Cultivating Sustainable Infrastructure Project Delivery through Integrated Design and Envision-Rating System within Construction Education

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Abstract

Infrastructure projects are characterized by distinct challenges such as funding sources, conflicting stakeholder interests as well as various social, economic, and environmental implications. Embracing sustainable infrastructure (SI) and utilizing effective project delivery methods (PDM) to deliver such complex projects can potentially facilitate addressing these issues while improving sustainability performance. That said, it is evident that to deliver SI projects, stakeholders should have sufficient knowledge of how the infrastructure sustainability rating system, i.e., Envision rating system can facilitate in implementation of alternative PDMs. Although higher education can potentially support future engineering professionals by nurturing critical sustainability requirements along with efficient delivery methods of SI projects, unfortunately, sustainability courses within higher education rarely focus on such correlations. Therefore, this research highlights the importance of educating architecture/ engineering/ construction (AEC) students on how the Envision rating system can aid in executing alternative PDMs for SI through leveraging integrated design. Therefore, this study piloted training in a sustainable construction class to introduce the students to key concepts of SI and PDMs for construction projects. To this end, the study conducted a pre-survey before the workshop to capture the existing knowledge of the participants about these concepts. During the workshop, the participants were introduced to various topics including traditional and alternative PDMs, integrated design, Envision Rating system and its credits, so that the students can draw connections and realize the interrelationships between SI and delivery methods. A post-survey was conducted after the training. The findings indicated that before the training, all the AEC students were not familiar with SI and their correlations with PDMs while deciding on a delivery method for such projects. Moreover, the results highlighted that the workshop improved the students' knowledge and skills in integrated design and boosted their confidence in participating in and delivering high-performance sustainable infrastructure projects. Finally, this study would be valuable for implementing SI and enhancing the project management skills of the future AEC workforce.

Background

Sustainable infrastructures (SI) must be planned, built, and maintained carefully to fulfill their intended function due to their complex design and construction. Such complex projects typically involve a wide range of stakeholders. These stakeholders hold diverse roles and responsibilities including setting the project's parameters and performance standards to running and maintaining the finished infrastructure, all of which vary as the project progresses [1]. The path to sustainable goals, which might include zero energy, zero carbon, and zero waste, is high-impact, highly collaborative work that requires the partnership of design and construction teams along with all other stakeholders [2]. The project management team must recognize the stakeholders and their

needs by selecting suitable project delivery methods (PDMs) in order to successfully deliver SI projects. A project delivery method outlines the roles of the parties involved in the project (typically the owner, contractor, and designer) and the timing of their engagement when constructing the facility [3]. Although throughout the 20th century, Design-Bid-Build (DBB) was the most popular delivery method, as the need for quicker project completion and rising project complexity due to the result of technical advancements grew, other variations of delivery methods started to emerge where each attempted to regulate the cost, quality, and safety differently [4]–[6]. Thus, alternative PDMs such as Design-Build (DB), Integrated Project Delivery (IPD), and Construction Manager at-Risk (CMAR) emerged and have become some of the most frequently used delivery methods in North America. However, project team members must have sufficient knowledge about selecting the best delivery method, particularly for SI projects, which largely depends on the particular needs of a project and necessitates a full comprehension of the benefits and drawbacks of each delivery method. Additionally, the project team members must have adequate proficiency in how sustainability tools such as infrastructure rating systems can complement these delivery methods to build infrastructure projects sustainably. Therefore, it is critical to educate future construction professionals about various PDMs and how these methods contribute to delivering high-quality sustainable performances through utilizing sustainability rating systems.

For a better response to the escalating complexity of construction projects, construction techniques have substantially developed in terms of innovation, technological improvement, and economic expansion. Researchers compared project delivery techniques and found that the degree of team integration and the chosen delivery method had a substantial impact on how well the time, cost, and quality goals were accomplished [7], [8]. However, emerging construction methods and advanced PDMs that are being used in current practices are rarely introduced to architecture/ engineering/ construction (AEC) students through construction management (CM) education. Traditional CM courses are designed to teach students about the industry's standard operating procedures, the interactions and roles, and responsibilities of various construction stakeholders, and the tools available to manage and control various aspects of construction projects [9]. Thus, conventional PDMs such as the DBB delivery method have always been emphasized within CM teaching efforts [10]. The American Council for Construction Education (ACCE) accreditation requirements state that students must be proficient in various project delivery techniques as well as the roles and duties of all parties engaged in the design and construction process [11]. However, the literature rarely focused on how AEC students can improve their competencies in delivering SI, particularly by combining alternative PDMs and sustainability rating systems within CM education. Since the success of projects using alternative project delivery techniques depends on the engineers’ capacity to work with the approach, it is essential to teach the future construction workforces about suitable PDMs for SI as well as the correlation between alternative PDMs and infrastructure rating systems, i.e., Envision rating system. Previous studies highlighted that effective training and education of construction stakeholders are crucial for successfully adopting advanced project delivery practices in AEC organizations [12]. Thus, this study aims to educate the future construction workforce about how

the Envision rating system can support integrated design thus facilitating the implementation of alternative PDMs for SI projects.

Literature has highlighted the significance of alternative PDMs in successfully delivering sustainable projects. Since the acquisition of the design team and the acquisition of the constructor are formed as two separate procurement phases in the DBB delivery method, owners typically don't have clear sustainability objectives in mind or have set up their minds about whether or not to seek sustainability certification when hiring design teams [13]. On the other hand, it was observed that owners have certification goals in mind when hiring contractors. This demonstrates that owners utilizing the DBB delivery approach most often establish distinct sustainability targets with the assistance of the design team as opposed to internal resources or the aid of the constructor. Moreover, traditional contract delivery methods have generally been found to impede innovative construction techniques, prolong the construction timetable, and hardly deliver the owner the best value in complex construction projects [14]. Furthermore, some studies revealed that conventional delivery methods such as DBB might not account for the specifics of high-performance sustainable projects and might restrict the ability of the constructor to contribute to sustainable goals [15]. Another study highlighted that the period in which the constructor became involved is the major element affecting all performance outcomes in sustainable construction [16]. These studies indicated that alternative PDMs which incorporate early team integration and integrated design are essential for reaching the sustainability goals of construction projects, particularly for infrastructure projects. In order to equip future sustainability professionals with the proper knowledge and skills for delivering high-performance SI projects, construction education must incorporate topics related to delivery methods for SI.

SI projects with alternative delivery methods that adopt Envision rating system can potentially support higher sustainable and resilient performances. Although several sustainable infrastructure rating systems such as Envision, Greenroads, BE2ST-in-Highways, INVEST, etc., have been introduced to deliver comprehensive instructions for developing infrastructure systems sustainably, this study focuses on the widely used Envision sustainability rating system. This particular rating system has an edge because of its distinctive framework, which includes a wide variety of infrastructure projects, including energy, water, waste, transportation, landscape, and information. Envision rating system provides a pragmatic framework to assess the risk, cost-benefit, and investment criteria of numerous alternatives which gives decision-makers a more solid basis and reveals a variety of additional ways in which these sustainability-focused projects have the potential to add real value to their stakeholders [17]. To this end, the Envision rating system is briefly described in the following section.

The Envision™ Rating System

The Institute for Sustainable Infrastructure (ISI) and the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design collaborated to create the Envision rating system. This rating system includes 64 sustainability and resilience indicators, or

"credits," inside a precise framework made up of five categories: Quality of Life (QL), Leadership (LD), Resource Allocation (RA), Natural World (NW), and Climate and Resilience (CR). The Envision rating system comprises four certification levels, each of which is determined by a percentage of the total Envision points that apply to each criterion. These levels are Verified (20% to 30%), Silver (30% to 40%), Gold (40% to 50%), and Platinum (50% or above). In addition to other advantages highlighted by ISI, the Envision rating system is stated to support social equity and environmental justice principles in project processes and decision-making, assist communities in becoming carbon neutral, facilitate improved stakeholder engagement and interagency collaboration, and increase resilience, readiness, and long-term viability of civil infrastructure [18]. The five Envision categories, their accompanying subcategories, and their maximum achievable points are shown in Table 1 [19].

Table 1. Envision™ Categories, Subcategories, and points table

Categories	Subcategories	Max. points	
Quality of Life (QL)	Wellbeing	92	200
	Mobility	44	
	Community	64	
Leadership (LD)	Collaboration	72	182
	Planning	60	
	Economy	50	
Resource Allocation (RA)	Materials	66	196
	Energy	76	
	Water	54	
Natural World (NW)	Siting	82	232
	Conservation	78	
	Ecology	72	
Climate and Resilience (CR)	Emissions	64	190
	Resilience	126	
Total Points			1000

Envision rating system and integrated design can be mutually beneficial for each other which in turn supports the alternative delivery methods for infrastructure projects [20]. For instance, the LD credits largely align with the integrated design which requires team chartering, early sustainability kick-off, and documented collaboration with construction, operation, and maintenance stakeholders to obtain higher levels of achievement under this credit. Moreover, integrated design along with alternative delivery methods allows collaboration with contractors early on which can facilitate procuring resources and tracking them effectively which aligns with the requirements of RA categories. Furthermore, integrated design and alternative delivery methods support CR credits by creating a more robust risk matrix by utilizing holistic and interdisciplinary approaches. Overall integrated design and alternative delivery methods support mitigating potential challenges in applying Envision rating system on infrastructure projects. Thus, it is critical to introduce the AEC students to how the Envision rating system can support

the integrated design and alternative project delivery methods to achieve better sustainability outcomes for infrastructure projects.

Aligning with this critical research need, this study introduces the AEC students to various PDMs and how Envision rating system supports alternative delivery methods through leveraging integrated design to achieve better sustainable outcomes. The objectives of this study include (1) assessing knowledge improvement of the AEC students about various concepts of traditional and alternative PDMs, SI and Envision rating system; (2) capturing and comparing students' perception before and after the training about the effectiveness of using alternative delivery methods for SI projects; and (3) assessing the efficacy of the training through students' feedback. The outcomes of this study would help improve SI project delivery and foster the project management capabilities of future AEC professionals.

Methodology

This study introduced the AEC students to the interrelationships between Envision rating system and alternative PDM to enhance their competencies in delivering SI projects. The training centered on assisting students in identifying their knowledge of topics including integrated design, the value of early integration, traditional and alternative project delivery methods, and so on. Additionally, the training provided the students with an overview of the Envision rating system, as well as how this rating system can support integrated design as an alternate project delivery strategy. The training was attended by students from various backgrounds. According to the findings of the pre-survey data, 71% of the participants were Hispanic, whereas 29% were non-Hispanic students. Moreover, 6 percent of the students identified themselves as African American, 76% as white, 9% as Asian, 3% as Native American, and 6% as members of more than one ethnic group.

This study surveyed the AEC students enrolled in the Fall 2022 semester of the CM program's cross-listed Sustainable Approach to Construction course. This was a 3-credit optional course that was offered to both undergraduate and graduate students. The objectives of the course were to review sustainable materials and practices as well as teach sustainable construction concepts and methods. Additionally, the course taught the students about sustainability rating systems such as Leadership in Energy and Environmental Design (LEED) and Envision rating system. The course included a training module every semester that covered special sustainability topics. Thus, the Fall 2022 semester had the training module teaching the students about PDMs for SI projects. Registered students majoring in architecture, engineering, and construction participated in this study. The survey was distributed to the participants using the online surveying application Qualtrics. Multiple-choice questions and sociodemographic data were included in the pre-survey. The multiple-choice questions were designed to gauge students' understanding of delivery methods, SI, Envision rating systems, integrated design and so on. Furthermore, the demographic questions captured the participants' social and academic backgrounds. Then the students were allowed to watch a video that explained in detail about the integrated design, the value of early integration, conventional and alternative project delivery methods, and the

Envision rating system and its credits that support the integrated design and alternative project delivery. The video duration was 40 minutes. The outline of the video module is described as follows.

- Traditional vs. Alternative Project Delivery
    - Structural and process differences between traditional and alternative delivery process
    - Challenges of implementing Envision on alternative project delivery
- How can integrated design support the success of alternative project delivery?
    - Why use the integrated design on alternative delivery projects
    - What does the integration look like (differences between high and low integration)
    - The value of early integration
    - How to implement the integrated design (concepts and strategies)
- How can Envision support integrated design?
    - Relationship between Envision and Integrated Design
    - Keys to successfully implementing Envision
- Envision Credit Examples
    - List of relevant credits
        - QL1.6 Minimize Construction Impacts
        - LD1.2 Foster Collaboration and Teamwork
        - LD2.1 Establish a Sustainability Management Plan
        - LD2.3 Plan for Long-Term Monitoring and Maintenance
        - Resource allocation credits
        - CR2.3 Evaluate Risk and Resilience
        - CR2.4 establish Resilience Goals and Strategies
        - CR2.6 Improve Infrastructure Integration
- Summary of Lessons Learned

Additionally, the students were instructed to prepare a write-up summarizing the video on how the Envision rating system complements the integrated design. This write-up was not included in the analysis of this study but was intended to get the students thinking about these ideas and give them a better grasp of how the Envision rating system and alternative PDMs interact. Finally, the authors distributed the post-survey to capture students' knowledge improvement through the same multiple-choice questions. Furthermore, both the pre and post-survey asked the students to share their agreement level on applying integrated design and alternative PDMs in SI projects. The post-survey also included questions that captured students' feedback about the efficacy of the training. The detailed questionnaire used for the pre-and post-surveys were included in this research's appendices A and B, respectively.

The McNemar test was used in the study to examine the multiple-choice questions collected through pre- and post-survey data. This study selected the McNemar test for the analysis because this test looks at differences in a dichotomous dependent variable (i.e., categorical variables with just two categories) across two related groups [21]. The authors used SPSS to run the McNemar test with a 90% confidence interval and a P-value of 0.1. Moreover, the study utilized a box plot

to show the pre- and post-survey data relating to students' judgment about how integrated design and alternative project delivery method complements SI projects. Furthermore, the study presented a pie chart showing students' feedback about the efficacy of the training.

Figure 1 shows the research overview of the project.

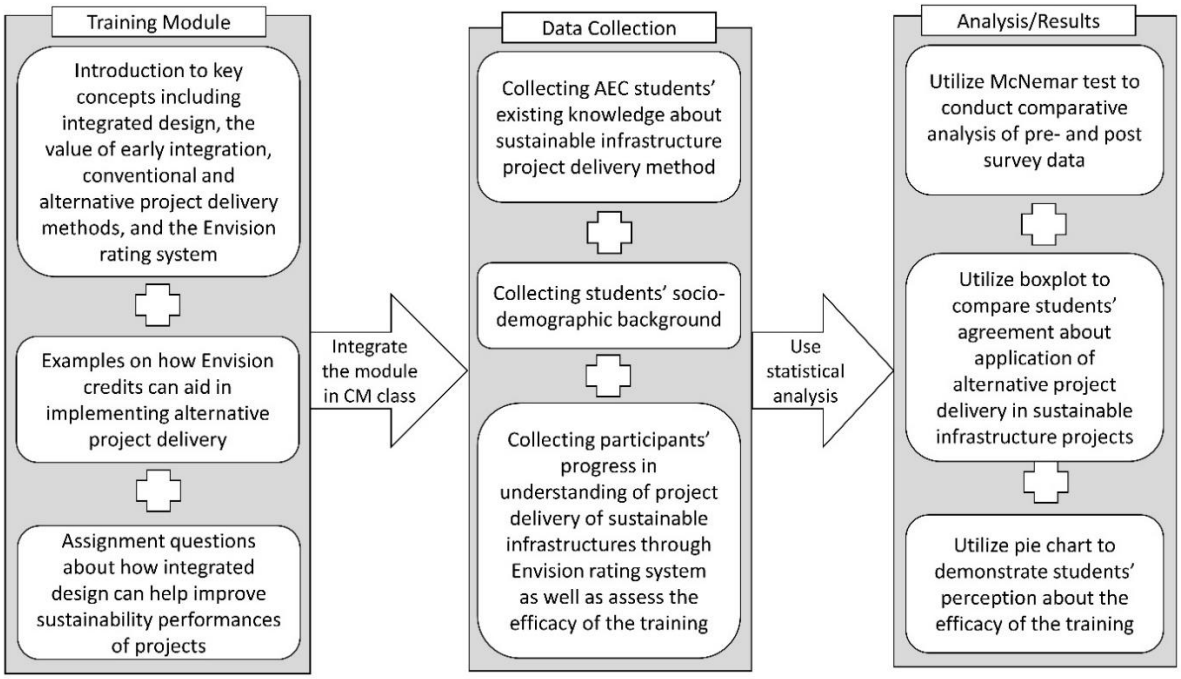

Figure 1. Research Overview

Results

This section presents the analysis and results of students' pre and post-training knowledge. The participants of this study included a diverse group of students. The total number of respondents was 34 including 8 female and 26 male students of multiple races, such as White, Asian, African American, and Native American among others. The majority of the students were within the 18-25 and 26-39 age range and were senior and grad students as shown in Figure 2.

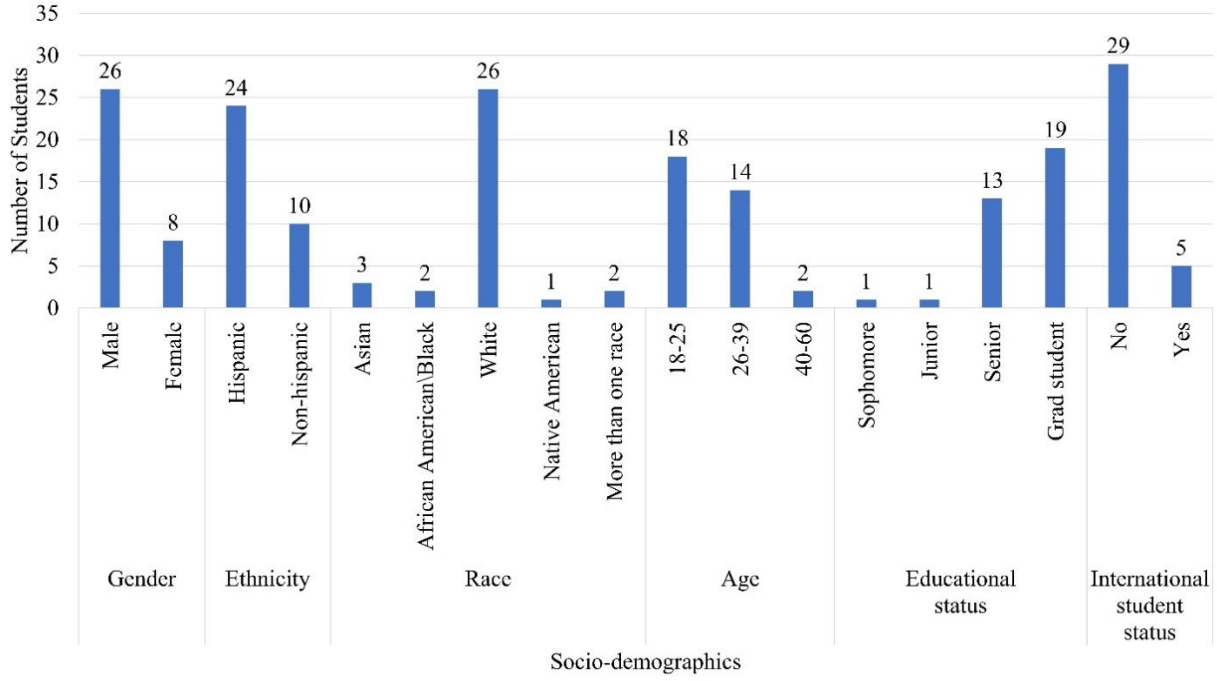

Figure 2: Socio-demographic information of CM students

The study assessed the students' ability to identify concepts related to traditional and alternative project delivery methods, integrated design, and Envision credits supporting integrated design through pre and post-survey. This research utilized the McNemar test to determine if there are any differences in the statements between pre and post-survey responses. Table 2 highlighted the findings which included the serial, variables/statements, mean differences between pre and post-survey responses, standard deviation, and p-value. The p-values less than 0.1 for variables 4 and 5 showed that there is a significant positive difference between the means of the two datasets. This indicated that the post-survey had a significantly higher number of correct responses for these statements and highlighted that the training was helpful to improve students' knowledge about low and high integration in integrated design approaches to implement alternative delivery methods for SI projects. The p-values greater than 0.1 for the remaining variables indicated that the participants might have higher understanding of the variable prior to the training.

Table 2. Results for McNemar Test of Pre-and Post-training data (n=34)

Sl.	Variables/Statements	Mean Difference	Std. Deviation	P-value
Pre-1	Pre and post-training answers for traditional project delivery	0	0.41	1
Post-1			0.41	
Pre-2	Pre and post-training answers for alternative project delivery	0.03	0.507	1
Post-2			0.504	
Pre-3	Pre and post-training answers for coordination in alternative project delivery	0.14	0.485	0.18
Post-3			0.41	
Pre-4	Pre and post-training answers for example of low integration in integrated design.	0.24	0.485	0.039
Post-4			0.5	
Pre-5	Pre and post-training answers for example of high integration in integrated design.	0.32	0.507	0.001
Post-5			0.359	
Pre-6	Pre and post-training answers for the value of early integration.	0.12	0.327	0.219
Post-6			0.431	
Pre-7	Pre and post-training answers for implementing Envision rating system.	0.12	0.475	0.454
Post-7			0.504	

Additionally, the survey questionnaire asked the students about their agreement on whether the integrated design and alternative project delivery should be applied to SI projects. Figure 3 shows the comparison between the responses in pre and post-survey using box plots where 1= strongly disagree and 5= strongly agree. The results highlighted that the median value of students' ratings increased from 4 to 5 indicating that the training helped the students to understand the importance of integrated design and alternative delivery methods for delivering SI projects.

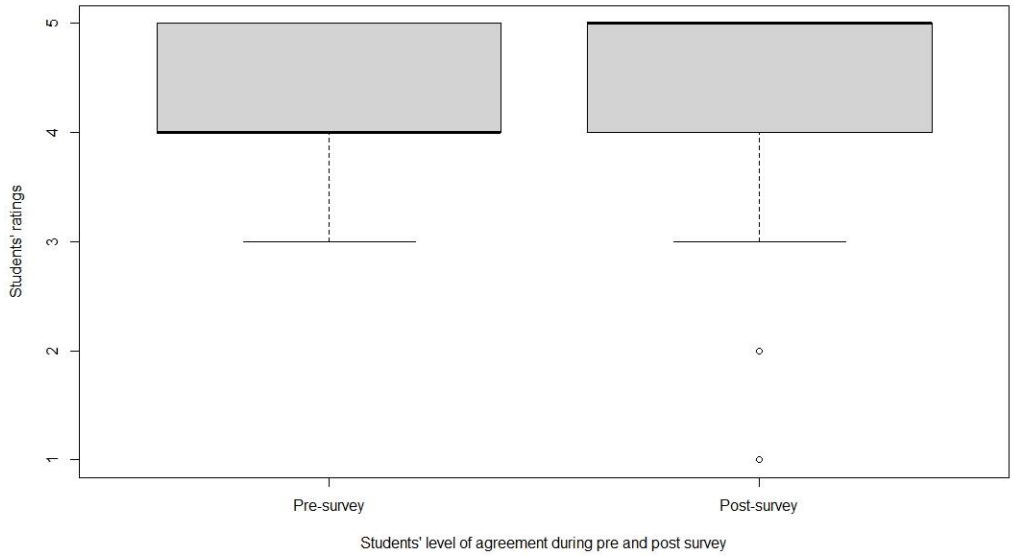

Figure 3. Box plots for pre-and post-course results of students' agreement

Figure 4 shows the total percentage of positive, negative, and neutral feedback for the training. Almost 91% of the students responded with positive feedback about the training, which included statements such as, “I think it was helpful because, I had little experience learning about this delivery method. Watching the video gave me an introduction to it as well”, “I feel the training was indeed helpful to better grasp an understanding of how integrated design and alternative project delivery can improve sustainability performances of infrastructure projects. Getting a group of people involved in the project together to collaborate their knowledge and ideas will allow them to come up with creative methods to improve infrastructure projects' sustainability performances”, among others. In comparison, 4% of students had negative feedback which included statements like, “it was not sufficient information”. This indicated that for educating the future construction workforces properly about these concepts, a detailed module consisting of the elaborated description of integrated design, alternative PDMs, and Envision rating system can be developed and incorporated within the CM curricula.

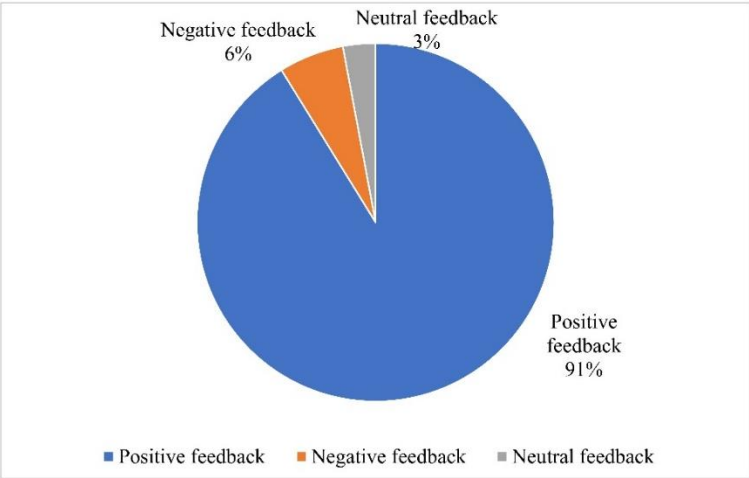

Figure 4. Pie chart for students’ qualitative feedback on the training

Limitations and Future Work

This study aimed to introduce the AEC students to the effective project delivery methods for SI as well as improve their competency in delivering these projects through Envision rating system. However, the research admits several limitations. The training was conducted in a minority-serving college, which may not be reflective of all STEM institutions, according to the study. The survey responses may also be biased and subject to self-evaluation. Therefore, future research may focus on integrating training across a variety of institutions with different socio-demographic backgrounds to evaluate the efficiency of the intervention. Additionally, such training must be included in every semester along with rigorous evaluation, participation, and monitoring to achieve long-lasting change.

Conclusion

Infrastructure projects face unique difficulties when it comes to funding, competing stakeholder interests, and a variety of social, economic, and environmental consequences. Addressing these difficulties while enhancing sustainability performance may be achieved by embracing Envision infrastructure sustainability rating system that can support integrated design and aid in implementing alternate PDMs. To deliver SI projects, this study highlighted the significance of educating AEC students on how the Envision rating system and alternative PDMs can complement each other and help to achieve more sustainable and resilient outputs. To accomplish this goal, the study designed and implemented an intervention in a sustainable construction class that demonstrated to the AEC students how the infrastructure rating system, specifically the Envision rating system, can support the integrated design and alternative PDMs and enhance the sustainability performance of the projects. The finding from pre and post-survey showed that the workshop enhanced the students' knowledge as well as their confidence in employing alternative PDMs and integrated design for improved sustainability performance of SI projects. The outcomes also showed that most of the students shared positive feedback about the training indicating its efficacy in disseminating infrastructure sustainability knowledge. This study contributed to the sustainability body of knowledge by developing an effective training module to teach the students about critical sustainability topics which include the integration of alternative PDMs in delivering SI projects and the potential of Envision rating system to support such integration. Additionally, this study reflected students' positive interest to apply alternative PDMs in SI projects in their future careers thus contributing to building sustainable and resilient developments. The results of this research will be useful for developing SI and advancing the required professional competencies of the future AEC workforce.

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Appendix A

Pre-survey

Project Delivery Method for Sustainable Infrastructure

Please select the response that best matches the statements below.

Q1. _____ is a type of traditional project delivery.

a) Design-Build
b) Design-Bid-Build
c) Integrated Project Delivery
d) Public Private Partnership

Q2. A type of alternative project delivery is _____.

a) Early Contractor Involvement
b) Integrated Project Delivery
c) Public Private Partnership
d) All of the above

Q3. Alternative project delivery ensures coordination between _____ .

a) Design engineer and Design Subconsultants
b) General Contractor and Subcontractor
c) Design Engineer and Construction Manager
d) Construction Manager and Subcontractors

Q4. Which of the following is an example of low integration in integrated design?

a) Inclusive from the outset
b) Iterative process
c) Linear process
d) Life-cycle costing

Q5. Which of the following is an example of high integration in integrated design?

a) Emphasis on up-front costs
b) Systems often considered in isolation
c) Less time and energy in early stages
d) Whole systems thinking

Q6. The value of early integration refers to _____ .

a) Increasing ability to make changes with increasing project timeline
b) Decreasing ability to make changes with increasing project timeline
c) Decreasing cost to make changes with increasing project timeline
d) Increasing cost to make changes with decreasing project timeline

Q7. _____ is a key factor to successfully implement Envision rating system.

a) Partnering sessions
b) Co-location
c) Incorporation into project risk matrix
d) Expert facilitation

Perception about Sustainable Infrastructure and Integrated Design

Q1. Do you think that integrated design and alternative project delivery should be applied to sustainable infrastructure projects?

1) Strongly disagree
2) Somewhat disagree
3) Neither agree nor disagree
4) Somewhat agree
5) Strongly agree

Socio-Demographic Background

Q1 Please specify your Gender.

a) Male
b) Female
c) Non-binary/gender fluid
d) Other

Q2 Please specify your ethnicity.

a) Hispanic
b) Non-Hispanic

Q3 Please specify your Race.

a) African American\Black
b) Asian
c) White
d) Native American
e) More than one race
f) Other

Q4 Please specify your age.

a) 18-25
b) 26-39
c) 40-60
d) Above 60
e) Prefer not to answer

Q5 Are you an international student?

a) Yes
b) No

Q6 Please specify your Educational Status.

a) First Year
b) Sophomore
c) Junior
d) Senior
e) Grad Student

Appendix B

Post survey

Project Delivery Method for Sustainable Infrastructure

Please select the response that best matches the statements below.

Q1. _____ is a type of traditional project delivery.

a) Design-Build
b) Design-Bid-Build
c) Integrated Project Delivery
d) Public Private Partnership

Q2. A type of alternative project delivery is _____.

a) Early Contractor Involvement
b) Integrated Project Delivery
c) Public Private Partnership
d) All of the above

Q3. Alternative project delivery ensures coordination between _____ .

a) Design engineer and Design Subconsultants
b) General Contractor and Subcontractor
c) Design Engineer and Construction Manager
d) Construction Manager and Subcontractors

Q4. Which of the following is an example of low integration in integrated design?

a) Inclusive from the outset
b) Iterative process
c) Linear process
d) Life-cycle costing

Q5. Which of the following is an example of high integration in integrated design?

a) Emphasis on up-front costs
b) Systems often considered in isolation
c) Less time and energy in early stages
d) Whole systems thinking

Q6. The value of early integration refers to _____ .

a) Increasing ability to make changes with increasing project timeline
b) Decreasing ability to make changes with increasing project timeline
c) Decreasing cost to make changes with increasing project timeline
d) Increasing cost to make changes with decreasing project timeline

Q7. _____ is a key factor to successfully implement Envision rating system.

a) Partnering sessions
b) Co-location
c) Incorporation into project risk matrix
d) Expert facilitation

Perception about Sustainable Infrastructure and Integrated Design

Q1. Do you think that integrated design and alternative project delivery should be applied to sustainable infrastructure projects?

1) Strongly disagree
2) Somewhat disagree
3) Neither agree nor disagree
4) Somewhat agree
5) Strongly agree

Feedback question

Q1. Do you think the Project Delivery Method Training for Sustainable Infrastructure was helpful in understanding how integrated design and Alternative Project Delivery can improve sustainability performances of infrastructure projects? Please explain your answer.