Jurnal Kejuruteraan 37(7) 2025: 3363-3376
https://doi.org/10.17576/jkukm-2025-37(7)-19

# Green Technologies Pedagogy Using Virtual Learning Spaces for Architecture Students: A Scoping Review

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*Received 19 November 2024, Received in revised form 1 February 2025*
*Accepted 2 March 2025, Available online 30 October 2025*

ABSTRACT

*This paper examines the impact of Virtual Learning Spaces (VLS) on green building education and to augment architectural pedagogy as well as sustainability awareness among undergraduate learners. Through a scoping review methodology, the literature database was searched for relevant concepts, which were retrieved and analyzed from the year 2014 onwards to identify common VLS strategies. In this paper, the three aspects of the major methods of implementation of VLS are investigated along with the position of VLS to clarify student comprehension of green building principles and its influence on student outcomes. The findings suggest that leveraging digital tools, including virtual reality (VR), gamified simulations, and interactive learning platforms, significantly enhances student engagement, conceptual understanding, and application of sustainability principles. Moreover, this study highlights the relevance of using VLS in the curriculum design process since it creates a connection between what is learnt and what is done. While VLS possesses significant benefits for green building pedagogy, effectiveness is contingent on well-structured implementation in conjunction with contemporary architectural theory and educational practices. Further research should focus on strategies for long-term adoption, usability enhancements, and integration with AI-supported learning platforms to provide a more optimal solution to sustainability education. These research backgrounds contributed to the debate on digital education and augmented focus on sustainability- aligned global goals and built environmental scenarios for architecture students prepping them for the real world environmental problems.*

*Keywords: Virtual learning spaces; green building pedagogy; architecture students; scoping review*

## INTRODUCTION

One aspect of sustainable architecture is green buildings, which is environmentally responsible and resource-efficient throughout the life cycle of a building: from planning to design, placement, construction, operation, maintenance, and even demolition. With an increasing need for sustainable solutions, architectural education must adapt to prepare future professionals with the right expertise to implement green technologies into their designs. With this, the Virtual Learning Spaces (VLS) have evolved as a game changer in the educational ecosystem delivering immersive and hands-on experiences connecting theoretical teachings to real world challenges.

Based on relevant case studies and literature, this paper examines ways in which VLS supports green building education, effective strategies that can be adopted for integrating digital tools in architectural curricula, and their effects on students learning outcomes. The implications of these findings extend to the broader discussions surrounding sustainability education, emphasizing the role of technology-enhanced pedagogy in preparing tomorrow's architects to meet both environmental and design challenges with innovative solutions. The goal is consistent with the UN SDGs focused on sustainable urban development and climate mitigation. Insights from the Chittagong Hill Tracts (Rashid & Ara 2015), Balinese vernacular homes (Kadek, Wijaya, & Warnata 2022), climate-adaptive designs in Nepal (Bodach, Lang, & Hamhaber 2014), and innovative reconstruction in Sichuan (Ye & Bai 2014) are examples of how traditional knowledge can inform contemporary sustainable building practices. This method not only complies with contemporary sustainability criteria but also preserves the cultural and environmental significance of architectural designs.

## IMPORTANCE OF GREEN BUILDING PEDAGOGY

Dealing with the importance of green building (GB) pedagogy represents a critical yet insufficiently addressed challenge in architectural education. As key factors in both reducing the impact on the environment and improving human health, GB practices play an important role, yet their principles are still not present in the training of future architects. This educational deficiency is in stark contrast to the advantages for our environment and the health benefits of GB (Zhe et al. 2011), Zhang & Tu (2021), and Balaban & Puppim de Oliveira (2017). Notably, while these studies focus on the broader benefits of GB, they illuminate the GB pedagogy gap, underscoring the need for a GB curriculum that not only advocates for sustainable architectural practices, but that also equips students with these necessary skills. More importantly, when effective, architectural education with suitable GB content will pave the way for architects who are well-versed in incorporating sustainability and innovation into the mix of their designs. An important component of GB's pedagogy is opening architects' eyes to knowledge and tools that support ecological balance and well-being through architecture. Design and construction has so much to consider, and this highlights the importance of a GB curriculum.

## THE POTENTIAL OF VIRTUAL ENVIRONMENT LEARNING IN GREEN BUILDING TEACHING

In green technology, virtual learning environments is a multifaceted concept encompassing a range of strategies, from integrating lifelong learning skills to applying new technologies and methods to achieve a sustainable future (McWhorter & Delello, 2016; Husanu & Mauk, 2016). Virtual learning environments play a role in project-based learning methods, where students explore the various stages of the building life cycle. Research by Frey and Ng (2023) shows that this learning experience improves the quality of teaching and students' understanding of green building principles.

During the COVID-19 pandemic, optimizing virtual teaching environments helps maintain social distance and optimizes cleaning and disinfection resources (Cascante et al. 2021; McCormick & Kiss 2015), as well as collaboration and knowledge sharing among education stakeholders (Donath et al. 2020). Diverse curriculum design is crucial, aiming to engage students from different backgrounds and motivate them to take action in support of sustainable development (Holden et al. 2008).

Integrating green technology strategies into architectural education has emerged as a transformative approach to enhancing learning outcomes (Mi 2024; Manrique 2019; El-Feki & Kenawy 2018). Studies by Huang and Chao (2015) have shown the effectiveness of games like GBGame in boosting student motivation, learning efficiency, and satisfaction, surpassing traditional lecture-based pedagogies. These interactive platforms provide an immersive learning experience, facilitating non-formal education that complements formal environmental education and engaging students in sustainable lifestyle practices through practical building interventions. This approach is further supported by Cole (2014) and Cole & Altenburger (2019), who emphasize the importance of incorporating strategy games in promoting active participation in sustainability practices among students.

This indicates that one of the basics of green building teaching is changing the methodologies in educational faculties, institutes, and organizations. It requires an adjustment to the learning premises of green buildings. The dynamic, hands-on approach reflects real world green building practices, whereas traditional methods are passive and at times antiquated, making use of strategy games and other interactive learning tools to provide a long-term learning experience that ensures students learn through immersion. Such educational rerouting is not only a reflection on how architecture education is changing, but ways of preparing students to face the demands of a future in sustainable design and construction.

Furthermore, developing new learning methods to help societies adapt in the face of global changes is another crucial aspect of sustainable learning (Dlouhá et al. 2013). The application of green BIM teaching methods effectively increases classroom interaction and personalizes the learning experience (Kim 2014), while the comprehensive approach of project-based learning and critical thinking effectively cultivates students' abilities (Luo & Wu 2015). The comprehensive use of these teaching methods enhances the richness and interactivity of the learning experience and promotes an in-depth understanding and practice of sustainable development. According to Cole (2014) pointed out that applying architectural education to green schools can engage students in sustainable lifestyles, promote informal education, and support formal environmental education through architectural interventions.

In addition, applying green technologies such as cloud computing, 3D printing, big data, digital badges, the Internet of Things, and real-time group meetings shortens time and costs. It improves energy efficiency in virtual learning environments. These technologies play an essential role in supporting green initiatives. Today, with the rapid development of educational technology, virtual reality (VR) and project-based teaching models have proven to be highly effective in providing green building education. However, these methods require more comprehensive implementation and updated VR platforms for their more comprehensive application (Hou et al. 2023). The green space-based learning model improves teachers' teaching practices and green infrastructure awareness and transforms underutilized green spaces into multi-functional educational environments (Locicero & Trotz 2018).

Students serve as partners in higher education assessment, enabling more profound learning experiences through self- or peer assessment, co-creation of assessment activities, and collaborative opportunities for shared assessment processes (Bheoláin et al. 2020). Although immersive virtual reality in STEM education is expected to improve learning outcomes and user experience, more research is still needed to measure student learning performance (Pellas et al. 2020). In virtual learning environments, teachers' synchronous face-to-face presence can promote students' mental health by enhancing communication between students and teachers (Caprara & Caprara, 2022).

This article aims to explore and design a green building virtual teaching space suitable for college students through the Scoping Review method and provide answers to the following research questions:

1. What VLS methods are commonly applied in green building education?
2. How do VLS contribute to students' comprehension of green building concepts?
3. What are the pedagogical and experiential outcomes of VLS integration in architectural education?

The first exploratory research question focuses on the interactivity and accessibility of virtual teaching spaces, discussing how VLS methods mediate the effective communicating and teaching of green building knowledge. The second question usage of virtual environments and environmental technology is revealed to enhance students' understanding of the green building context, alongside the discussion of practical interactions between technology and the learning integrated into architectural education. The third question explores how virtual teaching space design aligns with educational objectives, and aims to assess the specific pedagogical and experiential effects of VLS on student learning outcomes.

## METHODOLOGY

This study uses a scoping review approach to systematically map key concepts within green building education, with a particular focus on their integration into virtual learning environments. The methodology chosen fits well with the objectives of this research by facilitating a comprehensive exploration of the existing literature body. This exploration aims to identify the main trends, challenges and opportunities in the field of green building pedagogy, with particular emphasis on the use of virtual spaces for educational purposes. Following the guidelines of the Joanna Briggs Institute (JBI) Reviewer's Manual, along with the methodologies outlined by Levac et al. and Arksey and O'Malley, this scoping review adheres to the PRISMA-ScR checklist. This adherence is critical to enhancing the thoroughness of the review and reducing the potential for reporting bias, a key concern highlighted in Table 1.

The methodology for this scoping review has been adapted from the framework suggested by Colquhoun et al. (2014), as illustrated in Table 1. The search strategy for examining the application of green building principles in virtual learning spaces encompasses a multifaceted approach, examining several essential aspects:

1. Interaction and accessibility of virtual learning environments.
2. The feasibility of incorporating technology into educational settings.

3. The alignment between the design of teaching spaces and the learning objectives of green building education.

The scoping review method in this paper is modified from the framework proposed by Colquhoun et al. (2014) as shown in Table 1.

TABLE 1. Scoping Review Method Procedure

| Standard | Content |
|---|---|
| Inclusion & exclusion criteria | Inclusion criteria: Original research articles involving the application of virtual learning technologies and strategies in green building education.<br><br>Exclusion criteria: non-English literature other than Chinese, review articles, non-academic reports, and literature not directly related to virtual environment or green building education. |
| General search Strings | “Green Building Education” AND “Virtual Learning Spaces””Architecture Students” AND “Sustainable Design Education””Digital Architectural Teaching” OR “Online Architecture Courses””Virtual Environments” AND “Educational Methods in Green Building” |
| Final search string | (“Green Building” OR “Sustainable Architecture” OR “Eco Construction”) AND(“Education” OR “Learning”) AND(“Virtual” OR “Online”) NOT “Machine Learning” |
| Screening | Date range: Literature from the past ten years to ensure currency and relevance. Language: English and Chinese literature.Document types: Peer-reviewed journal articles, conference papers, academic papers, and textbooks.Topic relevance: Only literature directly related to green building education, virtual teaching spaces, architecture students, and sustainable design education were included. |

The literature selection criteria were explicitly designed to capture publications that provide insights into various pedagogical approaches relevant to this field, including but not limited to mathematical modeling, agent-based simulation, digital twins, or geographic information systems (GIS). In addition, this study critically assesses the strengths and limitations of the identified methodologies, as reported in the original studies, to illuminate potential avenues for the advancement of these pedagogical techniques. Regarding literature that meets the defined criteria, information on teaching methods, technology applications, and learning outcomes will be carefully extracted from each article. A thematic analysis will then be carried out on this collated data to identify effective education strategies and to identify areas ripe for pedagogical enhancement in green building education. The preliminary search was conducted across multiple databases, including Google Scholar, ScienceDirect, Scopus, IEEE Xplore, and Emerald, using an array of initial search terms. Through an iterative process involving the use of sources such as the Oxford English Dictionary, search terms have been refined and expanded. The final search strings crafted for this review included terms such as “green building education,” “virtual learning spaces,” “architecture students,” “sustainable design education,” “digital architecture teaching,” and “online architecture courses,” among various combinations. To ensure the contemporaneity and relevance of the findings, the search was limited to literature published in the last decade, explicitly excluding studies on machine learning applications in this field.

## RESULTS

2018 records were identified spanning from 2012 to 2023 using the PRISMA-Scr checklist. 623 record duplications were excluded. Despite using the same search string (and customized search syntax), there are significant differences in the records retrieved by the search system. Furthermore, IEEE Xplore was chosen to obtain results for specific research areas, retrieving significantly fewer records than other search systems. Moreover, the search found only 2 Chinese publications.

Table 2 describes the literature search and selection process, which involved identifying 2018 potentially relevant records by applying the developed search string. Of the total records, 623 (30.9%) were duplicated or had no abstract and were therefore deleted. After title and abstract screening and publication screening, 34 of the remaining 1395 records (2.5%) were identified as potentially relevant for data synthesis. However, after screening the research direction of the article, 18 of these 34 records (52.9%) had to be excluded from further investigation. And because there are 7, the content of the paper is not part of the research and one Unavailability of full-text literature. Finally, of the original 2018 records, only 8 (0.4%) were included in the data synthesis.

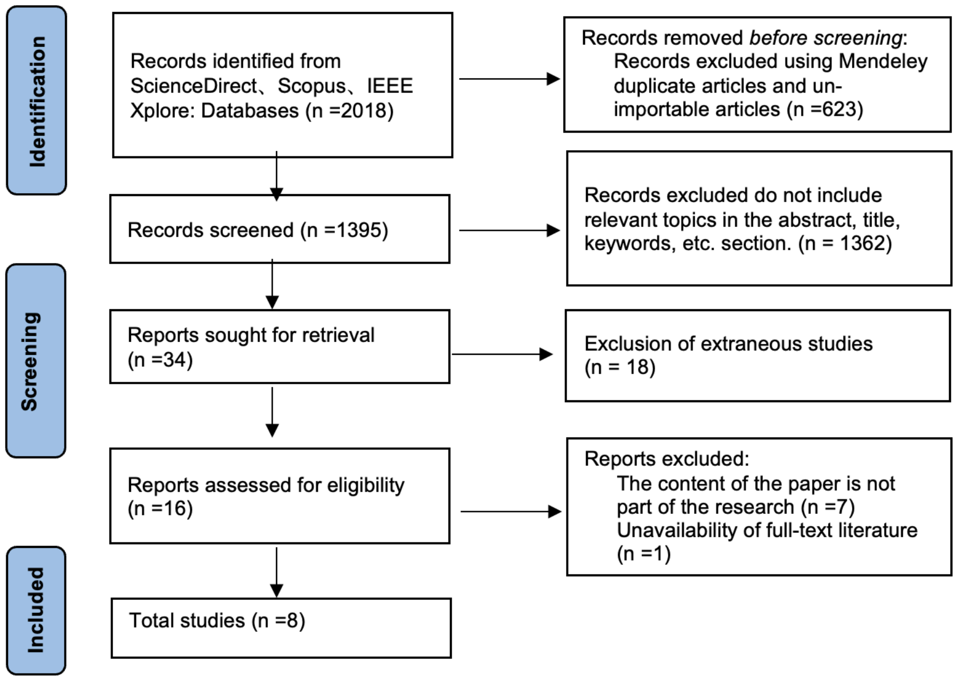


FIGURE 1. Scoping review literature search

Based on the steps of the Scoping Review, eight final selected literature were reviewed. This literature was reviewed to explore how virtual spaces can be effectively utilized to teach green building concepts and skills in professional building education, the role of virtual teaching spaces in improving students' understanding of green building theory and practice, and how virtual learning environments can impact on students' learning experiences and outcomes. The table below analyses each article along these three dimensions to reveal trends and gaps in current studies on the use of virtual spaces in green building teaching.

The scope of these studies includes exploring practical ways to use virtual spaces to teach green building concepts in architectural education, examining the role of virtual learning environments in enhancing students' understanding of green building theory and practice, and finally, evaluating the impact of virtual learning environments on students' educational experiences and outcomes. The review continues with the implementations derived from the three dimensions of trends and gap from Table 3.

TABLE 3. coping literature results

| | | | Dimensions | | |
|---|---|---|---|---|---|
| | | | #1 | #2 | #3 |
| Reference | Title | Key Points | VLS Methods in Green Building Teaching | Role of VLS Methods in Understanding Green Building Concepts | mpact of VLS Methods on Learning Experience & Outcomes |
| Hou et al. (2023) | Project-based learning and pedagogies for virtual reality-aided green building education | VR-assisted project learning model for teaching green building. | VR-assisted site visits and practical projects as teaching methods. | N/A | Model effectively enhances student understanding of green building knowledge. |

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| | | | | | |
|---|---|---|---|---|---|
| Avsec et al. (2022) | Enhancing Transformative Learning and Innovation Skills Using Remote Learning | Emphasizes the importance of remote learning in transformative learning and innovation skills for sustainable architectural design education. | N/A | Transformative learning theory applied in VLS for sustainable architecture education. | N/A |
| Brzezicki and Jasiołek (2021) | A survey-based study of students' expectations vs. experience | Analyzes the gap between students' expectations and experiences in sustainable architectural education. | N/A | N/A | Reveals significant differences between students' expectations and experiences in sustainable design knowledge. |
| Andrasik, P. (2021) | LEED Lab: A Model for Sustainable Design Education | Introduction of the LEED Lab model for green building performance assessment. | N/A | N/A | Potential for practical learning involving virtual elements. |
| Orozco-Messana et al. (2021) | Mind-Mapping for Interdisciplinary Sustainable Architecture | Application of mind maps in sustainable architectural education. | N/A | N/A | Potential improvement in student learning experience. |
| Cole et al. (2019) | Promoting green building literacy through online laboratory experiences | Online lab courses to enhance green building knowledge and skills. | N/A | N/A | Significant improvement in green building knowledge and skills. |
| Kelting et al. (2016) | Peer and student review of an online construction management sustainability course | Evaluation of an online construction management sustainability course through student and peer reviews. | N/A | N/A | Potential positive impact on student learning experience. |
| Liu et al. (2019) | Do Real Life Visuals Help Students to Learn Engineering | Investigates the effectiveness of incorporating real-life visuals in engineering education. | Application of visual tools in virtual spaces for complex concept teaching. | N/A | N/A |

## TEACHING SPACE DESIGN IMPLICATION

Based on the implications of the reviewed studies, providing students with an immersive, interactive and innovative learning environment via virtual reality technology is summarized as follows:

1. The user interface is the primary interaction point between the students and the virtual teaching space, which covers intuitive menus, buttons, icons and prompts. These interface elements allow students to intuitively choose and manipulate instructional content while also offering both the accessibility and feedback needed to help students locate and engage in virtual spaces with success.
2. Interaction method: It includes various sensing technologies like voice recognition, gesture control, eye tracking and touch screen technology. These methods enable students to naturally and intuitively interact with virtual environments,

including through verbal commands, body movements or touch operations, providing a flexible interactive experience.

3. The layout of the virtual environment: Some examples of the structure are virtual classrooms, design studios and construction sites in the virtual teaching space. These structures also offer several different learning and practice environments, from theory to practice, offering a well-rounded learning experience for students.
4. Structural composition: The structure of the virtual teaching space may include virtual classrooms, interactive design studios, and simulated construction sites. These structures provide different learning and practice environments, from theoretical learning to practical application, providing students with a comprehensive learning experience.
5. Technical elements feature highly realistic 3D building models, dynamic animation and informative graphics: These elements visually express what a green building would look like, its possible form and shapes, and the principles of design applied in practice, along with crucial data and parameter as a graphic representation.
6. Interactive element: It has simulation tools and virtual reality technology. The use of simulation tools within the green building vertical allows students to create, assess, and optimize buildings in a simulation environment. The advent of virtual reality technology enhanced the students' learning experience because it allows them to feel the space, atmosphere and influence of architecture through simulated learning.

Tech platform and tools: This is VR headsets and game engines. VR headsets allow students to perceive the virtual environment visually and auditorily to feel like they are inside the environment. Gaming engines are software frameworks that design and operate with these synthetic universes, empowering the Implementation of sophisticated user interfaces and interaction methods.

## COMPOSITION OF TEACHING COMPARTMENTS IMPLICATION

Findings from the reviewed studies highlight the various teaching components in the virtual teaching space, including their design and functionality. The following implications are designed to create a highly interactive and practical virtual learning environment.

VIRTUAL LEARNING ENVIRONMENT

1. Theoretical learning: Is the basis of the teaching process. It uses the form of interactive lectures and combines the virtual teacher's voice, text, graphics, and other multimedia means to explain the basic knowledge of green buildings to students. The design focuses on providing background knowledge to lay the foundation for subsequent case analysis and practical operations. Theoretical learning sections may introduce basic concepts of green building through interactive videos and diagrams.
2. Case analysis: It stimulates students' innovative thinking and design abilities by displaying and analyzing classic green building cases at home and abroad. The design is a virtual field trip, using 3D architectural models and animations to allow students to observe and experience green buildings in a virtual environment. Case study sections may include virtual tours of historically successful and failed green building projects.
3. Practical operation: Is the core of the teaching process, which allows students to design, evaluate and optimize green buildings in a virtual environment. The design is a teamwork project, combining simulation tools and virtual reality technology to cultivate students' comprehensive abilities and team spirit. The hands-on component uses virtual-reality tools to allow students to design and evaluate their green building projects.

## VIRTUAL LEARNING SPACE IMPLEMENTATION METHOD

Implementation of theoretical learning:

1. Virtual classroom: simulates a natural classroom environment, provides virtual teachers and teaching facilities, and enables interactive listening and questioning.
2. Virtual library: Provides relevant literature, materials, videos and other resources to support independent learning and information inquiry.

## IMPLEMENTATION OF CASE ANALYSIS:

1. Virtual Exhibition Hall: Displays 3D models and animations of green buildings in different styles to support students' observation and analysis.

2. Virtual tour: Provide a virtual tour guide and audio commentary to help students understand the critical points of green building design.

## IMPLEMENTATION OF PRACTICAL OPERATIONS:

1. Virtual Studio: Provides simulation tools and technologies to support students in designing and creating green buildings.
2. Virtual Exhibition Hall: Provides a variety of display and interaction methods for students to display design results and exchange ideas.

This comprehensive teaching model combines theoretical learning, case analysis and practical operation and provides an innovative and effective teaching environment for green building education through the interactivity and practicality of virtual space.

## THE EFFECTIVENESS OF THE VIRTUAL SPACES AS A TEACHING METHOD

1. Enhanced student engagement: Virtual teaching spaces can increase student engagement and interest by providing interactivity and visual appeal. For example, using VR technology to simulate architectural design can make students more immersive and, thus, more actively involved in the learning process.
2. Promote understanding and memory: Virtual space provides a dynamic and multi-dimensional learning method that helps students better understand complex concepts. For example, demonstrating sustainable technologies for green buildings through virtual models can help students better remember and understand these concepts.
3. Enhance collaboration and teamwork: The virtual space design supports teamwork projects and encourages students to solve problems together in the virtual environment. This not only enhances interaction among students but also promotes the development of teamwork and collaboration skills.

Explore possible challenges and impacts on student learning:

1. Technical barriers: Implementing virtual teaching spaces may encounter technical barriers, such as software compatibility issues, hardware requirements and network connection issues. These technical issues may limit the effectiveness and accessibility of the virtual space.
2. Student Adaptability: Students may need time to adapt to the virtual learning environment, especially those less familiar with new technologies. Therefore, teachers must provide adequate support and guidance to help students overcome initial challenges.
3. Long-term impact: The virtual space long-term impact on students' cognitive and skill development still needs further research. While it can improve engagement and learning in the short term, its long-term impact on students' critical thinking, creativity and real-world problem-solving skills is unclear.

## DISCUSSION

VLS have shown a remarkable way to engage students as well as reproduce sustainability-focused learning in architectural education-focused learning. The results are consistent with earlier research that shows how powerful immersive learning can be in sustainability education.

### EFFECT OF VLS ON STUDENTS

Real-world visual amenities incorporated in VLS provided better understanding and engagement among students. Liu et al. (2019)Based on math lessons, it found that integrating authentic visuals into engineering curriculum enhanced students' understanding and confidence. The evidence corroborates our assertions that integrating 3D physical models and interactive graphics into VLS towards green building topics engages the students much better.

Besides documenting problems together with students through peer and student feedback is a very important part of polishing online sustainability courses. Kelting et al. (2016), which highlighted that formalized peer assessment mechanisms promote VLS effectiveness, in accordance with our finding that collaboration-based platforms engender student interaction and better learning outcomes.

### COGNITIVE ADVANTAGES OF VIRTUAL LEARNING SPACES IN SUSTAINABILITY EDUCATION

The value of cognitive structuring tools (e.g., mind-mapping) has long been acknowledged in sustainability education. Orozco-Messana et al. (2021) is based on mind-mapping strategies within VLS that proved to contribute to interdisciplinary knowledge construction. This fits with our observations that through embedding sustainability-related content in VLS, students become more equipped to analyze complex green building systems.

Additionally, experiential learning models like LEED Lab (Andrasik, 2021), emphasize the need for theory to bridge with practice. That is an important reason for why VLS must incorporate real-world sustainability projects to reinforce students' understanding.

### THE IMPORTANCE OF VR-BASED VLS IN GREEN BUILDING EDUCATION

Increasingly, Virtual Reality (VR) and green building education has been identified as a viable method. Hou et al. (2023), highlighted the role of VR-assisted site visits in improving student understanding of sustainability principles, particularly for environmental measures. This is consistent with our findings that VR-based simulations in VLS can provide experiential knowledge of green building systems and compensates for the lack of physical site visits.

Thoughts and discussions on missing links between students' expectations vs actual experience in sustainability education run high, but do they translate into concrete moves to go further? Brzezicki & Jasiolek (2021). Students hope for a more thorough integration of sustainability topics into their courses, the survey has found. We also note a disconnect of VLS content with sustainability needs in the real world.

### CHALLENGES AND FUTURE RESEARCH DIRECTIONS

VLS has clear benefits but also has challenges in terms of accessibility and engagement and applying the learned material in some real world scenario. There are studies suggesting that blended learning approaches might perform better than fully virtual environments. Further studies should evaluate how hybrid models that combine the VLS tools with in-person experiences fare compared to their peers..

## STRENGTHS AND LIMITATION

This research conducts a specific investigation into the effect of VLS on undergraduate architecture students – restricting the potential application of the findings to other educational tiers. Although the results offer important information regarding the utilization of VLS in the undergraduate academic stage, their use during different academic stages (including graduate programs or vocational training) has not been evaluated yet. This aligns with Cole et al. level of student experience and expertise, suggesting the need for customized learning environments and personalized learning in the context of green building education.

This analytical framework, closely aligned to the objectives of this study, is also driven by the volume of trends and gaps identified in the research. However, notwithstanding a comprehensive search strategy, some recent studies may have been accidentally omitted. Future work should extend the dataset to include novel VLS technologies which are emerging, such as simulation-based training and virtual laboratories, as noted by Hou et al. (2023).

As well, this review does not include other educational routes like hybrid teaching and face-to-face seminars to specifically look in on virtual environments. Although this ensures focused analysis, a comparison of VLS with hybrid or experiential learning strategies could be the subject of future studies in order to realize their respective advantages and limitations in the field of green building education. As described by Perbandt et al. (2021) claim that although the online sustainability-related courses are helpful for motivating learners, more studies should involve comparisons between these and site-based courses.

Also, the research emphasizes the need for incorporating global viewpoints and geographic diverse material to develop a more holistic and globally significant framework for VLS in the architectural curriculum. Such large-scale data also allows for the exploration of regional differences, as demonstrated by the work of Ye & Bai (2014) investigating post-earthquake building reconstruction in Sichuan with a view to sustainable building strategies, leading us to conclude that VLS models must work more flexibly in varying regional environments and regulations. This framework could be further enhanced by including VLS strategies in institutional frameworks of other countries to encourage education for sustainability and the green building agenda in architectural education worldwide.

## CONCLUSION AND RECOMMENDATIONS

This study provides an in-depth exploration of the application of virtual learning spaces in green building education, revealing a series of critical findings that contribute to educational practice and theoretical research in this field. Firstly, research shows that virtual learning spaces can provide an immersive, interactive learning environment that helps students gain a deeper understanding and mastery of the theory and practice of green buildings. The virtual teaching space successfully simulates an actual architectural design and evaluation environment by combining the user interface, interaction methods, layout of the virtual environment, and visual, interactive, and technical elements.

This study highlights the critical role of Virtual Learning Spaces in advancing green building education, demonstrating their effectiveness in fostering engagement, enhancing conceptual understanding, and fix the gap between theoretical knowledge and practical application. The research findings underscore the importance of continuously improving VLS methods to ensure their widespread use and adaptability across different architectural education environments. While virtual tools offer significant pedagogical benefits, future research should explore their long-term impact on student competencies, particularly in the integration of sustainability and emerging digital technologies. Combining elements of virtual and experiential learning creates a balanced approach to ensuring that tomorrow's architects are well-equipped to face the challenges of a sustainable design.

## ACKNOWLEDGEMENT

This research did not receive any funding.

## DECLARATION OF COMPETING INTEREST

None.

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