Virtual and Augmented Reality in Building Science and Technology Education: A Review Framework.

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ABSTRACT

Virtual and Augmented reality (VAR) has been integrated in architecture, engineering, and construction (AEC) education as it can facilitate the learning process through immersive experiences. The paper aims to assess the current state and applications of VAR in building science and technology (BS&T) education. As for a systematic review, we developed a novel review framework for VAR-enhanced education in AEC domain, consisting of five hierarchical levels: (1) technology, (2) application field, (3) education objective, (4) evaluation method, and (5) student performance and assessment. This paper shares our preliminary results, including 20 technical papers. The key contribution of this study is the proposed review framework for systematically reviewing VAR applications in AEC and BS&T education.

INTRODUCTION

The transition to a net-zero or energy-positive society can be significantly accelerated through sustainable building development, especially considering buildings accounted for 36.9% of total U.S. end-use energy consumption in 2023 (U.S. Energy Information Administration 2024). Building energy performance is shaped by all phases of the building lifecycle, from design through operation, necessitating the collective effort of professionals in the Architecture, Engineering, and Construction (AEC) industry to drive sustainable development.

Among all subdisciplines in AEC associated with this sustainable development, building science and technology (BS&T) education plays a significant role in preparing future generations. BS&T education includes the study of building physics, energy-efficient system design, construction, and operation (e.g., heating, ventilation, and air-conditioning (HVAC), lighting), indoor environmental quality, and the integration of renewable energy systems to optimize building performance and sustainability. However, mastering BS&T has been a challenging task for AEC students due to its inherent complexity and the interdisciplinary nature

of the subject, which demands proficiency in engineering principles, physics, and environmental science (Anifowose et al. 2023). Often, AEC students – majoring in architecture, civil or architectural engineering, construction management/engineering – are required to take a broad spectrum of courses within their discipline during their academic years. For example, civil engineering curricula typically cover transportation, hydraulics, geotechnics, construction management, and structural engineering. As a result, students may have limited opportunities to develop a strong foundation in BS&T education, despite its critical role in sustainable building practices. Therefore, AEC educators should adopt more effective pedagogical approaches to enhance knowledge acquisition in BS&T.

The objective of this research paper is to systematically examine how BS&T education has integrated virtual and augmented reality (VAR) in its academic offerings, particularly in comparison to other AEC applications. Since early 2000s, VAR-enhanced AEC education has garnered attention from various stakeholders due to its potential as an effective learning modality. Within AEC fields, VAR has been employed in diverse applications, such as jobsite visits (Le et al. 2015), safety training (Zhu et al. 2024), among others. However, our literature review reveals that previous studies have not systematically reviewed the application of VAR specifically for BS&T education. Therefore, this study presents a review framework by analyzing recent technical papers that have incorporated VAR in AEC and BS&T education since 2015 and shares preliminary findings obtained through the proposed review framework.

REVIEW PAPERS IN VAR-Enhanced AEC Education

Table 1. Synthesis of Review Papers in VAR in AEC education.

Authors (Year)	Discipline			Technology		Technology Effectiveness	
	A	E	C	VR	AR	Learners	Instructors
Milovanovic et al. (2017)	○			○	○	○	
Wang et al. (2018)			○	○		○	
Diao and Shih (2019)	○	○			○	○	
Davila Delgado et al. (2020)	○	○	○	○	○	○	
Hajirasouli and Banihashemi (2022)	○		○		○	○	
Tan et al. (2022)	○	○	○	○	○	○	
Kline Andrew and Ayer Steven (2024)			○	○	○	○	
Rocha et al. (2024)	○	○	○	○	○	○	
Wang et al. (2023)	○			○	○	○	○
Kıdık and Asiliskender (2024)	○			○	○	○	○

A: Architecture, E: Engineering, C: Construction, VR: Virtual Reality, AR: Augmented Reality

To establish our knowledge contribution to the AEC education, we conducted a literature review

of several review papers examining the application of VAR in AEC education, which are synthesized in Table 1. While the primary academic disciplines utilizing VAR have traditionally been *Architecture* and *Construction*, recent review studies have extended their scopes to *Engineering* education. Most of these review studies have focused on evaluating the effectiveness of integrating pedagogical technologies with learning environments from both learner and instructor perspectives. Additionally, previous research has explored emerging trends in VAR applications for education (e.g., integration with BIM), cost feasibility, or challenges in real-world implementation. However, the use of VAR technologies for learning BS&T has received little attention. This synthesis of review papers highlights the novelty of our review effort and its contribution to understanding the role of VAR-enhanced technology in BS&T education.

LITERATURE COLLECTION AND SCREENING

Figure 1 illustrates the literature collection and screening process conducted in this review effort. The paper selection process followed these steps:
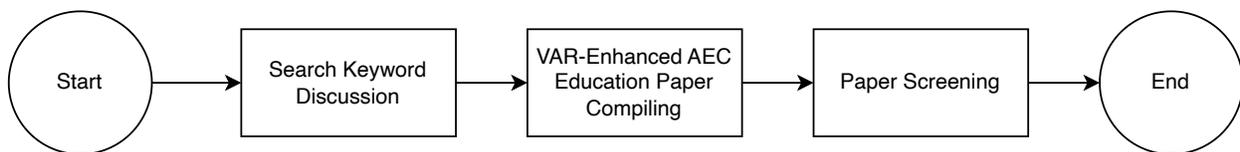

Figure 1. Literature collection and screening flowchart

- **Step #1:** We established search keywords to comprehensively capture papers relevant to our study goal, including "Engineering Education," "Virtual Reality (VR)," "Augmented Reality (AR)," "Energy Engineering," "Civil Engineering," "Architectural Engineering," "Construction Engineering," and "Construction Management."
- **Step #2:** All searches were conducted using Google Scholar, with two mandatory keywords: "Engineering Education" and either "Virtual Reality" or "Augmented Reality". These core keywords provided a foundation for identifying VAR applications in engineering education. To reflect recent research and developments, we included papers published since 2015, covering a 10-year timespan.
- **Step #3:** From the results obtained in Step 2, we further refined our research by incorporating BS&T-related keywords, such as "Building Science," "HVAC," and "Building Energy," and "Building Technology."
- **Step #4:** Finally, we examined each paper's abstract to assess its relevance to this review.

REVIEW FRAMEWORK

We have developed a review framework comprising five phases based on our literature review, as illustrated in Figure 2. The first two phases (technology and application field) were inspired by other previous review papers in this field, such as Wang et al. (2018). These two steps

establish a foundation for categorizing the collected papers based on their VAR technology (VR and/or AR) and application fields (e.g., construction management). The remaining three phases were structured following the evaluation process of an education intervention (Wilkes and Bligh 1999). The third phase involved identifying the educational objectives – i.e., the specific goals behind integrating VAR into AEC education. For instance, a study might aim to enhance AEC students' understanding of building physics concepts. The fourth phase focused on the evaluation methods used in these studies, distinguishing between quantitative approaches (e.g., 5-point Likert scale questionnaires) and qualitative methods (e.g., interviews with content analysis). The final phase examined student performance and learning outcomes, assessing the effectiveness of VAR-based interventions in improving comprehension, engagement, and skill development.

Based on our extensive literature review, this new systematic review framework has not been employed in previous review efforts within VAR-enhanced AEC education. Therefore, it is expected to provide a more structured and comprehensive analysis, offering valuable insights into the integration of VAR technologies in AEC and BS&T education.
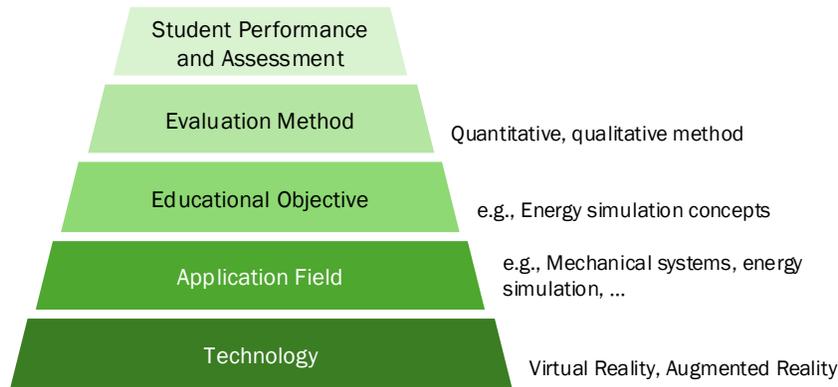

Figure 2. Proposed review framework for VAR-enhanced AEC education studies

Table 2. Attributes in each review phase

Review hierarchy	Attributes
Technology	VR use, AR use, VAR engine, and Modeling software
Application field	Application field (e.g., building physics, jobsite visits)
Education objective	Learning objective
Evaluation method	Quantitative evaluation (e.g., 5-Likert scale questionnaires), qualitative evaluation, number of students participated in evaluation, and target student body (e.g., pre-university, undergraduate, graduate)
Student performance and assessment	Key student performance and evaluation results, including VAR usability assessment.

Consequently, the authors established 10 review attributes in our review database, organized in Table 2. The information relevant to these review attributes was carefully extracted from each paper included in our review and served as the foundation for analyzing trends, key findings, and gaps in VAR-enhanced AEC education research. Regarding the VAR usability assessment, since VAR is an immersive technology that many are not fully familiar with the

technology, researchers have commonly included the use of VAR has been a part of many studies. Hence, we included it in our review process.

RESULTS

Our preliminary review results include a total of 20 technical articles (Abichandani et al. 2019; Aljagoub and Na 2023; Anifowose et al. 2023; Arif 2021; Chiou et al. 2020; Dinis et al. 2017; Dinis et al. 2017; Eiris et al. 2020; Hilfert and König 2016; Kamińska et al. 2017; Le et al. 2015; Luo and Mojica Cabico 2018; Pereira et al. 2018; Pham et al. 2018; Prichetnikov et al. 2020; Rossado Espinoza and Cárdenas-Salas 2021; Shin et al. 2022; Try et al. 2021; Turkan et al. 2017; Wolfartsberger 2019). Due to space constraints, we had to limit the number of papers included in this this conference paper while ensuring a representative selection of relevant studies.

Phase #1: As shown in Figure 3, VR has been consistently applied to AEC education throughout the search period, while AR applications have been notably less frequent, especially in recent years. In most cases (70%), Unity was used as the main engine while other engines, such as Unreal by Hilfert and König (2016) and iOS software development kit by Turkan et al. (2017), were also employed. For modeling work, building information modeling (BIM) tools such as Revit (Aljagoub and Na 2023; Anifowose et al. 2023; Dinis et al. 2017; Eiris et al. 2020; Rossado Espinoza and Cárdenas-Salas 2021), 3D Max (Kamińska et al. 2017; Prichetnikov et al. 2020; Shin et al. 2022), SolidWorks (Chiou et al. 2020) and SketchUp (Arif 2021; Eiris et al. 2020) were widely used. Additionally, computer-aided design (CAD) tools were frequently utilized (Dinis et al. 2017; Dinis et al. 2017; Wolfartsberger 2019).
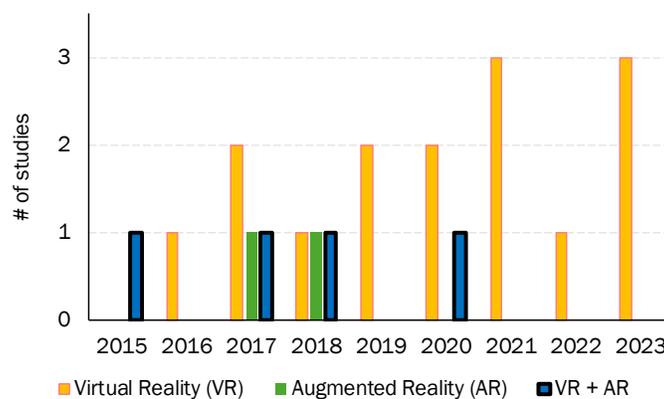

Figure 3. VR and AR applications in AEC education

Phase #2: Studies applied VAR in different AEC fields, as shown in Figure 4. VAR was most frequently applied to 'safety', followed by 'MEP' and 'appliance and equipment'. VAR was integrated into various BS&T education fields such as MEP (Aljagoub and Na 2023; Prichetnikov et al. 2020; Shin et al. 2022), building energy (Anifowose et al. 2023), appliance and equipment (Kamińska et al. 2017; Rossado Espinoza and Cárdenas-Salas 2021; Try et al.

2021), and renewable energy (Abichandani et al. 2019; Chiou et al. 2020). Given the broad scope of BS&T education, our synthesis indicates that a considerable portion of VAR-enhanced AEC education has been dedicated to BS&T-related topics, highlighting its significance in fostering in an immersive and effective learning environment.
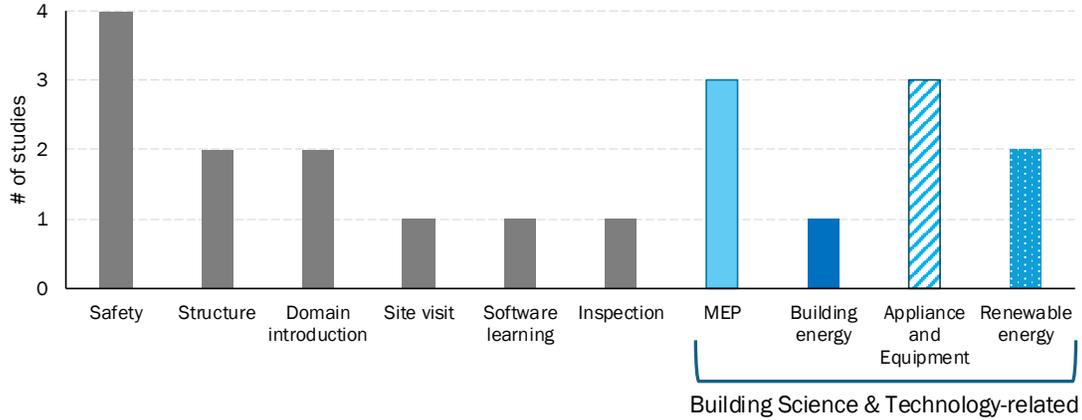

Figure 4. AEC education fields that VAR was applied. Building science and technology-related fields are highlighted with colors.

Phase #3: Educational objectives varied widely, reflecting the diversity of VAR applications in AEC education. VAR was used to facilitate student learning of AEC fundamentals and fields (Abichandani et al. 2019; Dinis et al. 2017), provide virtual construction field exploration (Pham et al. 2018), and enable hands-on experiential learning (Shin et al. 2022). For BS&T education, we identified vocational training (Shin et al. 2022), MEP plan reading (Aljagoub and Na 2023), and instruction-based learning (Anifowose et al. 2023).

However, some studies lacked clearly defined education objectives for their use of VAR, making it difficult to discern their pedagogical intent. For instance, Kamińska et al. (2017) and Dinis et al. (2017) examined student engagement with VR environments as learning tools, but did not explicitly outline specific educational goals, focusing instead on tool usability rather than learning outcomes.

In most cases, VAR-enhanced AEC education targeted undergraduate students (Figure 5), with a similar trend observed in BS&T education applications. A few papers focused on pre-university students, aiming to introduce them to engineering disciplines (Dinis et al. 2017; Dinis et al. 2017). The total number of papers included in Figure 5 reduced because some papers did not include the targeted student body in their study, e.g., Kamińska et al. (2017).
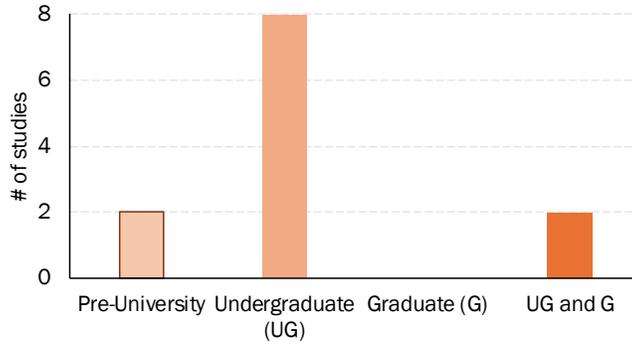
Figure 5. Targeted student bodies in VAR-enhanced AEC education.

Phase #4: All 16 studies that included student evaluation employed survey-based methods – typically utilizing Likert scales – to gather student feedback, analyzing the data quantitatively through descriptive and inferential statistics such as t-tests (Abichandani et al. 2019; Aljagoub and Na 2023; Arif 2021; Chiou et al. 2020; Dinis et al. 2017; Dinis et al. 2017; Eiris et al. 2020; Kamińska et al. 2017; Le et al. 2015; Luo and Mojica Cabico 2018; Pham et al. 2018; Rossado Espinoza and Cárdenas-Salas 2021; Shin et al. 2022; Try et al. 2021; Turkan et al. 2017; Wolfartsberger 2019). Only four studies utilized qualitative evaluations, utilizing interviews, audio recordings, or written responses in questionnaires, during the evaluation process (Abichandani et al. 2019; Chiou et al. 2020; Pham et al. 2018; Wolfartsberger 2019). Abichandani et al. (2019) and Chiou et al. (2020) presented student feedback without additional analysis. Pham et al. (2018) noted that interviews were conducted to evaluate VR usability. Wolfartsberger (2019) examined communication and collaboration among four-member groups with diverse professional backgrounds, using audio recordings to analyze their interactions and ability to identify equipment flaws.

Phase #5: Our synthesis revealed that studies assessed two main aspects of VAR in student performance evaluation: (1) VAR usability and (2) learning performance. The usability criteria used in studies (Eiris et al. 2020; Pham et al. 2018; Wolfartsberger 2019) are organized in the list below.

- Comfort (dizziness),
- Ease of navigation,
- Real-world visibility (sense of presence),
- Interactiveness,
- Motivation and engagement.

The purpose of these usability criteria was to determine whether VAR environments were deemed acceptable and user-friendly by students (or users). Some studies such as Arif (2021) primarily concentrated on usability evaluation rather than assessing learning performance. Overall, most studies reported an improvement in learning performance among targeted students using VAR. Several studies compared VAR-enhanced learning with traditional methods, such as

instructor-aided learning and/or video-aided learning (Pham et al. 2018; Try et al. 2021). Results consistently showed that VAR-enhanced learning generally outperformed traditional methods, as evidenced by both descriptive and inferential statistical analyses.

CONCLUSION

This review examined the current state of VAR applications in the BS&T education, particularly in comparison with other AEC fields. First, we synthesized existing review papers to highlight the novelty of this study. We then proposed a systematic review framework consisting of five hierarchical phases for analyzing VAR applications in AEC education. Using this framework, we analyzed 20 technical papers and found that BS&T has gained a moderate level of interests within this domain. Building science and technology spans multiple disciplines, including renewable energy, mechanical/electrical engineering, and appliances; hence, we identified studies that could be categorized as BS&T education. However, very few studies specifically examined individual building systems, components, appliances, and renewable energy systems within a holistic framework aimed at achieving a net-zero or energy-positive society

It is important to note that this paper presents only a portion of the research trends in applying VAR in AEC education due to space limitations. The authors intend to provide a more comprehensive review in a subsequent journal publication, covering all VAR applications in AEC education and BS&T education.

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