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Assessing Civil Engineering Students' Knowledge and Perception towards Sustainable Infrastructure Development at an HBCU

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Assessing Civil Engineering Graduate Students' Knowledge and Perception Towards Sustainable Infrastructure Development at an HBCU

Abstract

In advancing sustainable development to achieve long-term environmental and societal goals, civil engineers play a critical role. To address future sustainability challenges, civil engineering education must be designed to equip students with the necessary knowledge and skills. This study investigates the sustainability knowledge and perceptions of graduate students at a Historically Black College and University (HBCU), focusing on four key sustainability categories: environmental, social, design tools, and economic criteria. The results reveal significant strengths in environmental and social sustainability, as students exhibited a strong understanding of waste prevention, renewable energy, stakeholder engagement, and human health protection. However, weaknesses were identified in areas requiring advanced analytical skills and economic sustainability, such as Life Cycle Analysis (LCA), Environmental Assessment and Impact (EAI), system analysis, and cost-benefit analysis. These gaps suggest the need for a more comprehensive integration of advanced sustainability methodologies and economic principles into the curriculum. The study recommends enhancing sustainability education through experiential learning, interdisciplinary collaboration, and industry exposure to equip students with a well-rounded skill set for addressing global sustainability challenges. While this study provides valuable insights into student knowledge and perceptions, future research should explore the roles of faculty and industry professionals in shaping sustainability education, examining the impact of faculty training, industry partnerships, and professional mentorship on student learning outcomes.

Keywords: *Sustainable development, perception, civil engineering education, sustainable infrastructure, sustainability assessment tools, Historically Black College and University (HBCU)*

1. Introduction

Civil engineers are pivotal in advancing sustainable development to achieve long-term environmental, social, and economic goals. The American Society of Civil Engineers (ASCE) emphasizes that civil engineers play a key role in addressing sustainability challenges by incorporating innovative solutions that balance societal needs with environmental preservation [1]. As the world faces increasingly complex challenges related to climate change, resource depletion, and urbanization, the demand for sustainable infrastructure has never been more urgent. Civil engineers are uniquely positioned to design, construct, and maintain systems that not only meet the immediate needs of society but also contribute to the long-term health of the environment and communities [2]. Given this responsibility, civil engineering education must equip future professionals with the necessary knowledge and skills to navigate the complexities of sustainable infrastructure development.

Research by Gopichandran et al. demonstrates that integrating sustainability principles into civil engineering curricula significantly enhances students' preparedness for addressing these global challenges [9]. Sustainability in civil engineering encompasses environmental, social, and economic dimensions, collectively referred to as the "triple bottom line." The environmental dimension addresses resource efficiency, pollution reduction, and ecosystem preservation; the social dimension focuses on community impact, public health, and equitable access to resources;

and the economic dimension emphasizes long-term cost-effectiveness and resilience. The importance of embedding sustainability principles in civil engineering curricula is clear, yet research shows that sustainability education has often been insufficiently integrated into traditional engineering programs [10]. This gap is especially significant in Historically Black Colleges and Universities (HBCUs), where culturally responsive approaches to sustainability education are essential for addressing the unique infrastructure needs of underrepresented communities.

This study aims to assess civil engineering graduate students' knowledge and perceptions of sustainable infrastructure development at an HBCU. The research will present the findings of the Evaluation in which sustainability principles are embedded in the institution's curriculum and faculty initiatives, and it will explore the barriers and motivators influencing students' engagement with sustainable practices. This study's findings will provide critical insights into how HBCUs can better prepare students to address the pressing sustainability challenges in civil engineering.

Research Objectives:

i. To Determine the level of knowledge of sustainability among graduate civil engineering students.
ii. To explore the perceived barriers and motivators influencing graduate students' engagement with sustainable infrastructure practices.

2. Literature Review

Sustainability is a critical component of modern engineering education, emphasizing the role of engineers in addressing global environmental, social, and economic challenges. Universities act as "living laboratories" where sustainability principles are integrated into campus operations, curricula, and extracurricular activities [3], [4]. While global studies demonstrate that embedding sustainability into engineering education enhances knowledge and practical application, challenges remain in aligning institutional strategies with student interests [3]. Research highlights the need for culturally responsive approaches, particularly at Historically Black Colleges and Universities (HBCUs), to make sustainability education relevant and impactful [5].

Studies show that embedding sustainability into engineering curricula significantly improves student awareness and engagement [4]. Examples from India and Lebanon reveal that non-credit courses and structured programs can enhance sustainability literacy, though institutional efforts are often perceived as insufficient [4], [5]. Additionally, gender and disciplinary differences significantly shape students' perceptions, with female students and those in certain engineering fields demonstrating higher engagement levels [5]. These findings underscore the importance of targeted strategies to ensure inclusivity and equal representation across demographics [3].

Despite awareness of sustainability principles and the Sustainable Development Goals (SDGs), commitment gaps persist among students [3], [5]. Poor promotion of sustainability initiatives and insufficient faculty involvement hinder deeper engagement [5]. Addressing these issues requires effective communication, faculty-student collaboration, and the inclusion of local case studies [4]. Such strategies not only enhance curriculum design but also position HBCUs as leaders in sustainable engineering education, equipping students to tackle the complexities of sustainable infrastructure development in their communities and beyond.

While existing literature provides insight into sustainability education in civil engineering, there remains a lack of research specifically exploring the perceptions and knowledge of sustainability among graduate students at HBCUs. This gap in the literature underscores the need for this study, which aims to evaluate how these students engage with sustainable infrastructure practices.

3. Methodology

This study employs a mixed-method research design to assess civil engineering graduate students' knowledge and perceptions toward sustainable infrastructure development at an HBCU. The research incorporates quantitative and qualitative data collection techniques to provide comprehensive insights.

3.1 Quantitative Analysis

A structured survey instrument, the Sustainability Awareness Questionnaire (SAQ), will be distributed to graduate civil engineering students. The SAQ is designed to evaluate three core dimensions:

i. Knowledge of sustainable infrastructure principles: Participants will respond to questions assessing their familiarity with sustainability concepts and practices.

ii. Perceptions of sustainability's importance: Students will rate the significance of environmental, social, and economic sustainability in civil engineering.

iii. Awareness of industry practices: The survey includes items to measure participants' understanding of current sustainable practices in the civil engineering field.

The responses were collected, and the data were analyzed using Microsoft Excel to generate descriptive statistics, and correlations, and identify potential trends.

3.2 Qualitative Analysis

To complement the quantitative data, semi-structured interviews were conducted with faculty members to explore their perspectives on embedding sustainability principles into the curriculum. The interview questions covered:

- Current efforts to integrate sustainability into civil engineering courses.
- Challenges and barriers in promoting sustainability education.
- Recommendations for enhancing student engagement with sustainable practices.

The qualitative data underwent thematic analysis to identify recurring patterns and insights.

4. Results

4.1 Sample Demographics

The study comprised a total sample size of 17 participants (N = 17). Table 1 highlights the demographic characteristics of the respondents, including their gender and level of education within the Civil Engineering Department. Approximately 88% of the participants were male, while 12% were female. This higher male participation reflects the actual distribution of registered students, where the number of male graduate students in Civil Engineering significantly exceeds that of female graduate students.

Table 1: Demographic Characteristics of the Sample (N = 17)

Characteristics		Frequency	Percentage
Gender	Male	15	88%
	Female	2	12%
Level of Education	Masters	3	18%
	PhD	14	82%

4.2 Measuring Students' Knowledge and Perception

Pre-Test and Post-Test Analysis

Table 2 compares the pre-test and post-test analysis of students' self-reported personal ratings of their sustainability knowledge and perception with their actual performance on the sustainability knowledge and perception test. The ratings are categorized on a scale from 1 to 5, with 5 representing the highest level of knowledge and 1 the lowest.

Pre-Test Analysis:

When students were asked to rate their knowledge of sustainability, 5 respondents (29% of the sample) rated themselves as 5, indicating very high knowledge. Similarly, another 5 respondents (29%) rated themselves as 4, denoting high knowledge. Six respondents (35%) rated their knowledge as moderate (3), while only 1 respondent (6%) indicated very low knowledge by rating themselves as 1. Notably, no respondents rated their knowledge as low (2) (Table 1).

Post-Test Analysis:

After the test, a notable shift in ratings was observed, with a higher proportion of students falling into the lower rating categories. While 35% and 29% of students earned scores corresponding to ratings of 3 and 4, respectively, similar to the pre-test, 24% of students fell within the 1.5–2.5 range, and 6% scored below 1.5. This suggests a decrease in perceived understanding after completing the test.

Table 2: Sustainability Knowledge and Perception Rating Among HBCU Graduate Students

Respondents Personal Ratings	Pre-Test Analysis		Respondents Actual Scores	Post-Test Analysis	
	Frequency	Percentage		Frequency	Percentage
Rated 5 (Very High)	5	29%	4.5 - 5	1	6%
Rated 4 (High)	5	29%	3.5 - 4.5	5	29%
Rated 3 (Moderate)	6	35%	2.5 - 3.5	6	35%
Rated 2 (Low)	0	0%	1.5 - 2.5	4	24%
Rated 1 (Very Low)	1	6%	<1.5	1	6%

Table 3 presents a detailed breakdown of responses to the Sustainability Awareness Questionnaire completed by 17 graduate students. The questionnaire was designed to assess the participants' understanding of core sustainability principles within the context of civil engineering, including stakeholder engagement, cultural sensitivity, public health, environmentally safe materials, resource efficiency, waste reduction, and ecosystem preservation. The most appropriate or correct answers to each question are highlighted in bold for clarity.

Table 3: Breakdown of the Scores from the Sustainability Awareness Questionnaires (n = 17)

Sustainability Awareness Questions	**Freq.**	**%**
1. Which of the following strategies best ensures that civil engineering projects address community and stakeholder needs?		
a. Relying solely on expert opinions for design decisions.	0	0%
b. Conducting comprehensive stakeholder engagement and incorporating their feedback.	16	**94%**
c. None of the above	0	0%
d. Don't know.	1	6%
2. How can civil engineering projects effectively integrate local cultural factors?		
a. By standardizing designs globally to ensure consistency.	4	24%
b. By consulting with local experts and incorporating cultural practices into designs.	13	**76%**
c. None of the above	0	0%
d. Don't know.	0	0%
3. In what way do civil engineering projects most directly impact human health?		
a. By influencing access to clean water, air quality, and safety standards.	14	**82%**
b. By reducing construction costs.	1	6%
c. None of the above	1	6%
d. Don't know.	1	6%
4. Why is it important to use safe and environmentally benign materials in civil engineering projects?		
a. No idea	1	6%
b. To reduce project costs.	0	0%
c. To simplify supply chain logistics.	1	6%
d. To minimize environmental hazards and ensure public safety.	15	**88%**
5. What design strategies can minimize the depletion of natural resources during construction?		
a. Using recycled construction materials	15	**88%**
b. Encouraging single-use materials	0	0%
c. Over-extraction of local materials	0	0%
d. Don't know	2	12%
6. How can construction waste be effectively minimized in a civil engineering project?		
a. Implementing a recycling and reuse plan for materials	17	**100%**
b. Disposing of all waste in landfills	0	0%
c. Burning waste materials on-site	0	0%
d. Don't know	0	0%

Sustainability Awareness Questions	Freq.	%
7. How can civil engineers protect natural ecosystems during project development?		
a. Mitigating erosion during project development	5	29%
b. Designing with minimal land disturbance	2	12%
c. All of the above	**9**	**53%**
d. Don't know	1	6%
8. Which renewable energy source is most practical for infrastructure projects?		
a. Solar power integrated into building designs	**16**	**94%**
b. Generators running on fossil fuels	0	0%
c. Ignoring energy sources in the project	0	0%
d. Don't know	1	6%
9. What types of materials are considered environmentally safe in construction?		
a. Cheap, non-durable materials with no environmental consideration	1	6%
b. Materials with high environmental degradation potential	2	12%
c. Non-toxic, recyclable, and locally sourced materials	**13**	**76%**
d. Don't know	1	6%
10. Life cycle analysis evaluates a project's environmental impacts from material extraction to disposal.		
a. Strongly Agree	6	**35%**
b. Agree	6	35%
c. Neutral	4	24%
d. Disagree	1	6%
e. Strongly Disagree	0	0%
11. Environmental impact assessments evaluate project outcomes after completion.		
a. Strongly Agree	2	12%
b. Agree	9	53%
c. Neutral	2	12%
d. Disagree	1	6%
e. Strongly Disagree	3	**18%**
12. Systems analysis identifies opportunities for efficiency and resource optimization across systems.		
a. Strongly Agree	7	**41%**
b. Agree	6	35%
c. Neutral	3	18%
d. Disagree	1	6%
e. Strongly Disagree	0	0%
13. Smart technologies enable real-time monitoring of resource use and energy consumption.		
a. Strongly Agree	11	**65%**
b. Agree	4	24%
c. Neutral	2	12%
d. Disagree	0	0%
e. Strongly Disagree	0	0%

Sustainability Awareness Questions	Freq.	%
14. Incorporating renewable energy, such as solar panels, into design is an economically sustainable practice.		
a. Strongly Agree	10	**59%**
b. Agree	2	12%
c. Neutral	5	29%
d. Disagree	0	0%
e. Strongly Disagree	0	0%
15. Social sustainability focuses on minimizing project costs alone.		
a. Strongly Agree	1	6%
b. Agree	4	24%
c. Neutral	6	35%
d. Disagree	3	18%
e. Strongly Disagree	3	**18%**
16. Cost-benefit analysis is an essential tool for evaluating a civil engineering project.		
a. Strongly Agree	9	**53%**
b. Agree	4	24%
c. Neutral	3	18%
d. Disagree	1	6%
e. Strongly Disagree	0	0%

4.3 Analysis of Performance on Sustainable Design Criteria

Table 4 highlights a mixed performance across 16 sustainable design criteria assessed among 17 graduate students from an HBCU. While some criteria indicate strong understanding and application, others reveal notable gaps in knowledge and implementation.

Observations:

- Strong Areas: Students demonstrated excellent performance in criteria such as "Prevents Waste" (100%), "Uses Renewable Energy Sources" (94%), and "Addresses Stakeholder Requests" (94%). These results indicate a solid grasp of core sustainability practices and stakeholder-focused approaches.
- Moderate Areas: Criteria like "Minimizes Natural Resources" (88%), "Protects Human Health" (82%), and "Considers Local Cultures" (76%) show moderate understanding, suggesting areas for potential enhancement.
- Weak Areas: Significant gaps were observed in advanced and technical aspects of sustainability, including "Incorporates LCA" (35%), "Incorporates EAI Tools" (18%), and "Considers Economic Impact on Social Criteria" (18%). These findings highlight the need for targeted educational efforts in these domains to build a comprehensive understanding of sustainable design.

Table 4: Performance on the 16 Sustainable Design Criteria (N = 17).

S/N	Sustainable Design Criteria	Earned Scores
1	Minimizes Natural Resources	88%
2	Prevents Waste	100%
3	Protects natural Eco System	53%
4	Uses Renewable Energy Sources	94%
5	Uses Inherently safe Materials to Env.	88%
6	Addresses Stakeholder Requests	94%
7	Considers Local Cultures	76%
8	Protects Human Health	82%
9	Uses Inherently Safe Mat. to humans	76%
10	Incorporates LCA	35%
11	Incorporates EAI tools	18%
12	Incorporates System Analysis	41%
13	Uses Innovative Tech.	65%
14	Considers Econ. Impact Env. Criteria	59%
15	Considers Econ. Impact Soc. Criteria	18%
16	Conduct Cost/Cost-benefit	53%

4.4 Analysis of Sustainability Performance Across the Four Design Criteria

The graphs in Figure 1 reveal a mixed performance across four sustainability categories: Environmental, Social, Design Tool, and Economic. While certain areas exhibit strong understanding and application, others expose significant gaps in knowledge or implementation.

4.4.1 Strengths:

Environmental Criteria: The students demonstrate a strong understanding of several core environmental sustainability principles. "Prevents Waste" (100%) and "Uses Renewable Energy Sources" (94%) show exceptional performance, indicating a good grasp of these concepts. Additionally, "Minimizes Natural Resources" (88%) and "Uses Inherently Safe Materials to Environment" (88%) indicate a good level of competency.

Social Criteria: High scores in "Addresses Stakeholder Requests" (94%) and "Protects Human Health" (82%) reveal a good understanding of social considerations in sustainability practices.

4.4.2 Weaknesses:

Environmental Criteria: A significant weakness lies in "Protects Natural Eco System" (53%), indicating a limited understanding of environmental impact mitigation and ecosystem preservation.

Design Tool Criteria: Criteria related to advanced sustainability tools and analysis, such as "Incorporates LCA" (35%), "Incorporates EAI Tools" (18%), and "Incorporates System Analysis" (41%), suggest limited familiarity or application of these essential design tools.

Economic Criteria: Performance in economic sustainability is relatively weaker. Scores for "Considers Economic Impact on Environmental Criteria" (59%), "Considers Economic Impact on Social Criteria" (18%), and "Conduct Cost/Cost-benefit" (53%), are low. This suggests a need for greater focus on the economic dimensions of sustainability.

Overall, the results highlight a need for a more comprehensive approach to sustainability education that goes beyond just environmental considerations to encompass social, economic, and technological aspects.

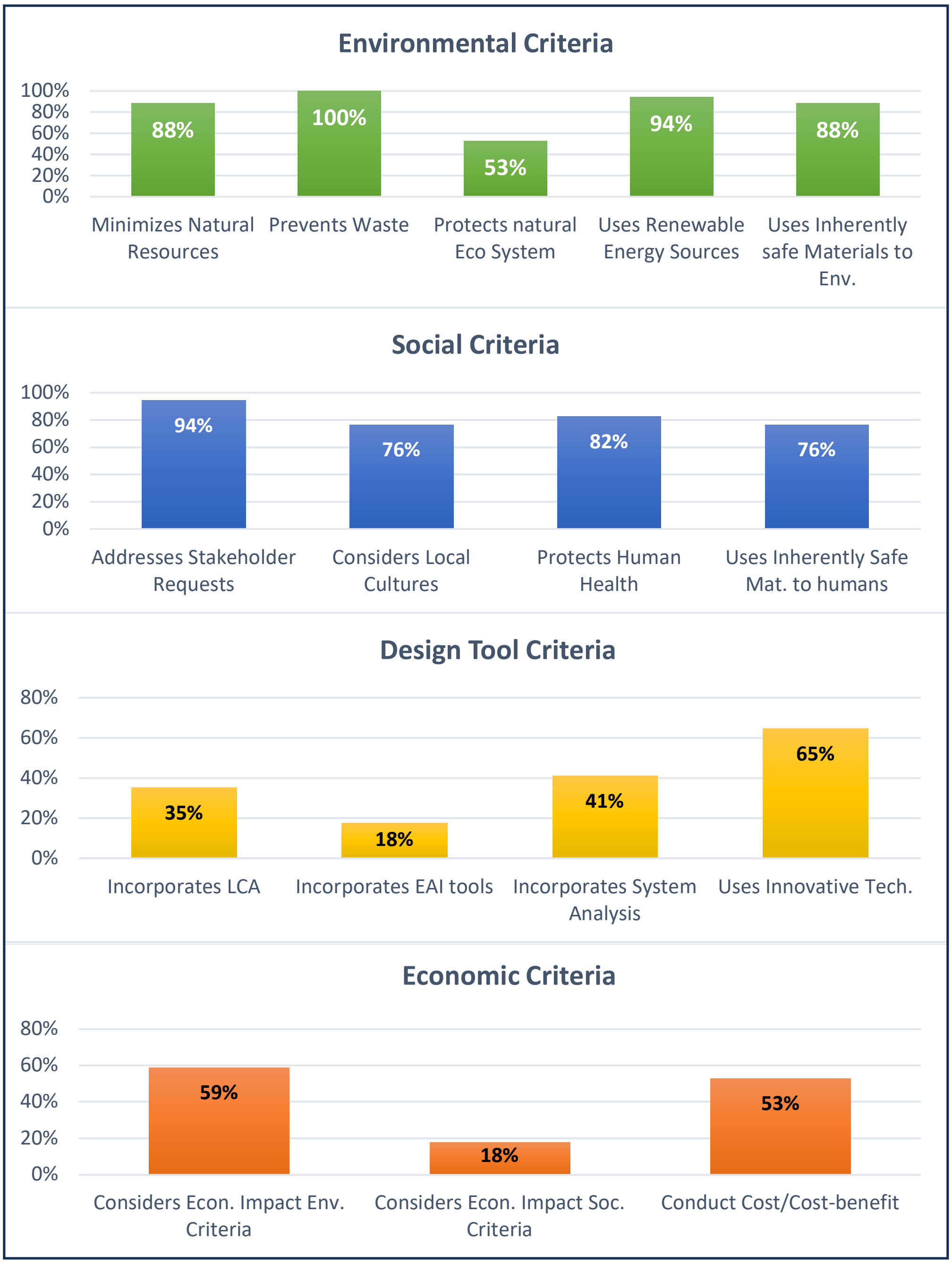

Figure 1. Graph showing the Four Sustainability Design Categories

4.5 Perceived Barriers and Motivators Influencing Graduate Students' Engagement with Sustainable Infrastructure Practices: Insights from Semi-Structured Interviews

This section examines the integration of sustainability into civil engineering education, the challenges faced, and recommendations for improvement based on insights gathered from semi-structured interviews.

4.5.1 Current Integration Efforts:

Respondents identified several current efforts to integrate sustainability into civil engineering curricula:

i. Integrating sustainability-focused modules or topics into existing courses, covering areas such as environmental impact assessment, sustainable materials, and green infrastructure design.

ii. Offering specialized courses or electives dedicated to sustainability in civil engineering, such as courses on sustainable infrastructure design or life cycle analysis.

iii. Establishing partnerships with industry professionals and researchers to provide guest lectures, real-world case studies, and exposure to current sustainable engineering practices.

4.5.2 Challenges and Barriers:

Several key barriers to promoting and integrating sustainability education in civil engineering were identified:

i. Lack of comprehensive curriculum integration of sustainability principles across all relevant courses.

ii. Limited opportunities for practical application of sustainability concepts.

iii. Insufficient student motivation or awareness regarding sustainability.

iv. Limited collaboration with industry partners on sustainability-focused projects.

v. Inadequate funding to support sustainability initiatives within the department or university.

4.6 Recommendations for Enhanced Student Engagement:

Respondents offered several recommendations to enhance student engagement with sustainable practices in civil engineering education:

i. Integrate experiential learning opportunities, including real-world projects and sustainability-focused assignments, to bridge the gap between theory and practice.

ii. Adopt hands-on teaching methods, such as interactive classroom activities and practical exercises, to promote active student participation.

iii. Establish stronger industry collaborations with organizations specializing in sustainability, including extended internship opportunities to provide meaningful practical experience.

iv. Introduce student exchange programs to expose students to global sustainability practices and innovations.

v. Provide training in industry-standard tools, such as Life Cycle Analysis (LCA), Environmental Impact Assessment (EIA), and relevant simulation software, to enhance practical skills and technical competence.

5. Discussion

The findings of this study highlight both strengths and weaknesses in the sustainability knowledge and perception of graduate students at an HBCU. The analysis demonstrates commendable performance in some aspects of environmental and social sustainability, while also revealing critical gaps in understanding and application, particularly in the economic and design tool criteria.

5.1 Strengths in Sustainability Knowledge

The high performance in environmental criteria such as "Prevents Waste" (100%) and "Uses Renewable Energy Sources" (94%) aligns with findings in previous studies emphasizing the increasing awareness of waste prevention and renewable energy use among engineering students [11]. These results indicate that sustainability education at the institution has successfully conveyed foundational environmental principles. Similarly, the strong performance in addressing stakeholder requests (94%) and protecting human health (82%) suggests an appreciation of the social dimensions of sustainability, consistent with the emphasis on stakeholder engagement in sustainable engineering curricula [12].

5.2 Gaps in Knowledge and Application

Despite these strengths, there are notable deficiencies in areas requiring advanced analytical tools and economic considerations. The low scores for "Incorporates LCA" (35%), "Incorporates EAI Tools" (18%), and "Incorporates System Analysis" (41%) suggest limited familiarity with advanced sustainability assessment methods. This aligns with other studies reporting that graduate engineering students often lack exposure to life cycle analysis and systems thinking approaches in their training [13]. Such tools are essential for addressing the complexities of sustainable design, as they enable engineers to evaluate trade-offs and long-term impacts effectively.

Economic criteria also represent a critical area of weakness, with "Considers Economic Impact on Social Criteria" (18%) and "Conduct Cost/Cost-Benefit" (53%) scoring poorly. This deficiency indicates that economic sustainability, a pillar of the triple bottom line, is often underemphasized in engineering programs, as observed in prior studies [14]. Addressing this gap is vital because economic considerations are integral to ensuring the feasibility and scalability of sustainable solutions.

5.3 Recommendations for Curriculum Enhancement.

The results call for a more comprehensive approach to sustainability education. Incorporating experiential learning opportunities, such as case studies, workshops, and practical projects focused on life cycle assessment and cost-benefit analysis, could bridge the knowledge gaps observed in the design tool and economic criteria. Research has shown that integrating real-world problem-solving tasks into engineering curricula improves students' competency in applying theoretical knowledge to practical sustainability challenges [15].

Additionally, faculty development programs aimed at equipping instructors with the latest tools and methodologies in sustainability education could further enhance learning outcomes. Collaboration with industry experts and policymakers may also provide students with valuable insights into the socio-economic implications of sustainable design.

5.4 Broader Implications

The findings underscore the need for engineering programs at HBCUs and other institutions to adopt an interdisciplinary approach that integrates environmental, social, and economic dimensions of sustainability. Doing so not only prepares students for the multifaceted challenges of modern engineering but also positions them as leaders in promoting sustainable development goals (SDGs) [16].

6. Conclusion

This study provides valuable insights into the sustainability knowledge and perception of graduate students at a Historically Black College and University (HBCU), with a specific focus on four key categories: Environmental, Social, Design Tools, and Economic criteria. The findings reveal both commendable strengths and critical gaps that have significant implications for sustainability education.

Graduate students demonstrated a strong understanding of environmental and social sustainability principles, as evidenced by high scores in criteria such as waste prevention, renewable energy usage, addressing stakeholder requests, and protecting human health. These strengths highlight the effectiveness of current pedagogical approaches in instilling foundational sustainability concepts.

However, the study also identified notable weaknesses in areas requiring advanced analytical skills and economic considerations. Specifically, low performance in incorporating tools such as Life Cycle Analysis (LCA), Environmental Assessment and Impact (EAI), and System Analysis underscores a need to integrate these advanced methodologies into the curriculum. Furthermore, gaps in economic sustainability understanding, including cost-benefit analysis and economic impact criteria, suggest that this critical dimension of sustainability is underemphasized.

To address these shortcomings, it is recommended that engineering programs adopt a more holistic approach to sustainability education. This includes integrating experiential learning opportunities, interdisciplinary collaborations, and exposure to industry-standard tools and methodologies. Such efforts will equip students with the comprehensive skill set needed to address the complex and interconnected challenges of sustainable development.

Ultimately, this study underscores the importance of refining sustainability education to align with the growing demands of the modern engineering profession. By fostering a deeper understanding of all dimensions of sustainability; environmental, social, economic, and technological—HBCUs and similar institutions can position their graduates as leaders in advancing sustainable development goals (SDGs) and driving systemic change in the field of engineering.

Although this study offers critical insights into the knowledge and perceptions of civil engineering graduate students regarding sustainable infrastructure development, it overlooks the significant roles that faculty members and industry professionals play in shaping sustainability education.

Faculty are instrumental in developing and implementing curriculum content that integrates sustainability principles [9], while industry professionals provide real-world perspectives and practical applications that bridge the gap between theory and practice [10]. Future research should investigate how faculty engagement, interdisciplinary collaboration, and partnerships with industry experts can enhance the effectiveness of sustainability education. Such studies could explore strategies for faculty training, the integration of industry-standard tools and methodologies, and the impact of professional mentorship on student learning outcomes and preparedness for addressing sustainability challenges [15].

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