Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #49019

Integrating Sustainability Principles into Civil Engineering Capstone Project: Strategies and Pedagogical Approaches at an HBCU

Mr. Julius Ogaga Etuke, Morgan State University

Julius Etuke is a COREN-registered civil engineer and a member of the American Society of Civil Engineers (ASCE), with over 15 years of experience in structural design, construction, and consultancy. He has led major infrastructure projects across Nigeria and holds a BSc in Civil Engineering and an MSc in Civil Engineering (Construction Management). Julius is currently pursuing a Ph.D. in Sustainable and Resilient Infrastructure Engineering at Morgan State University, where he serves as a graduate research assistant, focusing on sustainable transportation design. He has served as a STEM research judge, including at the University of Bridgeport, and previously lectured at Delta State University, Abraka, where he taught core civil engineering courses and held key departmental roles. His academic contributions include peer-reviewed publications on infrastructure resilience and engineering education, reflecting his strong commitment to sustainability, research, and capacity building in civil engineering.

Oyinkansola Aladeokin, Morgan State University

Oyinkansola Aladeokin is a doctoral student and teaching fellow in the Department of Civil and Environmental Engineering at Morgan State University in Baltimore, Maryland. She holds a Bachelor of Technology (B.Tech) degree in Civil Engineering from Ladoke Akintola University of Technology and a Master of Science (M.Sc) in Sustainable and Resilient Infrastructure Engineering from Morgan State University. With over a decade of professional experience in infrastructure design and construction, she is passionate about advancing the development of safe, sustainable, and resilient civil infrastructure. Oyinkansola is also dedicated to mentoring and empowering the next generation of civil engineers. Her research spans a wide range of areas, including intelligent transportation systems, traffic safety, student development, and sustainable infrastructure.

Mr. Pelumi Olaitan Abiodun, Morgan State University

Pelumi Abiodun is a current doctoral student and research assistant at the department of Civil Engineering, Morgan State University, Baltimore, Maryland. Pelumi got his BSc and MSc degree in Physics from Obafemi Awolowo University, where he also served as a research assistant at the Environmental Pollution Research unit, in Ile-Ife, Nigeria. As part of his contribution to science and engineering, Pelumi has taught as a teaching assistant both at Morgan State University and Obafemi Awolowo University. With passion to communicate research findings and gleaned from experts in the field as he advances his career, Olaitan has attended several in-persons and virtual conferences and workshop, and at some of them, made presentation on findings on air pollution, waste water reuse, and heavy metal contamination.

Dr. Oludare Adegbola Owolabi P.E., Morgan State University

Dr. Oludare Owolabi, a professional engineer in Maryland, joined the Morgan State University faculty in 2010. He is the director of the sustainable infrastructure development, smart innovation and relient engineering and the director of undergraduate programs in the department of civil engineering at Morgan State University.

Integrating Sustainability Principles into Civil Engineering Capstone Project: Strategies and Pedagogical Approaches at an HBCU

Abstract

The increasing global challenges in critical infrastructure and environmental sustainability highlight the urgent need to integrate sustainability principles into civil engineering education. However, many civil engineering students struggle to apply these principles, particularly in capstone projects. This study assesses sustainability integration in capstone projects at a Historically Black College and University (HBCU) and identifies effective strategies to enhance student engagement with sustainability concepts.

A mixed-methods approach was employed, combining quantitative analysis of capstone project scores using a Sustainable Design Rubric and qualitative insights from semi-structured interviews with students, and industry professionals. Paired t-tests revealed statistically significant gaps ($p < 0.05$) between potential sustainability points (M_{pot}) and earned points (M_{earn}), indicating challenges in applying sustainability assessment tools, renewable energy solutions, and economic evaluations. These gaps were attributed to limited resources, insufficient practical exposure, and a lack of structured training on sustainability frameworks.

To address these challenges, the study recommends a multifaceted intervention including curricular enhancements, faculty training, practical exposure through real-world case studies, industry collaborations, and service-learning projects, and access to advanced sustainability tools and databases. Additionally, global learning opportunities and financial support such as student exchange programs and international workshops are proposed to broaden sustainability perspectives. By implementing these strategies, institutions particularly HBCUs, can better equip Civil Engineering students with the knowledge and skills needed to advance sustainable infrastructure practices.

Keywords: *Sustainability in Civil Engineering Education, Capstone Projects, Pedagogy, Historically Black Colleges and Universities (HBCU), Mixed-Methods Research, Sustainability Assessment*

1. Introduction

Sustainability is increasingly recognized as a cornerstone of modern engineering, emphasizing the need for designs and systems that balance environmental, economic, and social considerations. It requires that the current needs be met in a way that does not hinder future generations from meeting their own needs [1]. In civil engineering, sustainability emphasizes the design and construction of infrastructure that minimizes environmental impact, conserves resources, reduces emissions, and enhances resilience within communities [2]. This approach integrates sustainable practices at every stage of infrastructure development, from planning and design to construction and management. Achieving these objectives relies on the use of innovative materials, advanced technologies, and comprehensive environmental management strategies, ensuring long-term efficiency and adaptability [3].

In the Department of Civil and Environmental Engineering (CEE), capstone projects—a mandatory component of the curriculum—serve as a culminating academic experience that requires students to apply their technical knowledge and research skills to solve real-world engineering problems [4]. These projects typically involve designing, analyzing, and implementing engineering solutions while considering various constraints such as feasibility, cost, and sustainability. Integrating principles of economic, environmental, social, ethical, and health and safety sustainability into capstone projects prepares students to meet the demands of the engineering profession. This approach aligns with the Accreditation Board for Engineering and Technology (ABET) criteria, which emphasizes graduates' ability to "design a system, component, or process to meet desired needs within realistic constraints, including economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" [5].

Sustainability in civil engineering encompasses more than just technical design; it involves creating systems that address environmental, economic, and social challenges. Despite its critical importance, capstone projects often fail to emphasize sustainability explicitly, leaving students underprepared for the demands of rapidly evolving engineering practice. While numerous studies have assessed the integration of sustainability principles into capstone projects, little to no research has focused on Historically Black Colleges and Universities (HBCUs) [6], [7]. This gap highlights the timeliness and relevance of this study, which seeks to evaluate how effectively undergraduate capstone projects at an HBCU incorporate sustainability principles.

Incorporating sustainability into Civil Engineering education, particularly in capstone projects, requires intentional pedagogical strategies that align with the evolving demands of the profession. Despite the growing importance of sustainability, many capstone projects continue to lack a strong emphasis on sustainable design principles [8], [9]. A significant challenge is ensuring that students have both the knowledge and the ability to apply sustainability in practical, real-world contexts [8]. Teaching strategies that effectively incorporate sustainability into engineering education have gained attention in recent years. Approaches such as project-based learning (PBL), interdisciplinary collaboration, and challenge-based learning provide students with opportunities to tackle complex sustainability challenges while applying engineering principles. These methods not only encourage students to integrate sustainability into their designs but also promote skills such as critical thinking, systems thinking, and collaborative problem-solving [9].

Additionally, this study aims to identify effective strategies and pedagogical approaches that can encourage students to integrate sustainability into their projects, ensuring that they are well-equipped to apply sustainable design practices in their professional careers. The findings aim to contribute meaningfully to the ongoing discourse on engineering education reform [5],[7].

2. Background Framework

2.1 Sustainability Design Criteria Rubrics

Rubrics are essentially scoring tools used to outline the expectations and requirements for an assignment. They are widely utilized in classrooms as both assessment and teaching tools, helping instructors guide students in completing tasks and providing a structured framework for evaluating student performance. This dual role enhances learning by clarifying expectations and offering feedback [6], [7].

In performance assessments, rubrics are particularly useful for judging the quality of constructs such as reports and presentations. These assessments require students to demonstrate advanced skills to address real-world challenges, making rubrics invaluable for evaluation. In disciplines like engineering, rubrics assess complex skills, including critical thinking and the integration of interdisciplinary knowledge. They also facilitate self-assessment, enabling students to reflect on their work. For instructors, rubrics offer a consistent method for grading and providing feedback. Moreover, rubrics can track changes in educational programs over time, particularly in response to reform efforts, underscoring their versatility in evaluating diverse competencies [7], [10], [11]. The sustainable design rubric adapted in this study was used to evaluate how effectively students integrated sustainability into their projects. It was developed through a three-phase process that examined student engagement in sustainable design, as well as the influence of project sponsors and course instructors. This approach aligned with the structure of the capstone design course. Components considered in the rubrics include task descriptions, dimensions, scales, and dimension descriptors. These components were derived from the nine sustainable engineering principles identified by Abraham [12], which are as follows:

i. Adopt holistic design approaches using systems analysis and environmental impact assessments
ii. Preserve and enhance natural ecosystems while prioritizing human health and well-being.
iii. Utilize life cycle thinking in all engineering activities to assess long-term impacts.
iv. Ensure that material and energy flows are inherently safe, non-toxic, and environmentally benign.
v. Conserve natural resources by promoting efficiency and sustainable alternatives.
vi. Minimize waste generation through optimized processes and circular economy principles.
vii. Incorporate local geography, cultural contexts, and community needs in engineering solutions.
viii. Drive innovation beyond existing technologies to enhance sustainability and resilience.
ix. Actively engage communities and stakeholders in the development and implementation of engineering solutions.

These sustainable engineering principles were systematically analyzed and refined to establish specific, measurable criteria for assessing sustainability within capstone projects. This process led to the identification of 13 core sustainable design criteria, complemented by three additional economic design criteria, resulting in a comprehensive framework of 16 sustainable design criteria, as illustrated in Fig. 1, developed by Watson [7]. The inclusion of economic criteria provided a more holistic evaluation approach, ensuring that environmental, social, and economic dimensions of sustainability were effectively addressed.

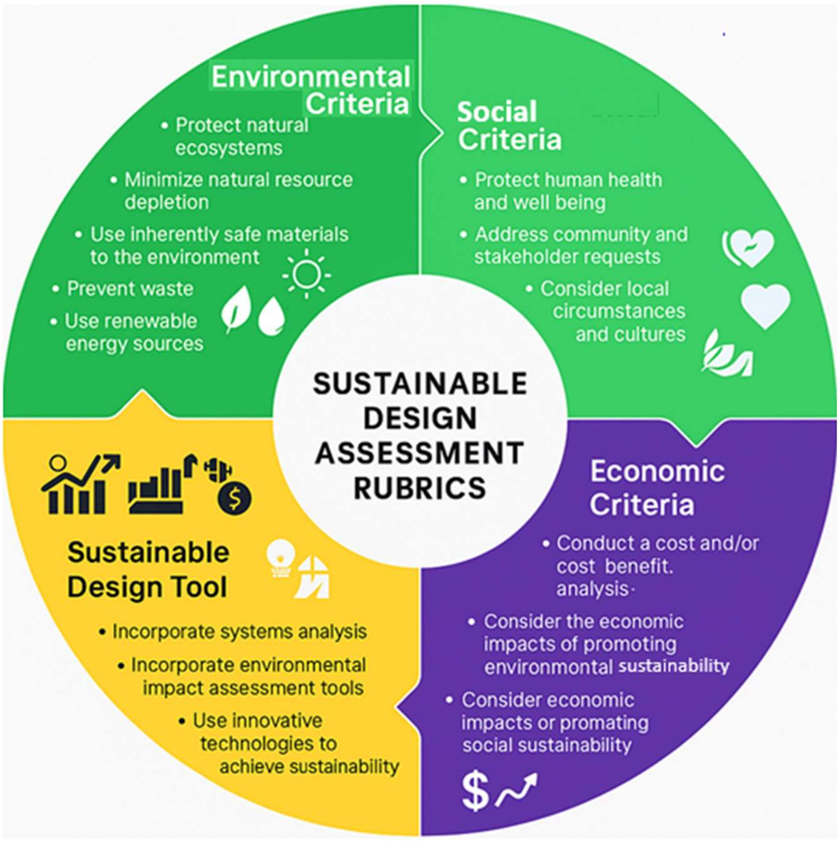

Figure 1. The 16 Sustainability Design Criteria developed by Watson [7]

2.2 The Four-Point Rating Scale (Earned and Potential Points)

The four-point rating scale, shown in Table 1, is a key component of the sustainable design rubric. It was designed by Watson [7] to help evaluators assess the extent to which students incorporate each of the 16 sustainable design criteria into their projects. The earned points scale measures the degree to which students address each sustainable design criterion in their projects. A score of 0 indicates no evidence of incorporating the design criterion in the project, while a score of 3 signifies extensive application of the criterion, demonstrating a high level of integration and consideration of sustainability aspects. In contrast, the potential points scale assesses the applicability of each sustainable design criterion to a given project. A score of 0 is awarded if the criterion is not applicable to the project, whereas a score of 3 is assigned if the criterion is not only applicable but also explicitly required by an instructor or project sponsor. These scales provide a structured framework to measure the depth and breadth of sustainability integration in student work.

Table 1. Four Point Rating Scale for Earned and Potential Points [7]

Potential Points	Earned Points
Score 0 (Inapplicable): The criterion is entirely irrelevant to the project.	**Score 0 (Unacceptable):** The criterion was not considered at all in the project report.
Score 1 (Valid): Although the sponsor does not mandate the application of the criterion, it is still relevant to the project.	**Score 1 (Developing):** The criterion is mentioned or discussed in the project report but was not actively implemented in the design process.
Score 2 (Required): The sponsor requires some application of the criterion in the project (e.g., 1–2 instances).	**Score 2 (Competent):** The project report provides evidence that the criterion was adequately applied in the design process (e.g., 1–2 instances).
Score 3 (Critical): The sponsor demands extensive application of the criterion within the project (e.g., 3 or more instances).	**Score 3 (Exemplary):** The project report shows substantial evidence of the criterion being extensively applied in the design process (e.g., 3 or more instances).

2.3 Sustainable Design Index

The sustainable design index (SDI), shown in Fig. 2, is a metric that quantifies how well a project meets expected sustainability performance standards. It is calculated as:

$SD_{score} = M_{pot} - M_{earn}$

An SD_{score} of +3 signified high expectations coupled with low performance, while an index of -3 indicated low expectations but high performance. An SD_{score} near 0 suggested that the project effectively met the established sustainability design criteria. This quantitative framework provided a structured approach to evaluate the integration of sustainability principles within student capstone projects, offering insights into areas for improvement and fostering accountability in sustainable design education. Universities can use average SD scores to assess how well their engineering or design programs integrate sustainability principles. Over time, improvements in teaching strategies should reduce SD_{scores}, indicating better sustainability outcomes in student projects [7].

Figure 2. Sustainable Design Index Scale by Watson [7]

3. Methodology

To assess the integration of sustainability principles into capstone projects in the Civil Engineering Department, this study adopted a mixed-methods assessment approach—both quantitative and qualitative. These assessments focused on determining the level of sustainability integrated into CEE capstone projects as well as identifying strategic approaches for incorporating sustainability principles into them. We selected 13 participants for this study. The sample consists of 2 Ph.D. students—who served as judges—9 graduate students, and 2 industry professionals. These participants were purposively selected to ensure a diverse representation of stakeholders with varying levels of experience in both sustainability and capstone projects. This study was carried out in two stages: Quantitative Analysis and Qualitative Analysis.

3.1. Quantitative Analysis: Sustainability Scoring and Statistical Assessment

The first stage involved the development of a scoring process using the Adapted Sustainability Design Rubric (ASDR) as the foundation for assessment. The rubric, shown in Fig. 1, was designed not only to assess students' abilities to engage with sustainable design across various dimensions but also to capture student performance and the influence of instructors or project sponsors on sustainable design expectations.

The key steps involved in the scoring process include: i) Training of Judges: Two Ph.D. students were trained to use the sustainability design rubric effectively and serve as judges. ii) Evaluation by Two Judges: To ensure a diverse perspective, each capstone project was evaluated by two judges. iii) Scoring and Discussion: Scores for each project were documented individually. In cases of discrepancies in judges' ratings, discussions were held to reach a consensus. iv) Data Collection: Data collected included the judges' individual potential and earned ratings for each criterion, as well as the consensus potential and earned scores.

To evaluate whether there was a significant difference between potential points (M_{pot}) and earned points (M_{earn}) across sustainability criteria, paired t-tests were performed. The null hypothesis (H_0) assumed that there was no significant difference between M_{pot} and M_{earn}, indicating that students met or exceeded sustainability expectations. The alternative hypothesis (H_1) suggested a significant difference, with earned points being lower than potential points, indicating a gap in sustainability integration. A p-value < 0.05 was considered statistically significant, leading to the rejection of H_0 and confirming deficiencies in sustainability integration.

Since the data were collected from the same projects and required a direct comparison of expected versus actual performance, paired t-tests were chosen as the most appropriate statistical method. All statistical analyses were conducted using Excel 2019.

3.2. Qualitative Analysis: Semi-Structured Interviews and Thematic Analysis

The second stage involved semi-structured interviews with graduate students and industry professionals to gain deeper insights into sustainability integration in capstone projects. The interview questions focused on: i) The current practices for integrating sustainability into capstone projects. ii) The challenges encountered by students and faculty in applying sustainability principles and iii) the recommendations for enhancing sustainability in project design and implementation.

Thematic analysis was conducted to identify recurring patterns and key themes from the interview responses. Responses were coded into categories such as curriculum gaps, resource constraints, industry collaboration, and instructional methods to provide structured insights into sustainability education.

The data collected using the mixed-methods assessment were analyzed using Excel 2019. Paired sample t-tests were performed to compare earned points and potential points for each of the 16 sustainable design rubrics, revealing significant differences. The responses from the semi-structured interviews were analyzed using thematic analysis. Participation was voluntary, and all participants provided informed consent prior to their involvement. To preserve the confidentiality of respondents, all data were anonymized.

3.3. Scope of Project Analysis

As shown in Fig. 3, a total of 50 capstone projects completed between Spring 2020 and Fall 2024 were analyzed using the Sustainable Design Index Scale by Watson [7]. These projects, which focused on various sections of a multi-use trail, were also evaluated as a distinct case study due to their shared specifications and constraints resulting from consistent sponsorship and project locations.

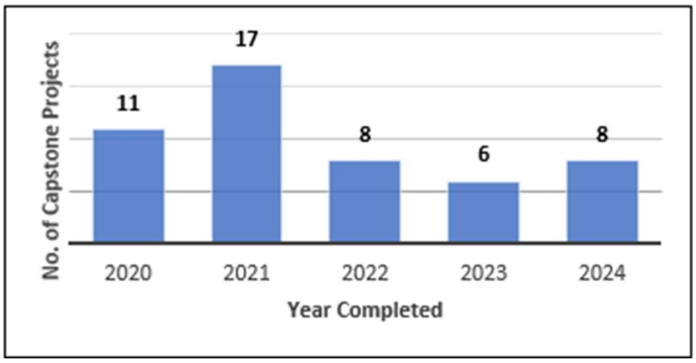

Figure 3. Number of Civil Engineering Capstone Projects Analyzed (2020–2024)

4. Results

4.1 Expected Potential Points

Potential points were calculated and analyzed to determine the extent to which sustainable design criteria could reasonably be applied on the students' projects. These points were compared to the Sustainable Design Index (SD_{score}). Figure 4 shows the expected potential scores across the 50 projects. The result shows that 41% were assigned a potential score of 1, while 51% a score of 2, and 8% a score of 3. Additionally, specific trends were observed across the four rubric dimensions

- social, environmental, economic, and sustainability design tool criteria. The average potential point across these criteria using the 16 sustainable design criteria was 1.67 (M_{pot} = 1.67).

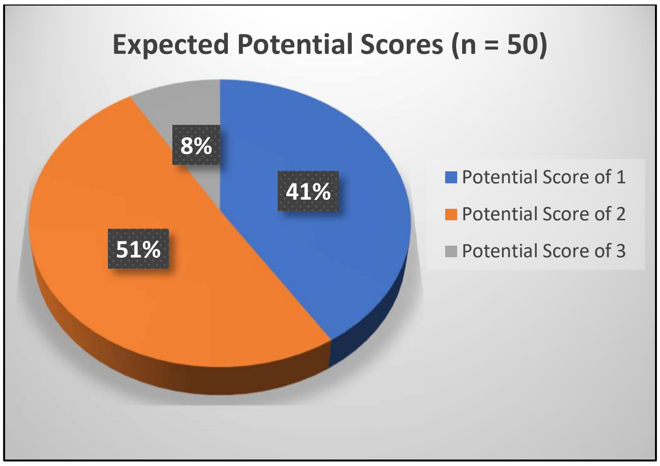

Figure 4. Expected Potential Scores

The results, as shown in Fig. 5, highlight that CEE capstone design projects placed a stronger emphasis on social criteria. The average potential score for all social criteria was 2.04 out of a possible 3 points. Within this category, all projects required students to address the criterion of "protecting human health and well-being" (M_{pot} = 3.0). This indicates that this aspect was given the highest priority in student projects. However, there was a noticeable gap in incorporating local circumstances and culture into their designs, highlighting a need for improvement in this area. This also suggests the necessity for enhanced instruction or revised project frameworks to promote a more balanced approach to social sustainability.

The environmental criteria were ranked as the second most emphasized aspect, with an average potential score of 1.68 (M_{pot} = 1.68). Among these criteria, all students were required to "use inherently safe materials" (M_{pot} = 2.0) as it was a course requirement. Economic criteria and sustainable design tools ranked third and fourth, respectively, indicating that these criteria were the least emphasized by project assessors. For economic sustainability, all students were required to "conduct a cost and/or cost-benefit analysis" (M_{pot} = 2.0), also as part of the course requirements. These results indicate that while safety and environmental protection are prioritized in student projects, there is a need for greater emphasis on waste prevention and the incorporation of renewable energy strategies.

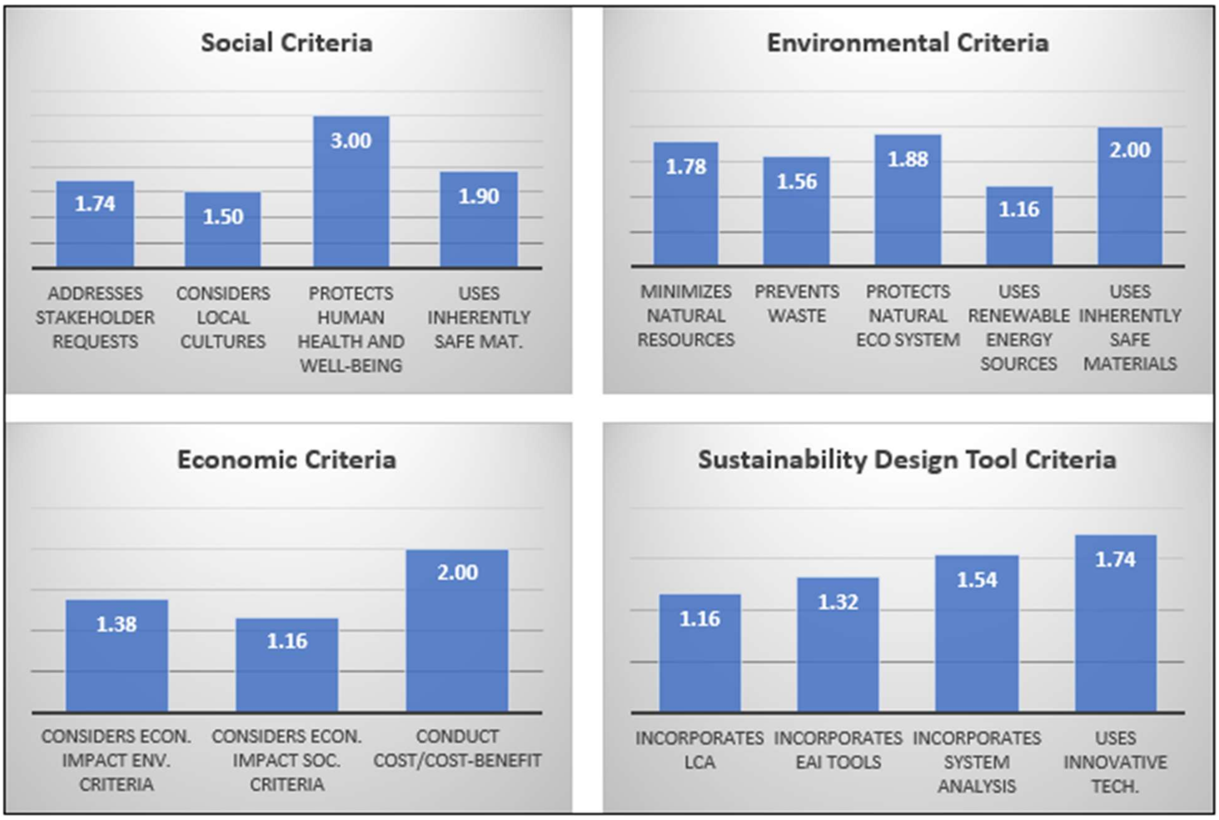

Figure 5. Potential Point Results from the 16 Rubrics for Sustainable Design Assessment

4.2 Students' Earned Points

Earned points were calculated and analyzed to identify the extent to which students addressed sustainable design criteria in their projects. According to the results shown in Fig. 6, 38% were assigned an earned score of 0, 20% a score of 1, 26% a score of 2 and 16% a score of 3 respectively. The mean earned score was 1.2 out of a maximum of 3 points. Furthermore, specific trends were observed across the four rubric dimensions.

From the earned points analysis, it was observed that students placed a greater emphasis on social sustainability compared to other dimensions as indicated in Fig. 9. Within this dimension, the following observations were made: 44 students' projects considered human health and well-being (M_{earn} = 2.12), 34 considered local circumstances and cultures (M_{earn} = 1.44), 40 addressed the use of inherently safe and benign materials (M_{earn} = 1.36), and 36 addressed community and stakeholder requests (M_{earn} = 1.26). The economic dimension was the second most addressed rubric dimension, with a mean earned score of 1.17 for all economic criteria. Again, due to course requirements, 34 students "conducted a cost and/or cost benefit analysis" (M_{earn} = 1.36). Only 24 students “considered the economic impacts of promoting social sustainability” (M_{earn} = 0.8), while 33 students “considered the economic impacts of promoting environmental sustainability” (M_{earn} = 1.34). The mean score across all social criteria was 1.55 (M_{earn} = 1.5).

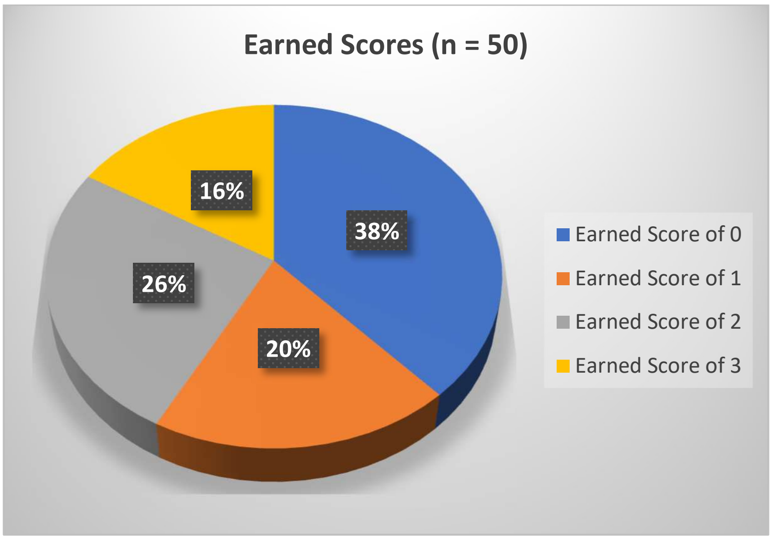

Figure 6. Chart for Earned Scores

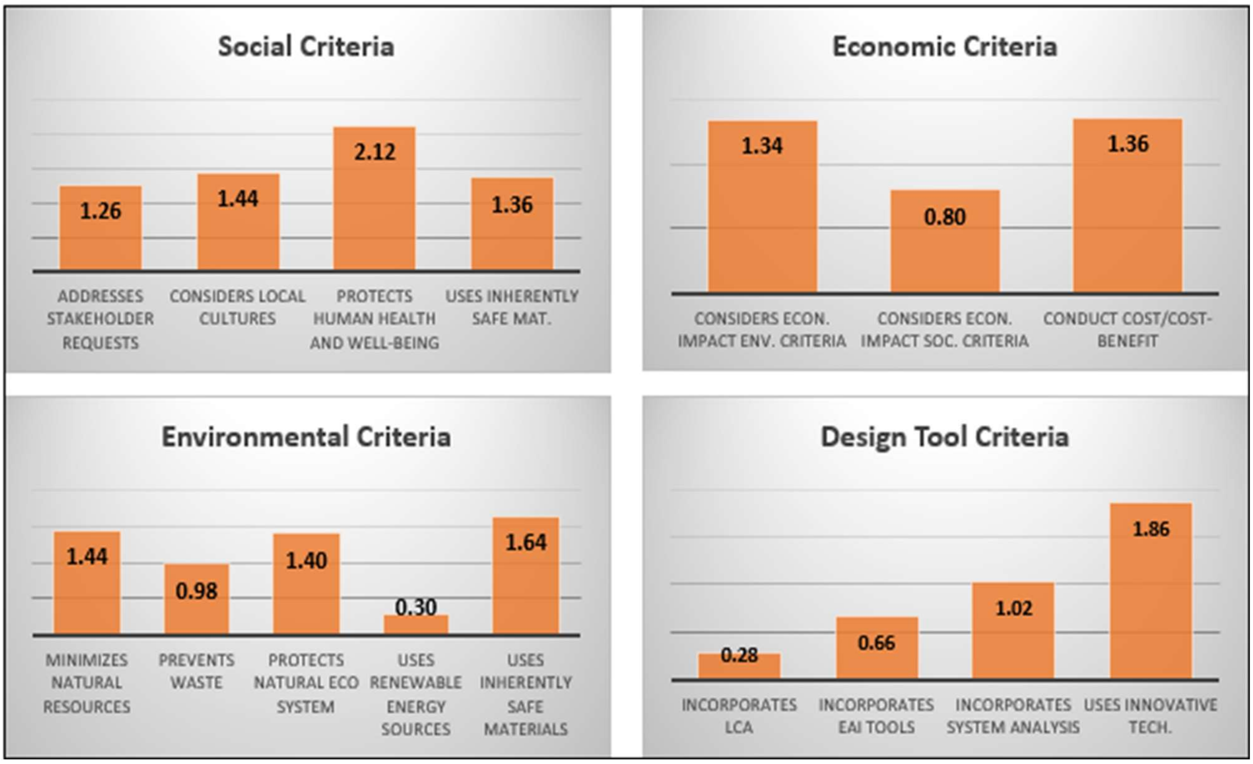

Figure 7. Earn Point Results from the 16 Rubrics for Assessing Sustainable Design

4.3 Comparison of the Potential Points and Earned Points

A detailed comparison of potential and achieved scores across four categories of 16 sustainable design rubrics is presented in Table 2 and Fig 8. The analysis indicates that student performance did not fully meet the established sustainability design criteria, emphasizing the need for stronger integration of sustainability principles in capstone projects.

On a Sustainable Design Index (SDI) scale of -3.0 to 3.0, the mean SDI score ($SD_{score} = M_{pot} - M_{earn}$) was 0.47, indicating that students' sustainability design performance was moderately below expectations but not at the lowest performance threshold. This result aligns with the high-expectation, low-performance quadrant of the SDI scale, suggesting room for improvement in aligning students' work with sustainability objectives.

A statistically significant difference ($p < 0.001$) was observed between the mean potential score ($M_{pot} = 1.67$) and the mean achieved score ($M_{earn} = 1.20$), reinforcing the gap between expected and actual sustainability integration in project work.

Table 2. Comparison between Potential and Earned Scores

No	16 Sustainability Rubrics	Potential Scores		Earned Scores		SDI (Score)	Paired T-test (P)	Remark
		M(Pot)	St. Dev	M(Earn)	St. Dev			
	Environmental Sustainability Criteria							
1	Minimizes Natural Resources	1.78	0.41	1.44	1.04	0.34	0.0066	**
2	Prevents Waste	1.56	0.54	0.98	1.24	0.58	0.0001	***
3	Protects Natural Ecosystem	1.88	0.68	1.40	1.20	0.48	0.0003	***
4	Uses Renewable Energy Sources	1.16	0.46	0.30	0.75	0.86	0.0000	***
5	Uses Inherently safe Mat. to Envi.	2.00	0.00	1.64	0.97	0.36	0.0128	*
	Average	1.68	0.29	1.15	0.66	0.52	0.0000	***
	Social Sustainability Criteria							
6	Addresses Stakeholder Requests	1.74	0.44	1.26	1.07	0.48	0.0005	***
7	Considers Local Circum. and Cultures	1.50	0.57	1.44	1.02	0.06	0.5538	*Not Significant*
8	Protects Human Health	3.00	0.00	2.12	0.95	0.88	0.0000	***
9	Uses Inherently Safe Mat. to humans	1.90	0.36	1.36	0.93	0.54	0.0001	***
	Average	2.04	0.22	1.55	0.70	0.49	0.0000	***
	Sustainability Design Tool Criteria							
10	Incorporates LCA	1.16	0.37	0.28	0.66	0.88	0.0000	***
11	Incorporates EAI tools	1.32	0.90	0.66	0.93	0.66	0.0000	***
12	Incorporates System Analysis	1.54	0.50	1.02	1.07	0.52	0.0001	***
13	Uses Innovative Tech.	1.74	0.44	1.86	0.92	-0.12	0.2610	*Not Significant*
	Average	1.44	0.39	0.96	0.48	0.49	0.0001	***
	Economic Sustainability Criteria							
14	Considers Econ. Impact on Env. Sust	1.38	0.49	1.34	1.12	0.04	0.7714	*Not Significant*
15	Considers Econ. Impact on Soc. Sust.	1.16	0.37	0.80	0.92	0.36	0.0044	**
16	Conduct Cost/Cost-benefit	2.00	0.00	1.36	1.09	0.64	0.0002	***
	Average	1.51	0.24	1.17	0.77	0.35	0.0010	***
	Total Mean	**1.67**		**1.20**		**0.47**		

*Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$*

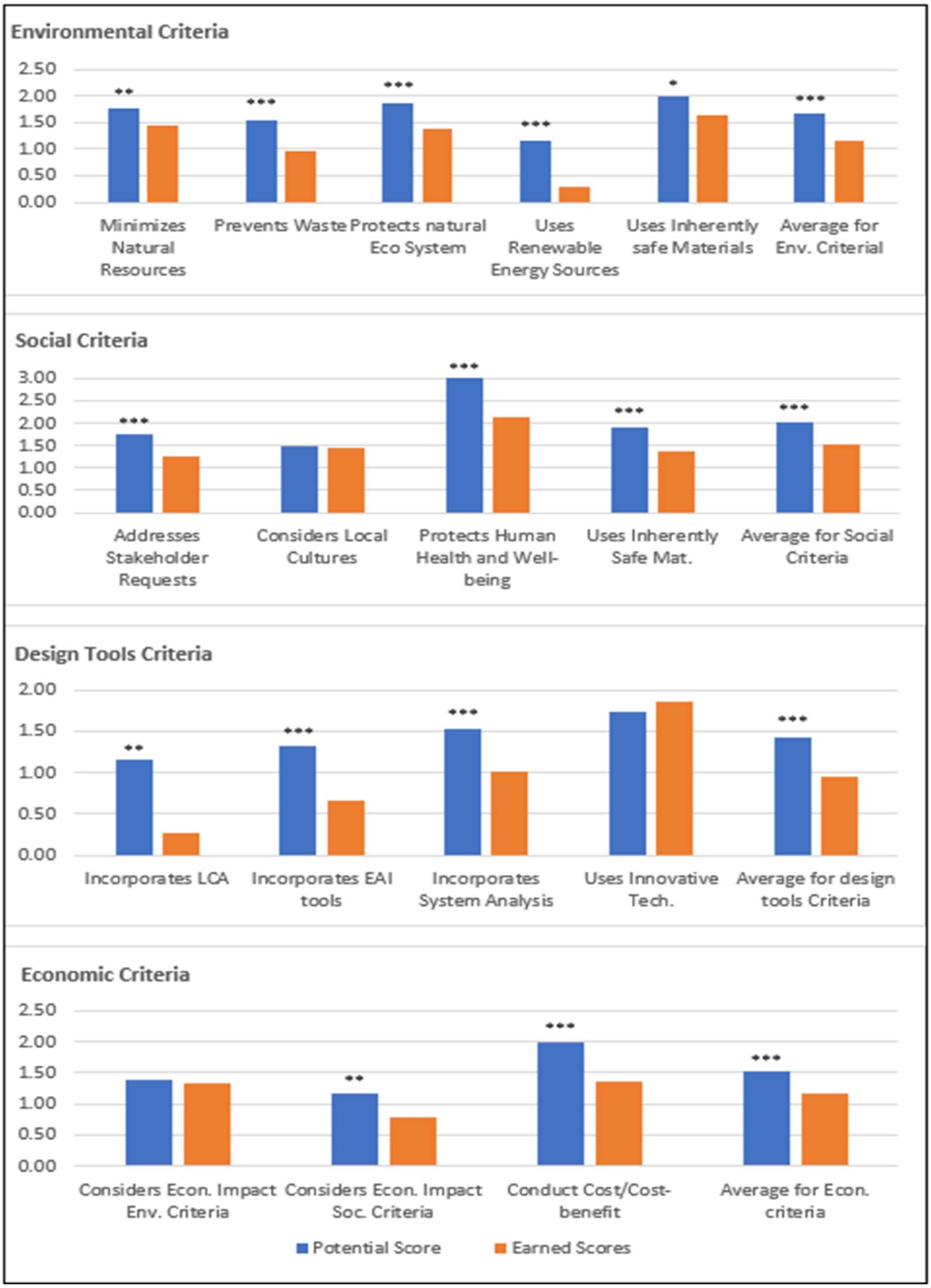

Figure 8. Comparison of Potential and Earned Scores (*p < 0.05; **p < 0.01, ***p < 0.001)

4.4 Thematic Analysis of Interview Data on Improving Sustainability in Capstone Projects

Table 3 presents a thematic analysis of the interview responses, categorizing findings into key themes, response frequency, and illustrative responses.

Table 3: Thematic Analysis of Interview Responses

Theme	Key Findings	Frequency (%)	Illustrative Responses
Current Practices for Integrating Sustainability	Application of sustainability principles in projects	9 out of 11 (82%)	"I have applied environmental sustainability principles in my projects."
	Most applied sustainability principles	Environmental (55%), Economic (27%)	"I focused on using cost-effective and sustainable materials."
	Inclusion of sustainability in the curriculum	3 out of 11 (27%)	"Sustainability is mentioned, but not well integrated into the curriculum."
	Suggested improvements	6 out of 11 (55%)	"More hands-on sustainability activities would improve understanding."
Challenges in Applying Sustainability Principles	Limited access to real-world projects	High	"We don't have enough real projects to apply what we learn."
	Insufficient design data availability	Medium	"It's difficult to find relevant sustainability data for designs."
	Knowledge gaps in sustainability principles	High	"Many students lack a clear understanding of sustainability concepts."
	Difficulty in translating concepts into real-world applications	High	"Applying sustainability in real projects, especially climate adaptation, is challenging."
	Financial constraints and industry mismatch	Medium	"Sustainability measures can be expensive, and industry expectations don't always align."
	Limited access to advanced tools and funding	Medium	"We need better access to innovative materials like self-healing concrete."
Recommendations for Enhancing Sustainability Integration	Workshops, seminars, and conferences	High	"Organizing awareness workshops will increase interest in sustainability."
	Hands-on teaching methods and interactive learning	High	"Engaging activities and simulations would make sustainability learning more effective."
	Case studies, field visits, and practical exercises	High	"Exposure to real-world sustainability practices is essential."
	Industry collaborations and extended internships	Low	"Partnering with sustainability-driven companies would enhance learning."
	Opportunities for sustainability conferences	High	"Attending conferences would expand our knowledge on global sustainability trends."

	Student exchange programs	Low	"International exposure would help in understanding global sustainability practices."
	Use of visual simulations and technological tools	Low	"Advanced simulations can demonstrate sustainability concepts effectively."

4.5 Pedagogical Approaches for Integrating Sustainability into the School Curriculum

From literatures reviewed, six pedagogical approaches were identified in Table 4 for integrating sustainability into the school curriculum. Each approach emphasizes a unique method for enhancing student engagement and comprehension of sustainability concepts.

Table 4: 6-Pedagogical Approach of Integrating Sustainability into School Curriculum

Pedagogical Approach	Description	Source
Project-Based Learning (PBL)	Assigning projects that address real-world sustainability challenges through collaboration with local industries or organizations to develop innovative solutions.	[13]
Active Learning	Uses interactive teaching methods, replacing traditional lectures with discussion-based learning to enhance student engagement and creative problem-solving in sustainability.	[14]
Scaffolded Learning	Large-scale sustainability projects are broken into smaller milestones with specific goals. Students receive guidance and feedback to improve outcomes progressively.	[15]
Community Engagement	Service-learning projects immerse students in addressing local sustainability issues, fostering accountability and demonstrating real-world impact.	[16]
Peer Review and Collaboration	Students evaluate each other's sustainability projects using a rubric, encouraging collaborative problem-solving and diverse learning perspectives.	[17]
Resources and Incentives	Providing access to sustainability-focused databases, tools, and mentorship to empower students in developing innovative and high-quality sustainable designs.	[18]

5. DISCUSSION

The integration of sustainability principles into Civil Engineering capstone projects presents significant opportunities for enhancing students' competencies in sustainable design. However, findings from this study (Fig. 8) reveal notable gaps between potential and earned scores across various sustainability rubrics, emphasizing the need for stronger pedagogical interventions to bridge this divide.

5.1 Environmental Criteria

In the environmental sustainability category, students demonstrated the greatest deficiencies in criteria such as "Uses Renewable Energy Sources" and "Uses Inherently Safe Materials," with earned scores significantly lower than potential scores ($p < 0.001$). These gaps suggest that while students recognize the theoretical importance of renewable energy and safe materials, they face challenges in effectively applying these principles in their projects. On average, the environmental criteria earned score of 1.15 falls short of the potential score of 1.68, emphasizing the need for enhanced guidance and resources to bridge this gap.

To address this, Project-Based Learning (PBL) is recommended, allowing students to engage with industry-sponsored projects to apply sustainability concepts in practical scenarios. [13]. Additionally, active learning strategies such as sustainability-focused workshops and seminars can equip students with the necessary skills to overcome these barriers [14].

5.2 Social Criteria

Findings in the social sustainability category were mixed. While students met or exceeded expectations in "Considers Local Cultures" ($p > 0.05$), deficiencies were noted in "Protects Human Health and Well-being" and "Uses Inherently Safe Materials." The highest performance was recorded in "Addresses Stakeholder Requests," where earned scores significantly exceeded potential scores ($p < 0.01$), indicating strong student engagement with stakeholder needs.

To address these challenges, community engagement initiatives could be integrated into the curriculum, where students directly address local sustainability issues in service-learning projects [16]. This would allow students to not only engage with stakeholders but also gain a deeper understanding of the social dimensions of sustainability, such as health, safety, and well-being, through direct interaction with communities.

5.3 Design Tools Criteria

Performance in the design tools category revealed notable deficiencies, particularly in "Incorporates LCA" (Life Cycle Assessment) and "Incorporates EIA Tools" (Environmental Impact Assessment Tools), with $p < 0.05$ and $p < 0.001$, respectively. Despite these gaps, students excelled in "Uses Innovative Technology," achieving earned scores comparable to potential scores ($p > 0.05$). This suggests that while students are open to adopting new technologies, they may lack familiarity with specific sustainability assessment tools, which are critical for informed decision-making in sustainable design.

To overcome these issues, institutions should expand resource availability, such as providing students with access to sustainability-focused databases, tools, and mentorship [18]. Collaborations with industries and research institutions can also facilitate hands-on exposure to sustainability assessment tools like LCA and EIA, ensuring students are well-equipped to integrate them into their projects [17].

5.4 Economic Criteria

Economic sustainability showed one of the most significant gaps, particularly in "Conducts Cost/Cost-Benefit Analysis," where the earned score of 1.00 was significantly lower than the potential score of 2.00 ($p < 0.001$). However, students performed relatively well in "Considers Economic Impact on Social Criteria" ($p > 0.05$), indicating moderate awareness of the intersection between social and economic sustainability.

Scaffolded learning approaches can address this challenge by breaking capstone projects into smaller, manageable milestones, incorporating step-by-step economic evaluations, and reinforcing cost-benefit analysis throughout the design process [15].

5.5 Thematic Analysis of the interview data

Findings from the thematic analysis (Table 3) indicate that while students recognize the importance of sustainability, they face significant barriers, including limited practical exposure, knowledge gaps, and resource constraints. Addressing these challenges requires targeted interventions such as enhanced industry partnerships, hands-on experiences, and innovative pedagogical strategies.

By integrating these recommendations, engineering programs particularly at HBCUs, can strengthen sustainability education and better prepare students for industry demands. Enhancing interdisciplinary collaborations, expanding experiential learning opportunities, and equipping students with advanced sustainability tools will ensure that graduates are well-prepared to implement sustainable engineering solutions effectively.

6. Conclusion

This study highlights the critical role of integrating sustainability principles into Civil Engineering capstone projects to equip students with the skills necessary for sustainable infrastructure development. Quantitative analysis revealed significant disparities between potential sustainability points (M_{pot}) and actual earned points (M_{earn}) across multiple criteria, indicating that students struggled to fully integrate sustainability into their projects. While stakeholder engagement and the use of innovative technologies were strengths, notable gaps existed in the incorporation of sustainability assessment tools, renewable energy solutions, and economic evaluations. Paired t-tests confirmed these gaps were statistically significant ($p < 0.05$), reinforcing the need for structured interventions to enhance sustainability integration.

To address these challenges, a multifaceted approach is recommended, including curricular enhancements through dedicated modules on sustainability assessment, renewable energy integration, and cost-benefit analysis; faculty development via targeted training and resources; and practical exposure through real-world case studies, service-learning projects, field visits, and industry collaborations. Additionally, ensuring access to advanced resources—such as cutting-edge materials, tools, and databases—will enhance project innovation, while global learning opportunities and financial support, including student exchange programs and international workshops, will foster a more comprehensive and globally informed sustainability education.

These findings underscore the urgent need for structured sustainability education in capstone projects. Addressing the identified challenges through curriculum enhancements, practical exposure, faculty support, and industry collaboration will significantly improve sustainability ratings in student projects. Future research should explore the role of faculty and industry stakeholders in fostering sustainability education and assess the long-term impact of these strategies on student learning outcomes.

By implementing these strategies, institutions, particularly Historically Black Colleges and Universities (HBCUs), can better prepare Civil Engineering students to address the complexities of sustainable design. These efforts will not only enhance the quality of capstone projects but also cultivate a new generation of graduates equipped to lead advancements in sustainable infrastructure practices globally.

REFERENCES:

[1] Z. Ye, H. Majlesein, P. Bhattacharya, and H. Mohamadian, "Disseminating sustainability concept for engineering education via typical control-oriented engineering applications," in *Proc. 2006 ASEE Gulf-Southwest Annual Conf.*, Southern University and A&M College, 2006.

[2] M. Khan and C. McNally, "A holistic review on the contribution of civil engineers for driving sustainable concrete construction in the built environment," *Developments in the Built Environment*, vol. 16, p. 100273, 2023. doi: 10.1016/j.dibe.2023.100273.

[3] C. J. Kibert, *Sustainable Construction: Green Building Design and Delivery*, 4th ed. Hoboken, NJ, USA: John Wiley & Sons, 2016.

[4] L. R. Brunell, A. Dubro, and V. V. Rokade, "Assessing the sustainability components of engineering capstone projects," in *Proc. 2021 ASEE Annual Conf.*, Virtual Meeting, Jul. 26-29, 2021, Paper ID #33977. [Online]. Available: https://peer.asee.org/assessing-the-sustainability-components-of-engineering-capstone-projects.

[5] Accreditation Board for Engineering and Technology, "Criteria for accrediting engineering programs: 2021–2022," Dec. 30, 2024. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2021-2022/. [Accessed: Dec. 30, 2024].

[6] W. J. Popham, "What's wrong—and what's right—with rubrics," *Educ. Leadership*, vol. 55, pp. 72-75, 1997.

[7] M. K. Watson, E. Barrella, T. A. Wall, C. Noyes, and M. O. Rodgers, "A rubric to analyze student abilities to engage in sustainable design," *Adv. Eng. Educ.*, vol. 6, no. 1, pp. 1–27, 2017. [Online]. Available: https://eric.ed.gov/?id=EJ1138862.

[8] A. R. Bielefeldt, "Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students," *Sustainability*, vol. 5, no. 10, pp. 4479-4501, 2013, doi: 10.3390/su5104479

[9] C. L. Dancz et al., "Utilizing Civil Engineering Senior Design Capstone Projects to Evaluate Students' Sustainability Education across Engineering Curriculum," *Adv. Eng. Educ.*, vol. 6, no. 2, n2, 2017.

[10] H. G. Andrade, "Using rubrics to promote thinking and learning," *Educ. Leadership*, vol. 57, no. 5, pp. 13-19, 2000.

[11] P. Ralston and C. Bays, "Refining a critical thinking rubric for engineering," paper presented at the *Am. Soc. Eng. Educ.*, Vancouver, BC, 2010.

[12] M. A. Abraham, *Principles of Sustainable Engineering: Sustainability Science and Engineering: Defining Principles*, pp. 3-10, Elsevier, B.V., Amsterdam, The Netherlands, 2006.

[13] T. Brown, "Design Thinking and Project-Based Learning (DT-PBL): A review of the literature," *ResearchGate*, 2023. [Online]. Available: https://www.researchgate.net/publication/373702631_Design_Thinking_and_Project-Based_Learning_DT-PBL_A_Review_of_the_Literature

[14] A. H. Benson and E. W. Jordan, "Active learning and sustainability education: Strategies for impactful teaching," *Nature Humanities and Social Sciences Communications*, vol. 9, 2024. [Online]. Available: https://www.nature.com/articles/s41599-024-02813-z

[15] L. Willard, D. Kim, and C. Johnson, "Building sustainability research competencies for graduate students," *Elementa: Science of the Anthropocene*, vol. 11, no. 1, 2023. [Online]. Available: https://online.ucpress.edu/elementa/article/11/1/00091/196199/Building-sustainability-research-competencies

[16] L. R. Bennett, C. B. Smith, and R. N. Taylor, "Service-learning and community engagement for sustainable engineering education," *SAGE Open*, vol. 11, no. 2, pp. 1–15, 2023. [Online]. Available: https://journals.sagepub.com/doi/full/10.1177/2158244020938702

[17] A. C. Sherman and J. Peterson, "Sustainability-focused project-based learning in a heat transfer course," *ASEE Annual Conference Proceedings*, June 2018. [Online]. Available: https://peer.asee.org/sustainability-focused-project-based-learning-in-a-heat-transfer-course.pdf

[18] Filho, W.L., Trevisan, L.V., Dinis, M.A.P. et al. “Fostering students’ participation in the implementation of the sustainable development goals at higher education institutions. Discov Sustain 5, 22 (2024). https://doi.org/10.1007/s43621-024-00204-7