineering and "AR" from augmented reality, emphasizing its focus on enhancing learning experiences in the field, “StructARLearn”. It is an abbreviation name for an Augmented Reality (AR) Educational platform designed specifically for Structural Engineering Education. It is an Educational Technology that overlays digital information, such as images, text, or 3D Models, onto the real-world environment. It enhances the user’s perception of reality by integrating computer-generated content into their view. StructARLearn is also an initiative aimed to have significant impacts on Structural Engineering Teaching and Learning Practices by providing students and teachers with interactive and immersive learning experiences, (Billinghurst & Duenser, 2012).

Recognizing these pedagogical challenges, scholars have called for transformative approaches that integrate advanced technologies into teaching and learning, (Ibrahim, 2024) and (Spector et al., 2014) and (Ubayi, 2024). Among such technologies, Augmented Reality (AR) has emerged as a powerful tool that overlays digital information—3D models, text, images—onto the physical world, creating immersive and interactive experiences (Azuma, 1997; Milgram & Kishino, 1994). AR has been shown to enhance visualization, support constructivist learning, and improve motivation and retention, (Bower & Sturman, 2015) and (Akçayır & Akçayır, 2017).

This paper introduces StructARLearn - a software platform created to enhance structural engineering pedagogy by combining Structure + Augmented Reality + Learning. StructARLearn allows students to explore structural components interactively, simulate real-world loading conditions, and engage in collaborative problem-solving. The objective is not only to improve learning outcomes but also to prepare future engineers for the challenges of modern structural design and smart construction systems.

Augmented Reality (AR) can be seen as a Technology that overlays Computer-Generated Information, such as images, text, or 3D models, onto the real-world environment, enhancing the user's perception of reality. AR integrates digital content seamlessly with the physical world, typically experienced through devices like smartphones, tablets, or AR glasses, (Azuma, 1997).

This Paper also, is aimed to leverage AR technologies for the Engineering Educators to create a more engaging and effective learning environment that prepares students for the challenges of the rapidly evolving field of Structural Engineering. The paper provides insights of AR technology Integration into Structural Engineering Pedagogy and Different Papers were consulted on AR in Education and based on the Studies some key factors and platform features were provided on this Integration Process.

II. LITERATURE REVIEW

In structural engineering specifically, AR provides opportunities to link theoretical principles with practice, helping students better understand load paths, dynamic behaviors, and failure mechanisms.

Historical Background of AR in Education: Augmented Reality (AR) in education has its roots in the late 20th century, with early experiments and developments laying the foundation for its integration into learning environments, (Sutherland, 1968) and (Anderson & Shattuck, 2012).

1. **1970s-1980s:** Emergence of AR Concepts: The conceptual groundwork for AR was laid in the 1970s and 1980s, with computer scientists exploring the idea of combining virtual and real-world elements to enhance user experiences, (Sutherland, 1968).
2. **1990s:** Early AR Applications: In the 1990s, researchers began experimenting with early forms of AR applications. One notable example is Boeing's use of AR for aircraft assembly, demonstrating the technology's potential for practical tasks, (Caudell & Mizell, 1992), and (Anderson & Shattuck, 2012).
3. **Early 2000s:** AR in Learning Environments: The early 2000s saw a shift toward exploring AR applications in learning environments. Educational researchers and technologists started to investigate how AR could be used to supplement traditional teaching methods, (Billinghurst & Duenser, 2012).
4. **Mid-2000s:** AR in Academic Research: Academic research increasingly focused on the educational potential of AR. Studies explored the impact of AR on engagement, knowledge retention, and the overall learning experience, (Klopfer & Sheldon, 2010).
5. **2010s:** Proliferation of AR Technologies: The 2010s witnessed a proliferation of AR technologies, driven by advancements in mobile devices and increased computing power. Educational apps and platforms began integrating AR features, making the technology more accessible in various academic disciplines, (Klopfer & Sheldon, 2010).
6. **Late 2010s-Present:** Mainstream Adoption: In recent years, AR has gained mainstream adoption in education. Schools, universities, and educational technology developers have embraced AR to create immersive and interactive learning experiences, (Radu, 2014) and (Akçayır & Akçayır, 2017).
7. **Research and Evaluation:** Ongoing research continues to evaluate the effectiveness of AR in education. Studies explore its impact on student outcomes, the development of AR-enhanced curricula, and the integration of AR into diverse educational settings, (Radu, 2014).

Figure 1. Evolution of technology integration in Civil Engineering pedagogy

AR in Engineering Education: Augmented Reality (AR) in engineering education involves the integration of augmented reality technologies into the teaching and learning processes within engineering disciplines. It enhances traditional educational methods by overlaying digital information, simulations, or 3D models onto the real-world environment, providing students with interactive and immersive learning experiences, (Radu, 2014). AR has been widely studied for its ability to improve learning in technical disciplines. Key contributions include:

1. **Visualization of Complex Concepts:** AR enables students to visualize and interact with complex engineering concepts by overlaying digital models, simulations, or annotations onto physical objects or environments. Therefore, Visualization of Complex Concepts: AR helps students understand structural principles by overlaying

simulations onto physical environments, (P. Wang et al., 2018).

2. **Hands-On Learning**: It offers hands-on learning experiences, allowing students to manipulate virtual objects or conduct simulations that mimic real-world engineering scenarios. Therefore, Hands-on Learning, allows learners to manipulate models, apply loads, and observe real-time deformation, (Bower & Sturman, 2015).
3. **Enhanced Understanding:** AR aids in enhancing students' understanding of spatial relationships, structural designs, and engineering principles by providing a visual and interactive layer to theoretical concepts, (X. Wang et al., 2013).
4. **Simulation of Real-World Scenarios:** AR can simulate real-world scenarios, allowing students to practice problem-solving skills in a controlled and interactive environment before encountering similar situations in the field. Therefore, Simulation of Real-world Scenarios enables students to explore what-if analyses in a safe, controlled virtual setting, (Jerry Dale et al., 2017).
5. **Remote Collaboration:** It facilitates remote collaboration by enabling students to share augmented reality experiences, fostering teamwork and communication in engineering projects. Therefore, Collaborative and Remote Learning, Facilitates group projects in shared AR spaces, even remotely, (Billinghurst et al., 2015).
6. **Interactive Laboratories:** AR can transform traditional laboratories into interactive environments where students can conduct experiments virtually, making experimentation more accessible and efficient, (Billinghurst & Duenser, 2012).
7. **Engagement and Motivation:** The interactive and immersive nature of AR engages students, fostering motivation and interest in engineering subjects through novel and dynamic learning experiences, (Billinghurst & Duenser, 2012).
8. **Professional Skill Development:** AR applications in engineering education contribute to the development of skills relevant to the modern engineering workplace, including proficiency in using advanced technologies and tools, (P. Wang et al., 2018).

Benefits of AR in Learning: [(Klopfer & Sheldon, 2010), (Radu, 2014)]

1. **Enhanced Engagement:** AR makes learning more interactive and engaging, capturing learners' attention through immersive experiences,
2. **Improved Understanding:** Visualizing complex concepts in 3D promotes better comprehension of abstract topics.
3. **Real-world Application:** AR allows learners to apply theoretical knowledge in simulated real-world scenarios, facilitating practical skill development.
4. **Personalized Learning:** Tailored AR experiences can cater to individual learning styles, adapting to the pace and preferences of each student.

Pedagogical Benefits of AR: The Studies emphasize that AR contributes to:

- Enhanced comprehension of abstract principles, (Radu, 2014).
- Stronger knowledge retention (Akçayır & Akçayır, 2017).
- Alignment with constructivist and problem-based learning frameworks, (Anderson & Shattuck, 2012).

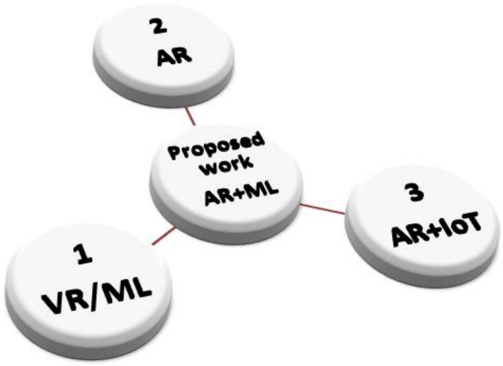

Figure 2. Evolution of technology integration in civil engineering pedagogy

Relevant Works:

Table 1: Evolution of AR Technology Application

Author & Year	Technology	Application Area	Key Contribution
(P. Wang et al., 2018)	VR/AR	Civil Engineering	Demonstrated improved comprehension of structural dynamics using VR.
(Bower & Sturman, 2015)	AR	Higher Education	AR enhances visualization and engagement in STEM.
(Jerry Dale et al., 2017), (Bahir Abdul Ghani, 2025) and (Syahidi et al., 2021).	AR + IoT	Construction	Proposed AR for site monitoring with IoT sensors.
Proposed Work: (StructARLearn)	AR + ML	Structural Pedagogy	Real-time load visualization, interactive modules, predictive simulations.

III. METHODOLOGY

3.1. What to do:

- **AR Model Development:** 3D models of structural components built in Unity3D with AR Foundation.
- **Simulation Integration:** Real-time response data (deflections, stresses) integrated using finite element backend.
- **Pedagogical Modules:** Load-deformation visualization, material comparison, failure modes.
- **User Interaction:** Gesture/touch to apply loads, change material, and visualize failure

StructARLearn Framework: The proposed framework is structured into four functional layers:

1. Content Layer – Structural models (beams, trusses, frames, bridges).
2. Visualization Layer – AR headsets/smartphones for immersive learning.
3. Simulation Layer – Load cases, boundary conditions, material properties.
4. Analytics Layer – Performance tracking, student assessment, ML-based predictions.

N.B.: StructARLearn Platform Development Process: The methodology for developing StructARLearn follows a structured software design and implementation process, emphasizing both technological integration and pedagogical alignment. (Caudell & Mizell, 1992) and (Modarelli et al., 2025).

Phase 1: Requirements Analysis

- **Educational Needs Assessment:** Review curriculum requirements and identify topics where AR integration offers the highest pedagogical value (e.g., beam deflection, truss analysis).
- **Stakeholder Consultation:** Interviews with educators and students to determine usability requirements, (Modarelli et al., 2025).

Phase 2: System Design

- **Conceptual Framework:** StructARLearn structured into four layers—Content, Visualization, Simulation, and Analytics.
- **Platform Selection:** Unity3D chosen for 3D model development; AR Foundation selected for cross-platform deployment on Android and iOS devices, (Modarelli et al., 2025).

Phase 3: Model Development

- Creation of structural models (beams, trusses, frames, bridges) using CAD software and import into Unity3D.
- Application of finite element methods (FEM) to enable real-time response simulations, (Sherman & Craig, 2019).

Phase 4: AR Integration

- Implementation of marker-based and marker-less AR using smartphone cameras and AR glasses.
- Gesture and touch controls integrated for load applications, boundary condition changes, and material selection.

Phase 5: Pedagogical Module Design

- **Beam Deflection:** Apply loads and visualize real-time deformation.
- **Truss Analysis:** Visualize force distribution along members.
- **Vibration Modes:** Demonstrate dynamic behavior and natural frequencies.
- **Failure Modes:** Show buckling, shear, and plastic hinge formation.

Phase 6: Testing and Evaluation

- Usability testing with a pilot group of students.
- Performance-based assessment measuring comprehension, retention, and problem-solving skills.
- Iterative refinements based on feedback.

Phase 7: Deployment and Scalability

- Deployment via mobile app stores and institutional licenses.
- Integration into MOOCs and blended learning courses.
- Long-term plan: integration with IoT sensors for real-time monitoring and AI-based adaptive learning.

Table 2. Framework of StructARLearn AR-based pedagogy platform.

IV. ANTICIPATED BENEFITS

Module	Description	Pedagogical Value
Beam Deflection	Apply loads to beam and view deflection	Enhances understanding of flexural behavior
Truss Analysis	Force distribution visualization	Improves grasp of load paths
Vibration Modes	Animate natural frequencies	Connects theory to dynamic behavior

- **Enhanced Comprehension:** Students see real-time structural responses.
- **Improved Retention:** Visual + experiential learning yields higher memory recall.
- **Accessibility:** Works on smartphones, reducing dependency on expensive VR headsets.
- **Scalability:** Can integrate with MOOCs and online learning.

PEDAGOGICAL FRAMEWORKS FOR AR INTEGRATION: [(Anderson & Shattuck, 2012), (Sherman & Craig, 2019) And (Akçayır & Akçayır, 2017)]

1. **Constructivist Approach:** Emphasizes hands-on, experiential learning where learners actively construct knowledge through AR interactions.
2. **Collaborative Learning:** Utilizes AR to foster collaborative learning experiences, encouraging teamwork and communication.
3. **Problem-Based Learning:** AR supports problem-solving approaches, allowing learners to apply knowledge in solving real-world engineering challenges.
4. **Situative Learning:** Embeds AR in authentic contexts, promoting situated learning experiences that connect theoretical knowledge to practical applications.

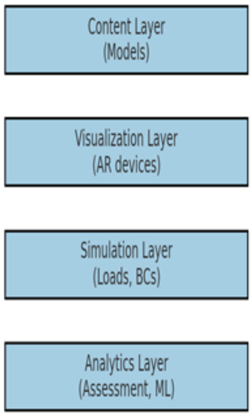

Figure 3. Framework of StructARlearn AR-based pedagogy platform.

ASSESSMENT METHODS AND LEARNING OUTCOMES OF AR: [(Akçayır & Akçayır, 2017) and (Radu, 2014)].

1. **Performance-based Assessment:** Evaluates students' ability to apply knowledge in AR-simulated scenarios.
2. **Knowledge Retention:** Assesses the long-term retention of information acquired through AR-enhanced learning experiences.
3. **Problem-solving Skills:** Measures the development of critical thinking and problem-solving skills facilitated by AR.
4. **User Feedback:** Gathers feedback from students on their experiences with AR, aiding in continuous improvement.

USER EXPERIENCE AND INTERACTION DESIGN: [(Azuma, 1997), (Billinghurst et al., 2015)].

1. **Intuitive Interfaces:** Prioritizes intuitive design to ensure users can navigate AR environments seamlessly.
2. **Realism and Immersion:** Strives to create realistic and immersive experiences through high-quality graphics and interactions.
3. **Adaptive Feedback:** Provides adaptive feedback to guide learners, offering support or challenges based on individual progress.
4. **Interactivity:** Promotes active engagement through interactive elements, encouraging exploration and participation.

ETHICAL CONSIDERATIONS IN AR EDUCATION: [(Klopfer & Sheldon, 2010), (Sherman & Craig, 2019) and (Ibrahim, 2024)]

1. **Privacy Concerns:** Safeguards student privacy by addressing data collection and storage practices associated with AR applications.
2. **Inclusivity:** Ensures that AR resources are accessible to all learners, considering diverse needs and abilities.
3. **Digital Citizenship:** Promotes responsible and ethical use of AR technologies, educating students about digital citizenship.
4. **Security Measures:** Implements robust security measures to protect against potential risks associated with AR applications.

RESEARCH FOCUS:

The research focused on integrating Augmented Reality (AR) in Structural Engineering Education, and this is summarized below:

1. **Development and Usability Testing:** Investigating the creation and refinement of an Augmented Reality (AR) platform for educational use, emphasizing user-friendly design and functionality, (Azuma, 1997) and (Sherman & Craig, 2019).
2. **Impact on Learning Outcomes:** Examining the effects of AR integration on students' academic performance, understanding of subject matter, and overall learning outcomes, (Akçayır & Akçayır, 2017).
3. **Integration with Existing Curriculum:** Assessing how the AR platform aligns with and complements the current educational curriculum, exploring potential enhancements or modifications, (Klopfer & Sheldon, 2010) and (Anderson & Shattuck, 2012).
4. **Long-term Implementation and Scalability:** Investigating the sustainability and scalability of the AR intervention over an extended period, considering factors like cost, institutional support, and adaptability to varying educational contexts, (Fruchter et al., 1988) and (Bower & Sturman, 2015).

PLATFORM FEATURES:

The creation of an innovative AR-based educational platform called the “StructARLearn” is summarized below:

1. **3D Visualization Module:** Offers an interactive, AR-enhanced 3D visualization of structural models and concepts. It also Allows students to explore and manipulate virtual structures in real-time.

2. **Simulation and Design Exploration Tools:** Integrates AR simulations for structural designs, enabling students to simulate various scenarios and assess the behavior of different structures.
3. **Interactive Learning Modules:** Develops AR-based learning modules that guide students through key structural engineering concepts. It Provides interactive exercises and quizzes within the AR environment.
4. **Collaborative Learning Spaces:** Enables collaborative learning in AR spaces, allowing students to work together on virtual structural projects. It Integrates communication tools for real-time collaboration.
5. **Performance Assessment Module:** Includes an assessment system to measure student learning outcomes within the AR platform. It also Offers feedback on individual and collaborative projects.
6. **Accessible Learning Materials:** Ensures accessibility by providing learning materials in various formats and accommodating different learning styles. Addresses inclusivity concerns by considering diverse student needs.

V. DISCUSSION

StructARLearn contributes to the modernization of structural engineering pedagogy by combining AR and FEM into a single platform. It transforms abstract concepts into immersive experiences, allowing students to construct knowledge actively. "StructARLearn" is explored and invented in this study, it is a hypothetical name for an augmented reality (AR) educational platform designed specifically for structural engineering education. Augmented reality is a technology that overlays digital information, such as images, text, or 3D models, onto the real-world environment. It enhances the user's perception of reality by integrating computer-generated content into their view.

By creating the StructARLearn platform, this research can contribute not only to the theoretical understanding of AR in education but also provide a tangible tool that educators can use to enhance the learning experiences of structural engineering students.

In the context of "StructARLearn" and augmented reality for structural engineering education:

1. **3D Visualization:** The platform would allow students to see and interact with 3D models of structures in their real-world surroundings using AR technology.
2. **Simulation and Design Exploration:** Students could use AR to simulate different structural designs and explore how they behave in various scenarios.
3. **Interactive Learning Modules:** The platform would provide interactive modules within the AR environment, guiding students through key concepts and offering quizzes and exercises.
4. **Collaborative Learning Spaces:** AR would enable collaborative learning, allowing students to work together on virtual structural projects in shared AR spaces.
5. **Performance Assessment Module:** StructARLearn would include an assessment system to measure and provide feedback on student learning outcomes within the AR environment.
6. **Accessible Learning Materials:** The platform would ensure accessibility by providing learning materials in different formats, accommodating various learning styles, and addressing inclusivity concerns.
7. Creating a novel educational platform like StructARLearn could have significant positive impacts on structural engineering education by providing students with interactive and immersive learning experiences. If you decide to pursue this initiative, make sure to conduct thorough research, collaborate with experts in both education and AR technology, and consider user feedback to refine and improve the platform.

VI. CONCLUSION

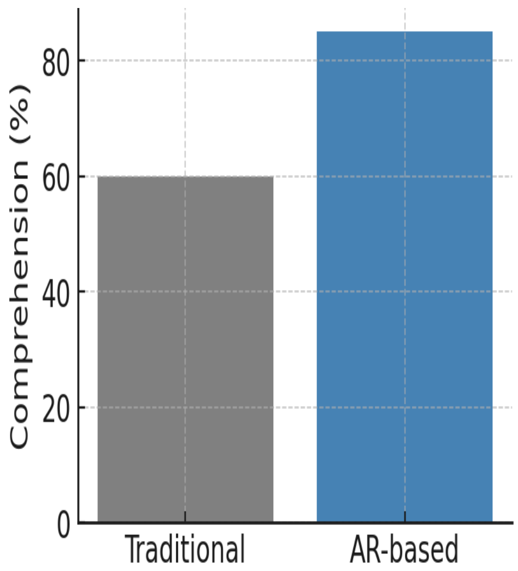

Figure 4: Comprehension Difference between Traditional vs AR-based Technology

StructARLearn is derived from Structure + AR + Learning: This demonstrates the potential of AR-based platforms in transforming structural engineering education. By aligning pedagogy with interactive technologies, the platform bridges the gap between theoretical models and real-world practice. Future research should expand on classroom testing, integration with IoT-enabled smart structures, and AI-driven adaptive learning. StructARLearn represents a step forward in preparing students for the complexities of modern structural engineering.

While AR in education offers significant benefits such as enhanced engagement and improved understanding, challenges like technical barriers and cost implications need to be addressed. Pedagogical frameworks, thoughtful assessment methods, user experience design, and ethical considerations play crucial roles in maximizing the effectiveness of AR in learning environments. Continuous research and development are essential to refine AR integration strategies and ensure its positive impact on education.

StructARLearn demonstrates the transformative role of AR in structural engineering pedagogy. By visualizing real-time load responses, it bridges the gap between theory and practice, preparing students for modern challenges in structural design and construction. Future work includes integrating IoT-based sensor data for real-world monitoring and ML-driven adaptive learning.

This Research focused on integrating Augmented Reality (AR) in Structural Engineering Education. "StructARLearn" is an Educational Technology that overlays digital information, such as images, text, or 3D Models, onto the real-world environment. The paper provides insights of AR technology platforms into Structural Engineering Pedagogy including 3D Visualization Module, Simulation and Design Exploration Tools, Interactive Learning Modules, Collaborative Learning Spaces, Performance Assessment Module, and Accessible Learning Materials.

Augmented reality, in general, enhances educational experiences by providing a more immersive and interactive learning environment. It has applications in various fields, and in this case, it is tailored to the specific needs of structural engineering education, offering a unique way for students to visualize, simulate, and understand complex concepts in their real-world context.

VII. CHALLENGES AND LIMITATIONS

However, challenges include but not limited to; high development costs, device limitations, and curriculum integration remain, (Akçayır & Akçayır, 2017).
These challenges are further discussed by: (Bower & Sturman, 2015), and (Billinghurst et al., 2015).

- Technical Barriers: Implementing AR requires access to compatible devices and reliable network infrastructure, posing challenges in resource-constrained environments.
- Cost Implications: Developing and deploying AR solutions can be expensive, hindering widespread adoption in educational institutions with limited budgets.
- Integration into Curricula: Incorporating AR into existing curricula may face resistance or require significant adjustments, impacting its seamless integration.
- Potential Distractions: Improperly designed AR experiences may lead to distractions, diverting learners' focus from educational objectives.
- Hardware Limitations – AR rendering requires compatible devices.
- Cost & Licensing – Advanced simulations need commercial solvers.
- Pedagogical Adoption – Resistance from traditional curricula.

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