

INCULCATING SUSTAINABILITY MINDSETS IN STUDENTS FROM ARCHITECTURE EDUCATION THROUGH CDIO FRAMEWORK

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ABSTRACT

Integrating sustainability mindsets with the CDIO framework is crucial for advancing sustainable development of products, processes, systems, and services. Emphasising sustainability values and knowledge enhances responsible decision-making. A sustainability mindset fosters responsibility and ethical awareness for future professionals in architecture education. This study empirically investigated the integration of UNSDG 13 (Climate Action) through CDIO standards 3 and 7 in architecture education to develop sustainability mindsets among students with transformative learning activities for first-year architecture students at Singapore Polytechnic. The pilot study explored case studies of vernacular architecture and utilised transformative pedagogies such as debates and role-playing to engage students with ethical dilemmas. A thematic analysis of students' reflections revealed emerging themes of enhanced understanding of ethical conflicts, appreciation for sustainability complexities, and preparation for ethical advocacy in (their future) professional settings. The findings underscore the effectiveness of transformative pedagogical approaches in developing key competencies related to sustainability, including value thinking, systems thinking, and integrated problem solving, thereby equipping future architects to navigate complex challenges and contribute meaningfully to sustainable development. This study contributes to the limited research on implementing CDIO in non-engineering fields (such as architecture), evidencing its potential to cultivate sustainability mindsets as an intrinsic component of architectural design.

KEYWORDS

Key Competence for Sustainability, CDIO Syllabus, Architecture Education, Transformative Learning, Standards: 1, 2, 3, 4, 7.

INTRODUCTION

The Conceive, Design, Implement, and Operate (CDIO) outcome-based curriculum design/redesign framework, which focuses on project-based learning and real-world applications, is widely utilised predominately in engineering education to enhance curriculum design, teaching methods, and assessment strategies. Given that sustainable products, processes, systems, and service lifecycle development and deployment are integral tenants of CDIO, it is advocated that the development of key competencies for sustainability can also be inculcated with CDIO (Cheah et al., 2025).

Sustainability mindset, as values, knowledge, and attributes that enable individuals to approach challenges and decision-making processes focusing on sustainability principles (Rimanoczy, 2020), is increasingly essential for promoting environmentally conscious decision-making. By inculcating these sustainability mindsets, alternative paradigms can be nurtured, fostering a sustainability mindset among students (Rieh et al., 2017) towards innovative and sustainable design solutions. Fostering a sustainability mindset in architecture education is crucial for instilling a sense of responsibility and ethical awareness among future practitioners (Núñez-Andrés et al., 2022). To date, there is a lack of empirical studies on the impact of integrating CDIO standards with a focus on UNSDG (United Nations Sustainable Development Group). This paper will hence focus on UNSDG No.13 (Climate Action) with the CDIO framework to foster sustainability mindsets among architecture students.

Architecture education includes more than just teaching design; it encompasses a wide range of topics, including structure, environmental science, sociology, and the arts, and requires an extensive understanding of how various fields, such as sustainability design strategies and principles (El-Feki & Kenawy, 2018; Farinea & Demeur, 2023), intersection and interdependence (Ummihusna & Zairul, 2021). This study aimed to empirically explore the integration of UNSDG No.13 through CDIO framework in Singapore Polytechnic's (SP) Diploma in Architecture's (DARCH) Architecture Foundation course to develop sustainability mindsets for first-year students through transformative learning activities. The two research questions guiding this study were: **RQ1**: How do first-year architecture students perceive ethical dilemmas related to sustainability development? And **RQ2**: How do first-year architecture students perceive their preparedness for ethical advocacy in professional settings after participating in a tutorial discoursing sustainability development? Students' qualitative reflections facilitate the exploration of recurring themes to gauge whether this pilot has provided a stable foundation for the future development of their sustainability mindset. Additionally, this study adds to the growing body of research that empirically explores the impact of infusing CDIO into a non-engineering course with the critical intention of developing learners' sustainability mindset.

UNSDG NO.13 (CLIMATE ACTION) IN ARCHITECTURE EDUCATION

Despite the increasing importance and relevance of UNSDG No.13 (Climate Action) in architecture education (Akgün et al., 2023), attempts to articulate the integration of SDGs into architecture curriculum and pedagogical practice remain scarce and underexplored (Burton & Salama, 2023). Furthermore, El-Kholei et al. (2024) emphasise the need to embed sustainability development goals (SDGs) into architecture education, ensuring that students are evaluated on their ability to incorporate sustainability into their designs. One of the key tenets of UNSDG No.13 urges collectives and individuals to take action to combat the ongoing climate crisis and its impact, including a strong focus on reducing greenhouse gas emissions from human activities. Buildings contribute up to 19% of greenhouse gas emissions (Mohkam

et al., 2022) and 30 - 45% of global energy use (Zamorano, 2022). Specifically, energy consumed for heating and cooling in residential, commercial, and industrial buildings accounts for a significant portion (Moldovan & Chisăliță, 2021). Although the energy efficiency of heating and cooling systems can be improved through innovative technologies, architects could arguably consider passive strategies adopted by traditional low-energy vernacular buildings to reduce their energy impact.

However, architecture education's obsession with building aesthetics (Till, 2009) has reduced the rightful focus on designing low-energy designs through passive techniques. Academia's role in instilling appropriate value systems can support the development of intrinsic *sustainability mindsets* through its curriculum and pedagogical approaches. Fostering a sustainability mindset in architecture education is vital for instilling a sense of responsibility and ethical awareness among future architects (Núñez-Andrés et al., 2022). Different approaches can be developed by instilling sustainability attitudes and encouraging a sustainability mindset among students (Rieh et al., 2017) , which are essential for creating innovative and sustainable design solutions for the future.

THEORIES AND FRAMEWORKS TOWARDS SUSTAINABILITY MINDSETS

The CDIO methodology has been regarded as beneficial for engineering disciplines in sustainable development, as it integrates sustainability principles with CDIO standards and syllabi (Daneykin et al., 2016; Konst et al., 2022; Rosén et al., 2021). Sustainable products, processes, systems, service development, and deployment are critical tenants of CDIO, which, in turn, potentially catalyses the promotion of *sustainability mindsets* and attitudes. Kassel et al. (2016) elaborated that sustainability mindset stems from a deep awareness of the ecosystem, social sensitivity, and introspection, resulting in behaviours that benefit the greater good. A sustainability mindset is driven by values, knowledge, and attributes that enable individuals to approach challenges and decision-making processes with a focus on sustainability principles (Rimanoczy, 2020). In our world of accelerated change, it is imperative to develop a sustainability mindset as a critical attribute (Cheah, 2021). This pilot crystalised Cheah et al.'s (2025) 'generic' framework to develop students' key competencies for sustainability and extended the works of Ho and Leong (2023) and Luong and Le (2016) by examining frameworks for implementing CDIO in architecture courses. Given the interdependence of architecture between multiple stakeholders, disciplines, climatic, theoretical, and technical considerations, this study contextualised three relevant sustainability mindset principles, namely, 1) **Systems Perspective/Thinking** and 2) **Ecological Worldview** advocated by Rimanoczy (2021) and Rimanoczy and Llamazares (2021) with 3) **Collaborative and Innovative Action** as pedagogical approaches endorsed by Hermes and Rimanoczy (2018) and Kassel et al. (2016).

Infusing Systems Thinking/Perspective in Architecture Education

Systems Thinking/Perspectives is a holistic approach to reality, centred on the relationships and interconnections between the components that constitute systems by emphasising their patterns, flows, and processes (Rimanoczy, 2021; Rimanoczy & Llamazares, 2021). A systems viewpoint considers the requirements and interests of these interconnected subsystems during research, strategy development, and decision-making (Hawken et al., 2013; Senge, 2008). The architect works with others, as their roles and responsibilities are embedded in a more extensive relational system between the complexity of architectural design and other allied and non-allied disciplines. A systems perspective aids the empathetic and defined stages of the architectural design process, while optimisation aids in reducing

complex issues to inform the ideation design process (Miranda & Miah, 2021). The cross-pollination of systems thinking/perspectives in the design process potentially yields benefits in shaping social, economic, and natural environments (Avsec & Jagiełło-Kowalczyk, 2021). Moreover, systems thinking facilitates an understanding of the interconnectedness of buildings, infrastructure, natural environments, and communities, and the varying sources and detriments of poorly designed buildings negatively impact energy consumption.

Infusing Ecological Worldview: Ecoliteracy in Architecture Education

The ecological worldview facet of inculcating a sustainability mindset engages environmental concerns in protecting and restoring resources, mobilities, and agilities in adapting to changing conditions from a global perspective (Goleman, 2010; Nattrass & Altomare, 1999). Knowledge gleaned in academics provides a context in which learners can use it as a lens to examine our life experiences and choices in shaping our ecological worldview (Kassel et al., 2016). The foundational principle of ecoliteracy was elucidated and introduced by Orr (1991) as a branch of literacy that focuses on establishing sustainable human communities by reconstructing educational systems. Architecture courses can develop ecoliteracy by teaching the principles of ecology and sustainable design. For instance, learners would be exposed to how sustainability can be traced back to the traditional, low-energy approach of vernacular architecture. These indigenous design principles can inform modern sustainability design. Passive cooling strategies, rather than active systems (e.g. air conditioning), are fundamental principles that reduce the operational energy consumption in buildings. Notions exploring the relationships and connectedness between sustainability issues/events/strategies within macro and micro contexts can be expounded and critiqued upon. As such, students can have greater opportunities to reflect on buildings' roles in the broader ecosystem sustainability movement by considering energy flows, material cycles, and human interactions.

Infusing Collaborative and Innovative Action in Architecture Education

With Systems Perspective/Thinking and Ecoliteracy in place, a collaborative and experiential pedagogical approach is advocated by Kassel et al. (2016) to facilitate the development of learners' sustainability mindset. Instilling mindsets and value systems as soft skills will be challenging to impart explicitly (Liow, 2021), and alternative models must be explored. Traditional/passive models of knowledge transfers whereby learners are conditioned to be fact-absorbers and regurgitate them during their summative assessments have not moved beyond the *cognitive* strategies into the realm of developing mindsets (Hermes & Rimanoczy, 2018). Architecture educators ought to explore collaborative pedagogies that promote cross-pollinative exploration and experimentation with sustainability design strategies, technologies, and spatial configurations that will foster cultures of continuous learning and mental/cognitive agility in the face of the imminent and evolving sustainability challenges. This collaborative approach can be facilitated through Interdisciplinary projects, workshops, and studio courses that unite students from diverse fields to foster a holistic understanding of sustainable design principles and applications.

FILLING THE GAP: TRANSFORMATIVE PEDAGOGIES IN ARCHITECTURE EDUCATION FOR SUSTAINABLE DEVELOPMENT

Sustainability is inherently connected to transformative learning, yet traditional top-down pedagogies often fail to foster the necessary critical engagement and innovation among students. Transformative pedagogies aim to develop a **reflective** knowledge base, an appreciation for multiple perspectives, and a sense of critical consciousness and **agency** while

promoting profound and significant changes in habitual patterns, enabling new ways to role enactment (Kark et al., 2016). Shifting away from the hierarchical top-down paradigms of education, transformative pedagogy involves collaboration, exploration, instructional constructivism, autonomy, **experiential learning**, and **reflection** to create meaning that can change students' learning approaches (Gal, 2023). The ubiquitous One-on-One design studio pedagogy often coerces students to emulate tutors' design preferences and value systems (Crowther, 2013; Flynn, 2022). This has led scholars to advocate for a re-evaluation of traditional educational models to promote transformative learning experiences (Salama, 2016; Salama, 2021). *Transformational pedagogy* in architecture bridges sustainability-related building sciences and creative design, improves knowledge transfer, and tackles educational and professional obstacles (Altomonte, 2009) that foster a more profound comprehension of ecological issues. Scholars (Bedford, 2022; Burton & Salama, 2023) equally stressed that design educators could capitalise on UNSDGs and infuse sustainability principles into the curriculum to foster critical thinking to change learners' habitual patterns. As contemporary scholars have advocated the potential of infusing transformative pedagogies into problem-based design studios (El-Kholei et al., 2024; Hendawy et al., 2024; Salama & Burton, 2022), this study bridges this gap by inculcating students' sustainability mindset through theoretical subjects/topics. Transformative learning was leveraged to integrate value thinking competence and intrapersonal worldview towards Sense Making to address complex ecological challenges effectively.

CDIO Standard 3 For Sustainability Mindset: Integrated Curriculum

CDIO Standard 3 emphasises the importance of an integrated curriculum (vertical and lateral linkages) amalgamating disciplinary knowledge with **personal** and **interpersonal skills** towards product, process, system, and service building. Interpersonal skills were commonly referred to as communication, teamwork, emotional intelligence, and conflict management competencies, are essential for success in the workplace and society (Cacciolatti et al., 2017; Korniienko & Barchi, 2023). Kiviniemi and Przybyla (2019) supported the notion of an 'integrated curriculum' that intertwines the transfer of disciplinary knowledge with the development of essential knowledge, skill and attitude competencies, of which the mapping of specific learning outcomes and building on learners' prior knowledge to various courses ensures greater multidisciplinary coherence (Bridgstock et al., 2019). As such, lessons that impart and strengthen learners with ethical decision-making skills and critical thinking can be delivered to identify broader relationships and interactions within sustainability. These skills and a broadened worldview of their prior knowledge are required for students to critically analyse and reflect on **ethical dilemmas** and **contradictions** in the context of sustainability principles. Aligning with the CDIO framework's focus on integrated collaborative learning experiences and active learning, educators can establish a conducive problem-solving platform for students to question their prior assumptions and biases towards emerging epistemologies.

CDIO Standard 7 For Sustainability Mindset: Integrated Learning Experiences

Educational frameworks must prioritise integrating sustainability principles to prepare future professionals for a changing world. Henceforth, it is imperative to systematically include sustainability attitudes into the learners' Integrated Learning Experiences with CDIO Standard 7. Lozano et al. (2017) suggest that successful integration is undermined by the inclusion of (and extension) sustainability competencies (technical knowledge) with instructional approaches that focus on fostering students' sustainability mindset. These integrative approaches emphasise the acquisition of disciplinary knowledge and personal and

interpersonal skills through comprehensive learning experiences that prepare students to address **real-world sustainability** challenges. Such trajectories echoed a study incorporating sustainability into an engineering course (Grimal et al., 2021). Grimal et al. (2021) advocated, amongst others, **collaboration**, problem-solving, and systems thinking as key drivers. Likewise, Tomasella et al. (2022) advocated the integration of the UNSDGs with *real-world experiential learning* (simulated workplace scenarios and case studies) to scaffold learners' understanding of sustainability issues and to develop a sustainability mindset. Such notions have led to the increasing importance of *collaborative* learning. Besides educational outcomes of improved teamwork abilities, communication and negotiation skills when engaged in a communal discourse of real-world challenges, such collective platforms potentially offer individuals and groups an understanding of their standpoints and contribute to socio-diversity, thus promoting sustainability practices (Andrade & Sorrentino, 2014). The progressive development of a sustainability mindset throughout the DARCH programme resonates with [66] advocating the development of values thinking and intra and interpersonal competencies. This paper discoursed efforts in DARCH's first-year Architecture Foundation course's adaption of CDIO Standard 4, focusing on teamwork and communication to enhance intrapersonal competencies while introducing students to basic system thinking as essential for fostering a sustainability mindset.

PILOT: OPERATIONALISING CDIO STANDARDS IN SP'S ARCHITECTURE COURSE

The pilot, implemented within the DARCH Programme at SP, highlighted the urgency of instilling sustainability values by fostering investigative approaches in students' creative design processes, aligning with the contemporary *zeitgeist*. Architecture education is a multidimensional field that discourses and incorporates philosophy, technology, and social consciousness in students' design projects, to which sustainability, energy efficiency, and environmental design principles are increasingly pertinent (Ceylan et al., 2021; Gucyeter, 2016). While imparting technical skill sets and techniques to infuse environmental, social and economic sustainability in student projects was the primary modus operandi in architecture education, pedagogical strategies towards inculcating sustainability mindsets were often overlooked. Such assertions were advocated by Sotnikova et al. (2019), who argued that a comprehensive teaching and learning approach must integrate sustainability as an intrinsic value embedded in theoretical courses and design studios to deepen students' knowledge and adaptation of sustainability mindsets (Dhaouadi & Leclercq, 2022). Additionally, instilling sustainability mindsets aligns with SP's goal of fostering ethical and responsible citizens. This pilot study explored the development of baseline sustainability competencies in values thinking, guided by the framework in Figure 1.

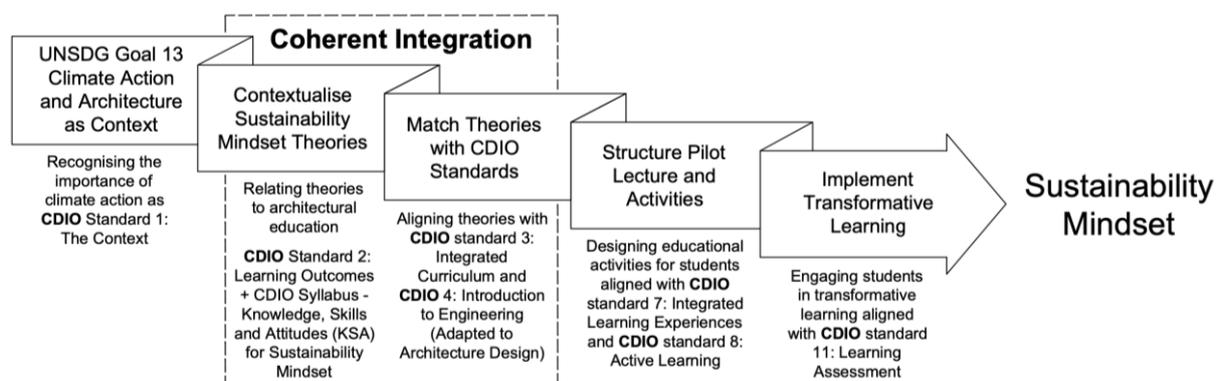


Figure 1. Relational Diagram and Conceptual Framework of the Pilot Study

CONSTRUCTIVE ALIGNMENT IN PILOT DESIGN: INTEGRATING SUSTAINABILITY AND ETHICAL COMPETENCIES IN ARCHITECTURAL EDUCATION

In the design of the two pilot activities, constructive alignment was used as guidance, ensuring that the course's learning objectives, instructional methodologies, and assessment tactics were coherent to support student learning effectively (Biggs, 1996). The lecture was conceived to rest on the foundations of prior lessons, focusing on a critique of contemporary sustainability issues and contradictions. The lecture had explicit links to adjacent DARCH courses whereby the passive approach in architecture design and its impact on thermal comfort and design strategies were expounded. Figure 2 illustrates the interplay between the elements of the pilot study's *constructive alignment with the CDIO syllabus and standards*.

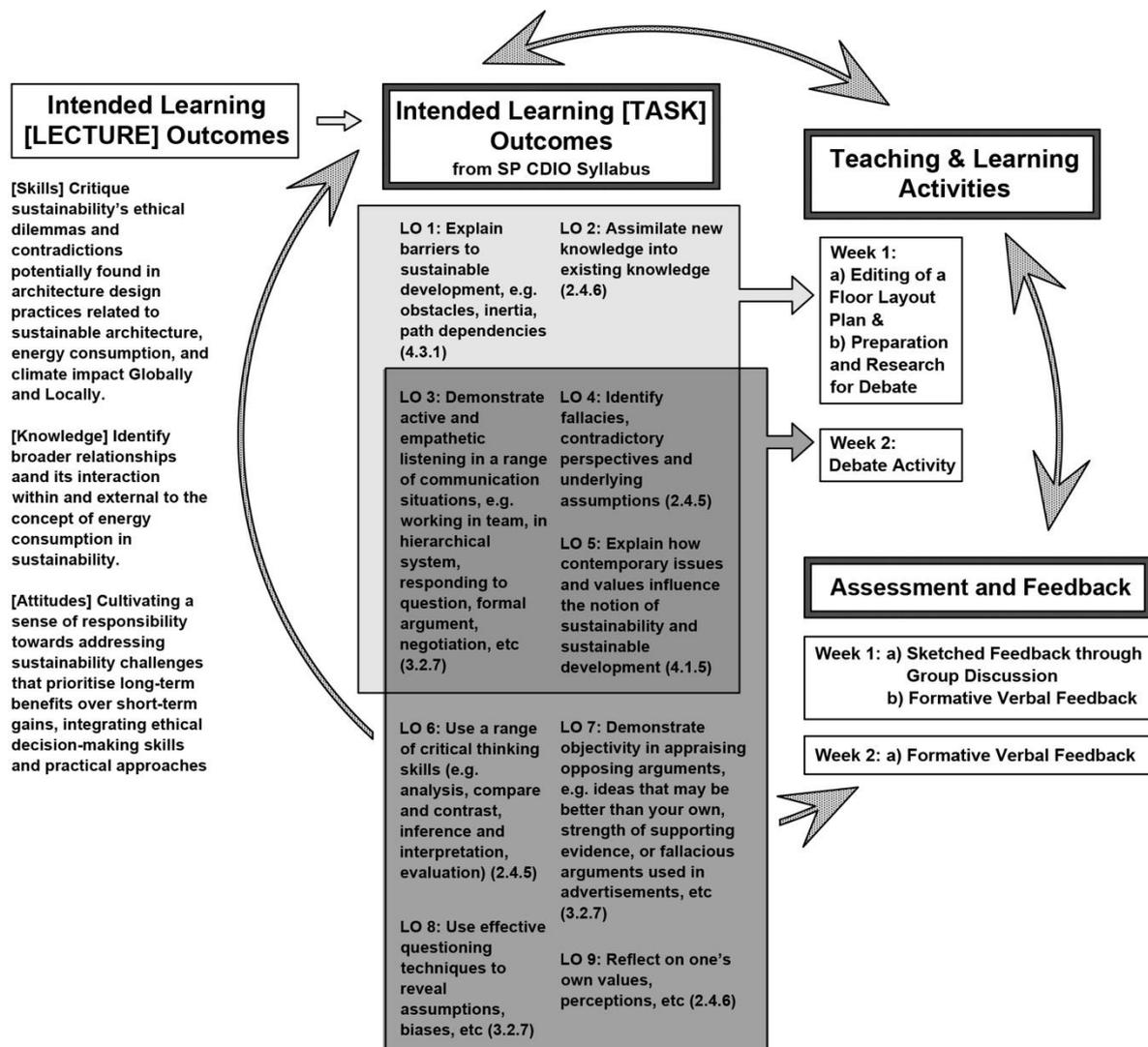


Figure 2. Relational mapping of the learning activities' Constructive Alignment framework with the SP CDIO syllabus and standards for the pilot.

The pilot lecture's **learning outcomes** explored notions of systems thinking to unveil the interconnectedness of buildings, stakeholders, and their natural environments concerning the energy consumption of buildings. Ecoliteracy is developed by teaching principles of ecology and low-energy sustainability design strategies and presenting real-world scenarios. Students can then reflect upon and analyse ethical dilemmas, enhance their ethical awareness and decision-making skills, practice identifying ethical issues and conflicts through case examples,

and prepare for ethical advocacy in organisational settings (Dodd & Jansson, 2004). Similar to the real-world scenarios discussed in the lecture, two tutorial activities (CDIO Integrated Learning Experiences) were designed as illustrated in Figure 3. Learners engaged in activities that exercise their agencies with ethical dilemmas and contradictions related to professional practices, focusing on building their **personal** and **interpersonal skills** and activating their awareness/competencies, systems thinking competencies, and practical experiences that equip them to make informed decisions that promote sustainability (Stewart et al., 2021). The discussion about real-world dilemmas stresses the importance of ethical practices in governing a person's behaviour or decisions in professional practice, ensuring that individuals prioritise long-term advantages over short-term gains (Biedenweg et al., 2013) will be explored in the next section.

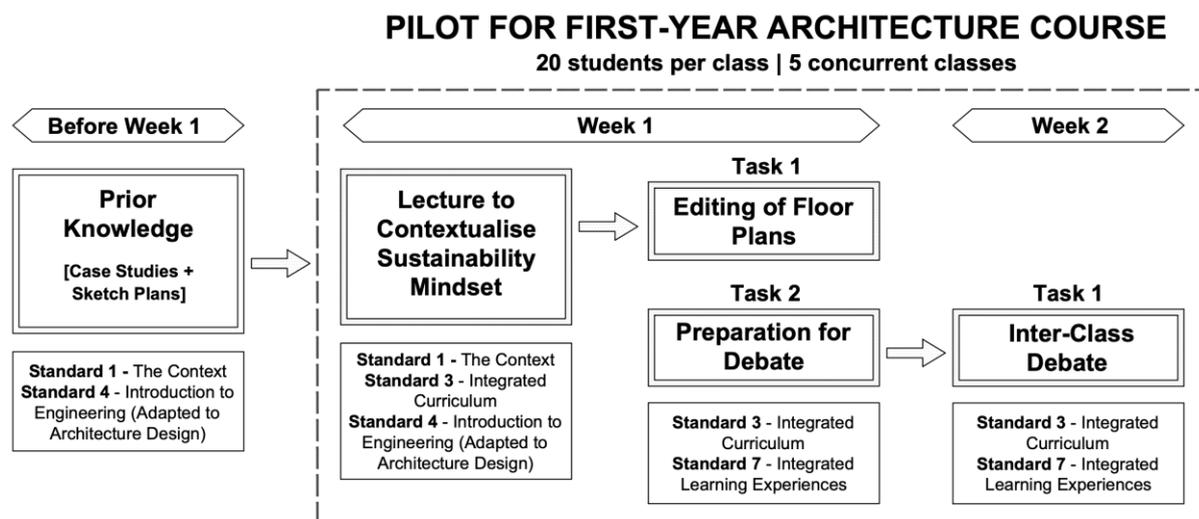


Figure 3. Transformative Learning activities and relations to CDIO standards

Integrating Real-World Scenarios: Floor Plan Redesign and Debate Activities in Architecture Education

The two learning activities spanned two weeks (Figure 3) and aimed to facilitate students' attainment of key competencies of sustainability, such as value thinking, systems thinking and integrated problem-solving. Activity 1 involved editing an apartment's floor plan, while Activity 2 grouped students for a debate. Architecture practices often face pressure from clients, leading to design compromises. **Activity 1** mirrored a real-life scenario where a client requested the master bedroom face the western landscape as a development 'selling point'. Although this offers desirable views, it exposes the room to intense western sunlight, increasing energy consumption due to air conditioning. Students must first identify the floor plan's shortcomings and comply with the client's demand for an unblocked western view with proposed sketches to reduce the building's cooling loads by reconfiguring the spatial layout.

As referenced in Figure 3, students were expected to be engaged in a debate in **Activity 2**. Debate-based pedagogy in higher education potentially enhances students' classroom engagement, critical problem-solving skills, perspective-taking skills, empathy, and advocacy skills (Mabrey et al., 2021). While allowing a discourse of competing and multiple perspectives, the debated framework of dilemmas, which requires solutions and one-sided choices, to a framework of paradoxes that embraces tensions and contradictions can contribute to meaningful, transformational learning (Kark et al., 2016). Debates theoretically empower learners to become active citizens beyond the classroom, preparing them for future societal

engagement (Thomas, 2011) with the crystallisation of value systems through mindset development via interactive educational interactions (McInnes, 2013). Echoing Hermes & Rimanoczy's (2018) assertion that the contentious debated topic creates fluid boundaries between what may be considered 'right' and 'wrong' hypothetically establishes a supportive learning atmosphere conducive to instilling a sustainability mindset.

Students were grouped into three groups (for, against, and the jury) for Role Play Debating activity. Typically, clients urge architects to choose cost-effective finishes to meet budget constraints. The architect was tasked with selecting a marble finish for a new 50-storey office tower's lift lobby in downtown Singapore. Two samples were shortlisted with the understanding that successful project execution might lead to future opportunities. However, the architect's firm is financially strained, with no new projects expected, and the architect is apprehensive about potential conflicts with the cost-focused client's Project Manager. In preparing for a presentation, the architect evaluates Sample A from Country X at \$35 per square foot with nine hours of transport time and Sample B from Country Y at \$65 per square foot with a 1.5-hour transport time. Both samples are similar in size, thickness, durability, maintenance, and appearance. The architect must decide which tile sample to propose.

DATA COLLECTION AND ANALYSIS METHODOLOGY

To answer **RQ1** and **RQ2**, students were invited to deposit their reflections via an online portal with these reflective questions. To answer **RQ1**, students will reflect upon, '*How has the tutorial on sustainability architecture and energy enhanced your understanding of ethical dilemmas and conflicts in the context of sustainable architecture?*' and aligned to **RQ2**, '*How has the tutorial prepared you for ethical advocacy in professional settings?*' after the lecture and second learning activity. The survey was administered to 5 studios of 20-21 students each and 130 responses were collected from both occasions via Microsoft Forms. Personal data were not collected as the option "*Anyone can respond – Anonymous response, doesn't require sign-in*" was selected to ensure their anonymity. This study was approved by Singapore Polytechnic's Institutional Review Board with protocol number: 202407-01. The dataset was analysed using the Atlas.Ti qualitative analysis software. After thoroughly reviewing the data, the 'Intentional AI Coding' function identified relevant codes related to specific concepts based on the research questions, which were validated and refined. These codes were then manually grouped and regrouped into themes by identifying patterns and trends (Braun & Clarke, 2006), and recurrent themes were reviewed to ensure accurate data representation supported by participant quotes.

However, it is important to acknowledge a few limitations of this research design and methodology. As this pilot assessed learners' sustainability mindsets shortly after the implementation of the activity, this short-term assessment only provides us with a potential glimpse of sustainability mindset in their future advocacies and not their long-term effects. With this projects' extension into the upper years of the DARCH programme, longitudinal studies will be carried out for a better understanding on how students' sustainability mindsets evolve over time. While students' qualitative data provides rich insights, that are inherently subjective and may be influenced by individual biases and confounding variables. These variables may include personal values, or external influences (e.g., family background, media exposure), may complicate efforts to isolate the impact of the educational interventions.

DISCUSSION

Two main themes were identified for each RQ. Notions of **Ethical Dilemmas** and **Enhanced Understanding** were themes related to **RQ1. Preparation for Future Practices** and **Appreciation of Sustainability** were themes identified in **RQ2**.

Deeper Appreciation and Enhanced Understanding of Ethical Dilemmas

Despite lacking formal experience in architectural design, students anticipated future conflicts between aesthetics, function, and sustainability through **Systems Perspective/Thinking**, highlighting how elements interact and foreseeing ethical dilemmas, as illustrated in the theme of **Ethical Dilemmas** for **RQ1**. One participant stressed: “*(The activities) enhanced my understanding of the ethical dilemmas in architecture. It showed the conflict between aesthetic goals and energy efficiency, as well as the challenge of balancing costs with sustainability*” and “*(the activities) let me understand how easy it is to pretend that the building is sustainable when it really isn't*”. As architectural practices are not solely aesthetically driven (El-Feki & Kenawy, 2018; Farinea & Demeur, 2023), the authors argue that these early exposures to the independent relationships of systems thinking have the potential to facilitate their transition into responsible designers. Such necessities were similarly argued by Kurjenoja et al. (2021), whereby the importance of developing design competencies sensitive to reality was considered paramount to develop, and O'Dwyer and Gwilliam (2019) advocated the need for architecture education to impart civic responsibilities to students and encourage them to consider social principles in their professional practices.

Value systems, soft skills, and mindsets can be challenging to impart through lectures and activities (Liow, 2021), as sound decisions must be made considering the situational context. Such assertions have complimented the second theme: **Enhanced Understanding**. This study explored group ‘debates’ to foster collaboration, critical thinking, and diverse perspective evaluation through **Collaborative and Innovative Actions**. One learner reflected: “*Especially after the debate session, there are still no right answers on how to solve sustainability issues and the practical/ethical balance in the decision we make as an architect*”, mirrored the debates as a pedagogical tool in addressing complex issues and shaping students' understanding of public policy, ethics, and social values. Debates stimulate critical thinking and reasoned argumentation, thus creating lasting educational memories (Palatty et al., 2018). Another learner reflected: “*(the activities) allowed me to realise that there are pros and cons to each architectural approach. It is also important to take risks for the greater good sometimes*”, reinforcing that students' enhanced understanding of these complex issues facilitates their development of a well-rounded and conscientious approach to design, preparing them for its complexities and agencies. This discursive/argumentative approach was echoed in Cheah's (2021) study, which advocated ‘sustainability as a discourse’. Seatter and Ceulemans (2017) clarified that by exploring sustainability as a collective discourse, emerging epistemologies can be derived through debates and disagreements among different viewpoints rather than subscribing to the widely accepted absolute beliefs and practices of sustainability. Furthermore, scholars (Balachandra, 2019; Sibanda & Naidoo, 2023) advocated the promotion of desired attitudes, mindsets, and behaviours through experiential learning.

Preparedness and Appreciation of Ethical Advocacy

Regarding students' reflections on their ethical advocacy in professional settings for **RQ2**, two main themes emerged as: **Preparation for Future Practices** and **Appreciation of Sustainability**. Highlighting the interplay among stakeholders' objectives and the need for effective communication underscores a **Systems Perspective/Thinking** as Preparation for

Future Practices. One participant remarked after the debate activity: *“I think the important thing is to discuss with both parties (clients with architects) to obtain a desirable outcome” and “(the activities) have prepared me to professionally prepare myself for future conflicts and dilemmas in the industry, as well as how to advocate for my ideas to my clients”*. The intersection of architecture and sustainability involves a nuanced interplay between ethical considerations and practical decision-making. Such conundrums were argued to be ubiquitous in professional practices, whereby clients’ objectives (aesthetics & budget) may not echo architects’ environmental considerations. Angral (2019) similarly suggested that clients often prioritise aesthetics and cost over adjacent pertinent issues, such as environmental considerations, leading to potential conflicts between the architect’s vision and the client’s expectations. Dansoh and Frimpong (2016) emphasised that ineffective communication and understanding of each party’s priorities might lead to misunderstandings and discontent. The architect’s job extends beyond design; it includes educating clients on the long-term advantages of sustainability, which may necessitate initial investments that coincide with aesthetic goals. Preparing students for these imminent polemical conflicts in academia can prepare them for future ethical advocacy in their careers.

Participants reflected on the **Appreciation of Sustainability** as extensions of students’ **Ecological Worldview**. Students’ thoughts reflected a deeper understanding of sustainability that broadens their ecological perspective beyond superficial concept that fosters the integration of sustainability as a core element. *“It made me understand that sustainability is just a term used to greenwash us, and we should rather use responsibility as we should be taking care of our planet”*, as one student reflected. Both the lecture and activities helped in catalysing of transformative learning moments as students realised that sustainability design practices must shift beyond the imagery hypes and trends in mainstream perceptions of sustainable development. Sustainable development must be regarded as a strategic framework in architectural practice, rather than a transient trend (Grover et al., 2018). This shift into critically analysing a piece of architecture designed with sustainability principles in mind is argued to be essential in their education. As one participant reflected: *“It made me rethink about what other design choices can be considered when trying to be “sustainable”*, this shift in viewpoint allows students to think of sustainability as an intrinsic component of the design process, rather than an afterthought or a superficial addition (for the sake of needing to have a sustainable design). Exposing architecture students to complex conflicts prepares them to navigate ethical challenges and advocate for sustainability solutions in their careers.

Extension of Prior CDIO studies and Future Research

This study explored in detail on how CDIO standards can be infused into the pedagogies of architecture education by adopting an interpretivist take of students’ sentiments and reflections, extending the paucity body of studies expounding on the macro application of CDIO standards in architecture education. While Ho and Leong (2023) discoursed the macro framework for operationalising CDIO standards to guide program managers, our research contributes to this trajectory by focusing on the micro aspects of pedagogy, specifically emphasising the development of a sustainability mindset. The study’s pedagogical approach can also be contextualised as an extension of a study by Reidar et al. (2023) whereby CDIO standards were used to enhance collaborative and contextual learning environments of architecture education. Likewise, the frameworks discussed in this study also compliments Luong & Le’s (2016) article of which the authors explored relevant problem design methodologies in architecture design that align with current and future real-world trends.

CONCLUSION

As climate emergency persists, continued pedagogical efforts to embed sustainable development goals into architectural curricula and pedagogies through CDIO standards to shape future practitioners to effectively address complex sustainability challenges in the built environment will be increasingly paramount. This study emphasises the critical role of integrating the CDIO Framework with UNSDG No.13 in architecture education operationalising Cheah et al.'s (2025) 'generic' framework to foster sustainability mindsets among students.

To achieve this, this research emphasises on transformative learning activities (debates and role-playing) which engage students in ethical dilemmas related to sustainability. This pedagogical approach encourages critical thinking and reflection, allowing students to navigate complex sustainability challenges. By fostering a deeper understanding of ethical conflicts and the complexities of sustainability, the study moves beyond traditional rote learning methods, promoting a more engaged and thoughtful learning experience.

Building on the insights of this study, which echoed key notions of Systems Perspective/Thinking, Ecological Worldview, and Collaborative and Innovative Action, future longitudinal studies will allow researchers to track changes in students' sustainability mindsets over time to enhance our understanding and attitudes towards sustainability evolve as they progress through the curriculum. Similarly, by utilizing an explanatory sequential mixed methods design can provide a more comprehensive understanding of students' sustainability mindsets. With a longitudinal framework, the quantitative measurements of sustainability mindset could quantify changes in time, while focus groups can offer deeper insights into students' experiences and reflections on their learning. This triangulation of data can strengthen the validity of the findings. Alternative models of transformative learning would be experimented supporting the development of learners' key competencies of/for sustainability. This project is currently in the stages of extending laterally within the first DARCH courses and vertically into the second-year studios for greater coherence and continuity.

The qualitative analysis of student reflections revealed a deeper understanding of the complex interplay between aesthetics, functionality, and sustainability in design. Furthermore, students expressed greater preparedness for ethical advocacy in their professional futures, highlighting the necessity of effective communication with clients regarding sustainability issues. Ultimately, the findings illustrate that transformative pedagogical approaches can effectively cultivate baseline key sustainability competencies, value thinking, systems thinking and integrated problem-solving, equipping future architects to navigate the multifaceted challenges and contribute to sustainable development.

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REFERENCES

- Akgün, Y., Erkarlan, Ö. E., & Neşeliler, P. (2023). A Guide for a Guide: Using UIA publications for an SDG-focused Studio. *International Journal of Architectural Research Archnet-Ijar*, 17(3), 443-458. <https://doi.org/10.1108/arch-11-2022-0245>
- Altomonte, S. (2009). Environmental Education for Sustainable Architecture. *Review of European Studies*, 1(2). <https://doi.org/10.5539/res.v1n2p12>

- Andrade, D. F. d., & Sorrentino, M. (2014). Dialogue as a Basis for the Design of Environmental Pedagogies. *Journal of Education for Sustainable Development*, 8(2), 143-154. <https://doi.org/10.1177/0973408214548373>
- Angral, A. (2019). Architect–client Relationship and Value Addition in Private Residential Projects. *International Journal of Architectural Research Archnet-Ijar*, 13(1), 58-71. <https://doi.org/10.1108/arch-12-2018-0026>
- Avsec, S., & Jagiełło-Kowalczyk, M. (2021). Investigating Possibilities of Developing Self-Directed Learning in Architecture Students Using Design Thinking. *Sustainability*, 13(8), 4369. <https://doi.org/10.3390/su13084369>
- Balachandra, L. (2019). The Improvisational Entrepreneur: Improvisation Training in Entrepreneurship Education. *Journal of Small Business Management*, 57(sup1), 60-77. <https://doi.org/10.1111/jsbm.12486>
- Biedenweg, K., Monroe, M. C., & Oxarart, A. (2013). The importance of teaching ethics of sustainability. *International Journal of Sustainability in Higher Education*, 14(1), 6-14.
- Biggs, J. (1996). Enhancing Teaching Through Constructive Alignment. *Higher education*, 32(3), 347-364. <https://doi.org/10.1007/bf00138871>
- Braun, V., & Clarke, V. (2006). Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*. <https://doi.org/10.1191/1478088706qp063oa>
- Bridgstock, R., Grant-Iramu, M., & McAlpine, A. (2019). Integrating Career Development Learning Into the Curriculum: Collaboration With the Careers Service for Employability. *Journal of Teaching and Learning for Graduate Employability*, 10(1), 56-72. <https://doi.org/10.21153/jtlge2019vol10no1art785>
- Burton, L. O., & Salama, A. M. (2023). Sustainable Development Goals and the Future of Architectural Education – Cultivating SDGs-centred Architectural Pedagogies. *International Journal of Architectural Research Archnet-Ijar*. <https://doi.org/10.1108/arch-08-2023-0201>
- Cacciolatti, L., Lee, S. H., & Molinero, C. M. (2017). Clashing Institutional Interests in Skills Between Government and Industry: An Analysis of Demand for Technical and Soft Skills of Graduates in the UK. *Technological Forecasting and Social Change*, 119, 139-153. <https://doi.org/10.1016/j.techfore.2017.03.024>
- Ceylan, S., Şahin, P., Seçmen, S., Somer, M. E., & Süher, K. H. (2021). An evaluation of online architectural design studios during COVID-19 outbreak. *Archnet-IJAR: International Journal of Architectural Research*, 15(1), 203-218. <https://doi.org/10.1108/ARCH-10-2020-0230>
- Cheah, S. M. (2021). Sustainable Development In Chemical Engineering Curriculum: Review And Moving Ahead. *Proceedings of 17th CDIO International Conference.*, Thailand: RMUTT and Chulalongkorn University.
- Cheah, S. M., Yang, K., Liow, Z., Wong, Y., Chia, C. L., & Wouterson, E. (2025). Using CDIO for Development of Students' Sustainability Mindset. *Proceedings of 21st International CDIO Conference.*, Melbourne, Australia: Monash University.
- Crowther, P. (2013). Understanding the signature pedagogy of the design studio and the opportunities for its technological enhancement. *Journal of Learning Design*, 6(3), 18-28.
- Daneykin, Y., Daneikina, N., & Sadchenko, V. (2016). Implementation of CDIO Approach in Training Engineering Specialists for the Benefit of Sustainable Development. *Matec Web of Conferences*, 48, 06003. <https://doi.org/10.1051/matecconf/20164806003>
- Dansoh, A., & Frimpong, S. (2016). Client Perspectives on Relationships With Architects on Private House Projects. *International Journal of Qualitative Research in Services*, 2(3), 155. <https://doi.org/10.1504/ijqrs.2016.082643>
- Dhaouadi, K., & Leclercq, P. (2022). Shaping Sustainability in Architectural Education: The Integrated Design as a Tool. *Journal of Design Studio*, 4(2), 217-226. <https://doi.org/10.46474/jds.1218258>
- Dodd, S.-J., & Jansson, B. (2004). Expanding the boundaries of ethics education: Preparing social workers for ethical advocacy in an organizational setting. *Journal of Social Work Education*, 40(3), 455-465.

- El-Feki, S., & Kenawy, I. (2018). Integrating Sustainability Within Architectural Education in Cairo. <https://doi.org/10.21625/resourceedings.v1i1.183.g84>
- El-Kholei, A. O., Amer, A. S., & Yassein, G. A. (2024). Embedding Sustainable Development Goals in Architectural Education: A Case Study of Menoufia University 2023 Graduation Projects. *International Journal of Architectural Research Archnet-Ijar*. <https://doi.org/10.1108/arch-12-2023-0326>
- Farinea, C., & Demeur, F. (2023). Start-Up Education for Architects: Fostering Green Innovative Solutions. <https://doi.org/10.5821/jida.2023.12350>
- Flynn, P. (2022). *Rethinking the Crit: New Pedagogies in Design Education*. Taylor & Francis.
- Gal, A. (2023). From recycling to sustainability principles: the perceptions of undergraduate students studying early childhood education of an education for sustainability course. *International Journal of Sustainability in Higher Education*, 24(5), 1082-1104. <https://doi.org/10.1108/IJSHE-05-2022-0165>
- Goleman, D. (2010). *Ecological intelligence: The hidden impacts of what we buy*. Crown Currency.
- Grimal, L., Gillot, C., Reyes, T., Troussier, N., Marty, P., & Brulot, S. (2021). Descriptive Study of the Integration of Sustainability in an Engineering Course. <https://doi.org/10.35199/epde.2021.80>
- Grover, R., Emmitt, S., & Copping, A. (2018). Sustainable Development and Architectural Practice: Framing Strategic Approaches in the United Kingdom. *Sustainable Development*, 27(3), 377-387. <https://doi.org/10.1002/sd.1910>
- Gucyeter, B. (2016). The Place of Sustainability in Architectural Education: Discussion and Suggestions. *Athens Journal of Architecture*, 2(3), 237-256. <https://doi.org/10.30958/aja.2-3-4>
- Hawken, P., Lovins, A. B., & Lovins, L. H. (2013). *Natural capitalism: The next industrial revolution*. Routledge.
- Hendawy, M., Junaid, M., & Amin, A. (2024). Integrating Sustainable Development Goals Into the Architecture Curriculum: Experiences and Perspectives. *City and Environment Interactions*, 21, 100138. <https://doi.org/10.1016/j.cacint.2023.100138>
- Hermes, J., & Rimanoczy, I. (2018). Deep learning for a sustainability mindset. *The International Journal of Management Education*, 16(3), 460-467.
- Ho, Y. G., & Leong, Y. Y. (2023). A CDIO Approach to Teach Sustainability In Architecture. *Proceedings of 19th International CDIO Conference*. , Trondheim, Norway: NTNU.
- Kark, R., Preser, R., & Zion-Waldoks, T. (2016). From a Politics of Dilemmas to a Politics of Paradoxes. *Organizational Behavior Teaching Review*. <https://doi.org/10.1177/1052562916634375>
- Kassel, K., Rimanoczy, I., & Mitchell, S. (2016). "The Sustainable Mindset: Connecting Being, Thinking, and Doing in Management Education". *Academy of Management Proceedings*, 2016, 16659. <https://doi.org/10.5465/AMBPP.2016.16659abstract>
- Kiviniemi, M. T., & Przybyla, S. M. (2019). Integrative Approaches to the Undergraduate Public Health Major Curriculum: Strengths, Challenges, and Examples. *Frontiers in Public Health*, 7. <https://doi.org/10.3389/fpubh.2019.00106>
- Konst, T., Kontio, J., & Nurmi, P. (2022). Sustainable Development in Engineering Education. *Proceedings of 18th International CDIO Conference*., Reykjavik, Iceland: Reykjavik University.
- Korniienko, I., & Barchi, B. (2023). The Concept of the Soft Skills and Emotional Intelligence Development. *Psychology Travelogs*(1), 16-26. <https://doi.org/10.31891/pt-2023-1-2>
- Kurjenoja, A. K., Schumacher, M., & Carrera-Kurjenoja, J. (2021). Landscape Sensitizing Through Expansive Learning in Architectural Education. *Land*, 10(2), 151. <https://doi.org/10.3390/land10020151>
- Liow, Z. (2021). Start It Right [S.I.R.] – A Heterarchy Studio Pedagogical Model For Generation Z Learners In S. W. Zollinger & J. Nyboer (Eds.), *Effective Design Critique Strategies Across Disciplines* University of Minnesota. <https://doi.org/https://doi.org/10.24926/edc.204>
- Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., & Lozano, F. J. (2017). Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal. *Sustainability*, 9(10), 1889. <https://doi.org/10.3390/su9101889>

- Luong, H. X., & Le, B. N. (2016). Capstone Problem Design for Optimal Learning Curve in Architecture Design. *Proceedings of 12th International CDIO Conference.*, Finland, Turku: Turku University of Applied Sciences.
- McInnes, D. (2013). The performance of academic identity as pedagogical model and guide in/through lecture discourse. *Teaching in Higher Education*, 18(1), 53-64.
- Miranda, A., & Miah, S. J. (2021). Designing an Innovative Unified Contextual Architecture for Improving Information Retrieval Service in Healthcare Organizations. *Information Development*, 39(2), 235-247. <https://doi.org/10.1177/02666669211049492>
- Mohkam, M., Mohammadi, S. M. H., Arababadia, R., & Javaran, E. J. (2022). Impacts of Phase Change Materials on Performance of Operational Peak Load Shifting Strategies in a Sample Building in Hot-arid Climate. *Environmental Progress & Sustainable Energy*, 42(1). <https://doi.org/10.1002/ep.13961>
- Moldovan, R., & Chisăliță, G.-A. (2021). Aspects Regarding Heating and Cooling in Energy Efficient Buildings Using Heat Pumps. *Revista Romana De Inginerie Civila/Romanian Journal of Civil Engineering*, 13(1), 72-82. <https://doi.org/10.37789/rjce.2022.13.1.9>
- Natras, B., & Altomare, M. (1999). *The natural step for business: Wealth, ecology and the evolutionary corporation*. New Society Publishers.
- Núñez-Andrés, M. A., Martínez-Molina, A., Casquero-Modrego, N., & Suk, J. Y. (2022). The impact of peer learning on student performance in an architectural sustainability course. *International Journal of Sustainability in Higher Education*, 23(1), 159-176. <https://doi.org/10.1108/IJSHE-11-2020-0447>
- O'Dwyer, S. T., & Gwilliam, J. (2019). Ways of Choosing. *Eaae Annual Conference Proceedings*, 128-131. <https://doi.org/10.51588/eaeeacp.24>
- Orr, D. W. (1991). *Ecological literacy: Education and the transition to a postmodern world*. State University of New York Press.
- Palatty, P. L., Saldanha, E., Rao, S., Rao, P., & Baliga, M. S. (2018). Effectiveness of Debate as a Teaching Method for Bioethics: Opinion of Undergraduate Students After a Class Session. *Global Bioethics Enquiry Journal*, 6(3), 135. <https://doi.org/10.38020/gbe.6.3.2018.135-138>
- Reidar, L., Anders, R., Bendik, M., & Simen, D. T. (2023). Engineering Minor in Architecture, A Model For Interdisciplinary Specialization And Contextual Learning. *Proceedings of 19th International CDIO Conference.*, Trondheim, Norway: NTNU. .
- Rieh, S. Y., Lee, B. Y., Oh, J. G., Schuetze, T., Álvarez, S. P., Lee, K., & Park, J. (2017). Integration of Sustainability Into Architectural Education at Accredited Korean Universities. *Sustainability*, 9(7), 1121. <https://doi.org/10.3390/su9071121>
- Rimanoczy, I. (2020). What Is a Sustainability Mindset? , 9-24. <https://doi.org/10.4324/9781003095637-1>
- Rimanoczy, I. (2021). *The sustainability mindset principles: A guide to developing a mindset for a better world*. Routledge.
- Rimanoczy, I., & Llamazares, A. M. (2021). Twelve Principles to Guide a Long-Overdue Paradigm Shift. *Journal of Management Spirituality & Religion*, 18(6), 54-76. <https://doi.org/10.51327/jkki4753>
- Rosén, A., Hermansson-Järvenpää, H., Finnveden, G., & Edström, K. (2021). Experiences from Applying the CDIO Standard for Sustainable Development in Institution-Wide Program Evaluations. *Proceedings of 17th International CDIO Conference.*, Bangkok, Thailand: Chulalongkorn University & Rajamangala University of Technology Thanyaburi. .
- Salama, A. M. (2016). *Spatial design education: New directions for pedagogy in architecture and beyond*. Routledge.
- Salama, A. M. (2021). *Transformative Pedagogy in Architecture and Urbanism*. <https://doi.org/10.4324/9781003140047>
- Salama, A. M., & Burton, L. O. (2022). Defying a legacy or an evolving process? A post-pandemic architectural design pedagogy. *Proceedings of the Institution of Civil Engineers-Urban Design and Planning*, 175(1), 5-21.

- Seatter, C. S., & Ceulemans, K. (2017). Teaching Sustainability in Higher Education: Pedagogical Styles that Make a Difference. *Canadian Journal of Higher Education*, 47(2), 47-70.
- Senge, P. (2008). The necessary revolution: How individuals and organisations are working together to create a sustainable world. *Management Today*, 24(10), 54-57.
- Sibanda, M., & Naidoo, P. (2023). Building an Entrepreneurial Culture in Electrical Engineering Education. 235-251. https://doi.org/10.2991/978-2-38476-134-0_16
- Sotnikova, O., Zolotukhina, I., & Prokshits, E. (2019). Modern Structure of the Higher Architectural and Construction Education. *E3s Web of Conferences*, 110, 02136. <https://doi.org/10.1051/e3sconf/201911002136>
- Stewart, A. L., Ahmed, S., Warne, T., Shanks, C. B., & Arnold, S. (2021). Educator Practices and Perceptions of Integrating Sustainability and Food Systems Concepts Into Elementary Education: Comparative Case Study in Two Northwestern States in the United States. *Frontiers in Sustainable Food Systems*, 5. <https://doi.org/10.3389/fsufs.2021.714226>
- Thomas, A. (2011). Towards a transformative digital literacies pedagogy. *Nordic Journal of Digital Literacy*, 6(1-2), 89-101.
- Till, J. (2009). *Architecture depends* (Vol. 55). MIT press.
- Tomasella, B., Wylie, A., & Gill, D. (2022). The Role of Higher Education Institutions (HEIs) in Educating Future Leaders With Social Impact Contributing to the Sustainable Development Goals. *Social Enterprise Journal*, 19(4), 329-346. <https://doi.org/10.1108/sej-03-2022-0027>
- Ummihusna, A., & Zairul, M. (2021). Investigating Immersive Learning Technology Intervention in Architecture Education: A Systematic Literature Review. *Journal of Applied Research in Higher Education*, 14(1), 264-281. <https://doi.org/10.1108/jarhe-08-2020-0279>
- Zamorano, M. (2022). Special Issue: Recent Advances in Energy Efficiency of Buildings. *Applied Sciences*, 12(13), 6669. <https://doi.org/10.3390/app12136669>

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