Faculty Perspectives on Teaching Sustainability in Civil and Construction Engineering Education in the United States

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Abstract

Despite the widely recognized necessity of integrating sustainability into Civil and Construction Engineering (CCE), curricula emphasized by accreditation and professional bodies (ABET, ASCE), a standardized and universally accepted definition of sustainable practice remains elusive within the discipline. This ambiguity complicates educational efforts and hinders students' ability to operationalize sustainability in future professional roles. This research addresses this gap by systematically examining the perceptions and teaching practices of CCE educators. Through a survey questionnaire distributed to CCE faculty members across U.S. universities, data was collected on the extent of sustainability integration, its perceived importance, and individual conceptualizations of the term. Analysis of the 64 completed faculty responses reveals a strong consensus (77% rating it as 'extremely' or 'very important') on the necessity of sustainability education, yet a notable portion (28%) reported not integrating it into their courses, indicating persistent challenges in curriculum adoption. Furthermore, while the majority (72%) integrate sustainability, the predominant method is interwoven throughout the curriculum (49%), suggesting a lack of dedicated, standardized course time. Crucially, content analysis of the faculty definitions synthesized eight emergent themes that collectively define sustainability within CCE. The most frequently cited themes were: Efficient Use of Resources (e.g., reuse, recycle), Minimizing Environmental Impacts, and the necessity of Balanced Integration of the Three Pillars (Social, Environmental, Economic). Other significant themes included Durability/Longevity and Life Cycle considerations. These findings transcend the general Brundtland definition, providing a disciplinary-specific conceptual foundation. This paper contributes a documented current state of sustainability teaching and offers a thematic framework for CCE, facilitating a more cohesive, integrated, and effective pedagogical approach for educating future engineers.

Keywords Sustainability education, Faculty perceptions, Civil engineering education

1. Introduction

The rapid pace of our contemporary, industrialized global society is outpacing the Earth's natural systems, leading to adverse outcomes such as climate change and energy shortage. Encompassing a holistic perspective, the integration of design for sustainability is emerging as a central driving force within the built environment, where substantial natural resources are consumed. Many scholars acknowledge the vital role of higher education in equipping students and the academic community with the professional skills and competencies necessary to address sustainability challenges effectively [1], [2], [3]. Sustainability education in civil and construction engineering (CCE) is particularly relevant as it addresses the complex interplay between human progress and the Earth's finite resources.

Similarly, many professional organizations such as American Society of Civil Engineers (ASCE), American Society of Engineering Education (ASEE), the Accreditation Board for Engineering and Technology (ABET) have emphasized sustainability education in their visions, body of knowledge, missions, and criteria, etc. In response to this issue, a wealth of literature reports the varied methods and case studies on the integration of sustainability in CCE programs [4]. However, there remains a limited understanding of how sustainability is currently taught across CCE programs, highlighting the need for more comprehensive research and standardized approaches to curriculum development in this critical area.

In CCE disciplines, while sustainability is universally accepted, a lack of definitional clarity creates ambiguity regarding what constitutes "sustainable" practices [5]. This issue is further complicated by the diverse subdisciplines within civil engineering, structural, geotechnical, environmental, transportation, and construction, which often lack a shared definition. For example, debates around waste management illustrate this ambiguity: some advocate for rigorous recycling, while others prioritize efficiency and cost-effectiveness, even if it generates more waste. Such varying interpretations complicate communication and hinder students' ability to integrate sustainability into their future work, emphasizing the necessity for a clear and holistic understanding of sustainability in CCE [6].

This research addresses the existing gap by capturing the perceptions of CCE educators regarding sustainability. Perceptions play a crucial role in shaping and refining definitions, particularly in the social sciences, where collective perspectives influence the meanings attributed to specific terms [7], [8]. Individual interpretations of sustainability, shaped by personal experiences, cultural backgrounds, and political viewpoints, collectively contribute to a nuanced understanding of the concept. Although substantial research explores engineering students' perceptions of sustainability, there is a notable lack of studies focusing on faculty perspectives [9]. Given that CCE educators significantly influence students and their future professional practices, understanding faculty perceptions is crucial.

This research seeks to elucidate how sustainability is taught in CCE programs by systematically collecting and analyzing the perceptions of 64 civil engineering faculty members from various U.S. universities. Through this analysis, the study aims to identify the key themes of sustainability that are emphasized in CCE programs, reflecting the unique perspectives of CCE scholars and practitioners. This objective is pursued through the following goals:

- examine the current extent and approaches of sustainability teaching within CCE programs in the U.S.
- investigate CCE educators' perceptions of the importance and relevance of sustainability integration in their teaching.
- synthesize the conceptual foundations and definitions of sustainability as collectively understood by CCE educators.

- Identify key barriers and opportunities influencing the effective integration of sustainability from the faculty perspective.

The main contributions of this article are twofold. First, it documents the current state of sustainability teaching, offering insights that complement traditional curriculum analyses. By examining how sustainability is taught across diverse U.S. universities, this study reveals a broader and more nuanced perspective on sustainability education. Second, it extends prior work by identifying eight emergent themes essential for understanding sustainability in CCE disciplines, offering opportunities for further refinement and operationalization. These findings will facilitate constructive discourse on the meaning of sustainability within CCE, contributing to a more cohesive understanding of how sustainability is imparted to future engineers and supporting more effective and integrated sustainability education within CCE disciplines.

2. Literature review

In the survey conducted by Murphy et al. [10] found that more than half of the top 100 US universities reported some level of course activity related to sustainability. In the same study, the authors outlined four primary pedagogical approaches in sustainability teaching for engineering students: offering standalone courses that focus exclusively on sustainability engineering, integrating sustainability principles into traditional engineering curricula, emphasizing technologies critical for developing sustainable engineering solutions, and delivering courses in collaboration with non-engineering departments to promote interdisciplinary engagement. A subsequent curriculum study by Farnsworth et al. [11] found that 181 out of 307 accredited programs in civil engineering, construction management, and construction engineering in the U.S. explicitly indicated sustainability in their curricula. This integration has been categorized into two kinds: sustainability specific courses and minor sustainability integration. Based on these distinctions, the authors developed three categories for sustainability integration: course that is dedicated to sustainability, sustainability is taught in a single module/unit, sustainability concept is woven throughout curriculum.

Furthermore, although there is much discussion related to the topic of sustainability, and agreement across broad thematic aspects, the CCE community has yet to adopt a disciplinary-specific definition of sustainability [12], [13]. Scholars and institutions, such as Burian [14], Tabrizikahou et al. [15] and ASCE [16], have predominantly embraced the general definition from the Brundtland report: 'meets the needs of the present without compromising the ability of future generations to meet their own needs' [17]. To effectively implement this broad definition, the concept of sustainability has evolved into two interchangeable paradigms: 'three pillars of sustainability' and 'triple bottom line', to integrate environmental, economic, and social aspects of sustainability [18], [19]. In recent years, the 17 United Nation Sustainable Development Goals are also found to be a useful approach in civil

engineering [20], [21]. However, this definition and its varied forms have been criticized for lacking specific contextualization or posing challenges to quantify [22], [23]. Similarly, peer disciplines, such as public health, environmental science, and ecology, have begun developing context-specific interpretations of sustainability, recognizing that a universal definition may overlook critical nuances within each field [24], [25], [26].

The meaning of a term or a concept within a discipline is inherently shaped by the perceptions of its members, who collaboratively contribute to a shared understanding. This dynamic process of definition-shaping is particularly evident in the social sciences, where collective perspectives heavily influence the meanings attributed to specific terms [7], [8]. In civil engineering, individual interpretations of sustainability, shaped by personal experiences, cultural contexts, and political viewpoints, contribute to a nuanced understanding of the concept [9]. This understanding is not static; it evolves through ongoing discourse and consensus within the academic community.

While extensive research has focused on engineering students' perceptions on sustainability, [27], [28], [29], [30], [31], [32], [33], the perspectives of faculty has been comparatively underexplored. Only a limited number of studies have investigated civil engineering educators' views on sustainability despite their critical role in shaping educational discourse [34] [35]. This research, therefore, specifically focuses on CCE faculty perspectives on the definitions of sustainability across various subdisciplines to enhance understanding of its meaning within civil engineering.

3. Research Method

This research investigated the perceptions of faculty members in CCE regarding the concept of sustainability and its integration into teaching practices, employing survey questionnaires as the primary data collection method. The use of surveys was selected for its ability to efficiently gather data from a large sample within a short timeframe, thereby facilitating the analysis of patterns related to sustainability education within CCE. The survey was distributed via email to CCE faculty members through the American Society of Engineering Education (ASEE) Civil Division member group. Supplementary outreach through professional networks was undertaken to encourage participation. A total of 64 complete questionnaires were received. To maintain anonymity, the survey did not collect detailed demographic information such as respondents' institutions or locations, thereby ensuring participant privacy.

3.1 Survey design

A comprehensive survey questionnaire was developed in Qualtrics to capture data on the how the concept of sustainability is understood and taught within CCE. The questionnaire aimed to evaluate current perceptions of sustainability concept and its integration into teaching. Its design was informed by existing literature and previous validated instruments, with modifications to suit the specific context of this research. The survey questionnaire comprised ten questions. Two questions focused on the respondents' teaching background, including the subjects they teach and their teaching experience. Three questions aimed to assess the perceived importance of sustainability in their teaching. Two additional questions explored their experience with teaching sustainability. The final two questions were open-ended and sought to understand how respondents define and perceive the concept of sustainability. Table 3.1 presents the survey questions and sample answers.

Table 3.1 Survey questions and sample answer

Questions	Question Type	Answer sample
How long have you been teaching in higher education?	Multiple choice	Less than 5 years, between 5 and 20 years, more than 20 years
Which sub-disciplines in civil engineering do you teach courses and/or conduct research in?	Multiple responses	Architectural, Coastal, Construction, Environmental, Geotechnical, etc.
How important is sustainability in civil engineering and/or construction management education to you?	Likert scale of five	From extremely important to not at all important
How well do you feel principles of sustainability are being taught in civil engineering and/or construction management education?	Likert scale of five	From it's significantly overemphasized to there is significant room for improvement
Compared to other institutions, how well does your institution teach principles of sustainability?	Multiple choice	Better, similar, or worse than others
Do you specifically integrate sustainability into any of the courses that you teach? If yes, please list them.	Yes and No	
What level of students have you incorporated sustainability concepts in your teaching?	Multiple responses	Freshman, sophomore, junior, senior, graduate
If you answered yes to above question, how is sustainability integrated into your teaching approach?	Multiple responses	Interwoven sustainability throughout, specific unit/module on sustainability, the course theme is about sustainability
How would you describe sustainability as it relates to civil engineering and/or construction management?	Open ended	*Ability to use resources, design, and build today in a way to not deprive future generations.*
Is there anything else you'd like to add or discuss regarding sustainability education in civil engineering and/or construction management?	Open ended	*Need materials/modules to better integrate sustainability; workshops on how to use state of the practical modeling tools*

3.2 Sampling and data collection

A stratified random sampling method was used to select participants from a pool of CCE educators in the U.S., ensuring representation across major subdisciplines such as structural, construction, and environmental engineering. The survey was distributed via email to CCE faculty through ASEE Civil Division member group, supplemented by convenience sampling through professional and academic networks to improve the response rate. An introductory email explaining the study's purposes, ensuring confidentiality, and providing a link and a QR code to the survey was sent to all selected participants.

3.3 Data analysis

The survey responses were analyzed in two approaches, descriptive statistics and content analysis. Descriptive statistics were calculated to summarize demographic characteristics and overall survey responses. Content analysis was employed to systematically interpret and understand the nuanced meaning of sustainability from two open-ended questions. This approach was selected for its effectiveness in identifying, analyzing, and reporting patterns or themes within the data. Content analysis involves a process of coding textual data, categorizing it into meaningful themes based on frequencies, and interpreting patterns of themes to uncover underlying insights related to sustainability definition in CCE teaching practices. Inspired by the themes from Sustainability Definition Framework for civil and construction engineering disciplines [9], the authors developed a

codebook for content analysis as shown in Table 3.2. The analysis was conducted by two independent human coders to ensure reliability and consistency in the identification of the themes. Each coder assigned scores based on the presence of each theme in the responses. For example, if one respondent describes sustainability as "Ability to use resources, design, and build today in a way to not deprive future generations." Coders identify two themes from this statement: efficient use of resources and long lasting. Consequently, the scores would be one for efficient use of resources and one for durability.

Table 3.2 Code book for content analysis

Topics/Themes	Explanation
Efficient use of resources	Energy efficiency, minimize cost, reuse, recycle, repurpose
Durability	Products, resources, systems can last long period of time
Meeting societal needs	Provide service and space to strengthen human interaction
Minimizing environmental impacts	Built environment interacts with and affects air, water, and soil
Life Cycle	Planning and design, development and construction, operation and maintenance, demolishing and repurposing
Balanced three pillars of sustainability	Environmental, social, economic dimensions
Ethics and stewardship	A sense of responsibility
Need for improvement	Highlight the importance of integrating sustainability into civil engineering
Others	Any other themes do not fall into any above topics/themes

4 Results

4.1 Demographic information related to teaching sustainability

Table 4.1 Descriptive statistics on sustainability integration in CCE education

Survey Question	**Options**	**Count**	**Percentage**
Years of teaching	Less than 5 years	12	19%
	Between 5 and 20 years	38	59%
	More than 20 years	14	22%
Focus area of teaching and research	Construction management	22	18%
	Construction engineering	18	15%
	Structural	17	14%
	Water resources	15	12%
	Environmental	13	11%
	Geotechnical	11	9%
	Transportation	9	7%
	Materials	8	7%
	Architectural	2	2%
	Costal	1	1%
	Civil engineering education	1	1%
	Infrastructure systems/management	1	1%
	Utility engineering	1	1%
	Land development	1	1%
	Surveying	1	1%
	Sustainability	1	1%
	Nuclear	1	1%
Levels of students taught sustainability	Freshman	16	10%
	Sophomore	20	13%

	Junior	44	28%
	Senior	55	35%
	Graduate	21	14%

The results indicate that a significant majority of faculty members (81%) who participated in the survey hold senior positions. The areas of expertise represented reflect the diverse subdisciplines within CCE. Sustainability concepts are integrated across various student levels, with the highest frequency observed at the junior (28%) and senior levels (35%). This distribution aligns with the typical progression of civil engineering education, where advanced students engage more deeply with complex topics.

4.2 Teaching sustainability in CCE higher education

Table 4.2 Sustainability education in CCE: importance, integration, and quality

Survey Question	Options	Count	Percentage
Perception on the importance of sustainability education in CCE	Extremely important	24	38%
	Very important	25	39%
	Moderately important	11	17%
	Slightly important	4	6%
	Not at all important	0	0%
Integration of sustainability into courses	Yes	46	72%
	No	18	28%
How sustainability is integrated into teaching	Interwoven throughout curriculum	39	49%
	Specific unit or module	25	32%
	Primary theme of the course	15	19%
Perceived quality of sustainability teaching	It is currently being taught well enough	7	11%
	There is room for improvement	45	70%
	There is significant room for improvement	11	17%
	There is slightly more emphasis given than necessary	1	2%
	It is significantly overemphasized	0	0%
Compare to other institutions	Better than others	11	17%
	Similar to others	44	69%
	Worse than others	9	14%

Perception on the importance of sustainability education: The results reveal that a majority of respondents (77%) regard sustainability education in CCE as highly important. Specifically, 38% rated it as "extremely important" and 39% as "very important." A smaller segment, 17%, considers it "moderately important," while only 4% rate it as "slightly important," and none view it as "not at all important." This pattern highlights the widespread acknowledgment of the significance of sustainability education within the CCE field. However, it is noteworthy that 28% of respondents reported not integrating sustainability into their teaching, despite its recognized importance. This gap highlights the real challenges educators face in incorporating sustainability into CCE curricula.

Integration Approaches: With a high percentage of faculty integrating sustainability into their teaching (72%), it is important to explore how this integration is implemented. As this was a multiple-response question, the results show that most faculty (49%) incorporate sustainability throughout the curriculum, while 32% dedicate an entire unit or module to the topic. Additionally, 19% of

respondents consider sustainability an essential concept for CCE students, using it as the primary theme of their courses.

Perceived Quality of Sustainability Teaching: While a majority of educators (86%) believe that the teaching of sustainability is currently adequate or superior to that at other institutions, there is a strong consensus (87%) that there is still room for improvement. This suggests that, despite the recognition of sustainability's importance, many educators feel enhancements are necessary to further strengthen its integration in the curriculum.

4.3 Synthesis of sustainability definition topics through content analysis

Five out of 64 respondents did not answer the two open-ended questions aimed at capturing nuanced understandings of the concept of sustainability. Using the remaining 59 responses, the authors conducted a content analysis to identify patterns and themes in their perspectives. The average overlap rate was 93.3%, and Cohen's Kappa reached 0.82, suggesting a high level of agreement between coders and indicating that the coding can be considered reliable. The results are summarized in Table 4.3, which presents the findings of the content analysis on sustainability definitions.

Table 4.3 Content analysis of sustainability definitions

Topics/Themes	Scores from Coder 1	Scores from Coder 2	Cohen Kappa	Overlapping Rate
Efficient use of resources	23	25	0.70	85%
Minimizing environmental impacts	18	19	0.93	97%
Balanced three pillars of sustainability	17	19	0.89	95%
Durability	15	16	0.92	97%
Meeting societal needs	13	12	0.53	83%
Need for improvement	13	12	0.91	97%
Life Cycle	7	9	0.68	92%
Ethics and stewardship	5	5	1.00	100%

1. Efficient use of resources

A recurring theme across the responses was the importance of efficient resource use. Many participants emphasized that civil engineers have a responsibility to design infrastructure that reduces waste and maximizes resource efficiency throughout the entire life cycle of a project. The discipline has a long history on emphasizing minimizing resource consumption, maximizing resource reuse, and recycle in sustainability [36]. This orientation is particularly distinctive in that it does not advocate for eliminating consumption entirely, but rather seeks to achieve a balance between production and consumption. At its core, the philosophy is grounded in principles of optimization and respect for limits, while simultaneously fostering technological advancement that aligns naturally with the engineering discipline. Illustrative excerpts from participants' responses are provided below:

*1, Ability to **use resources**, design, and build today in a way to not deprive future generations.*
*2, Linking environmental, social, and economic aspects into the entire life cycle of a project to ensure that **the resources needed** for the project don't impact the **availability of resources** for future generations.*

*3, It is about **reducing our use of resources**, using technology to enable the **reuse** of existing infrastructure, and **creatively and effectively managing our waste**.*

2, Minimizing environmental impacts

The responses revealed a strong consensus on the importance of minimizing environmental impacts in CCE. This theme is distinct in that it rests on the assumption that CCE projects inevitably produce adverse effects on natural systems. Such impacts may include pollution or disruptions to air, water, and soil. In many cases, minimizing environmental impacts aligns closely with the efficient use of resources, particularly through strategies such as energy efficiency, waste reduction, and the reuse of existing infrastructure instead of constructing new facilities. The following excerpts illustrate this theme:

1, *Choose materials from an energy and re-use perspective; minimize energy consumption; **minimize environmental impacts**.*
*2, Doing things in a way that **reduces impacts on resources and environment**. Optimizing energy use. Designing for re-use.*
*3, **Reducing the negative impacts** of civil engineering outputs **on the environment** and society.*

3. Balancing social, environmental, and economic pillars of sustainability

The theme of balanced three pillars of sustainability. which encompasses social, environmental, and economic dimensions of sustainability, was a central element of many responses. Respondents repeatedly emphasized the necessity of integrating these three pillars into civil engineering projects to ensure balanced and responsible development. They noted that while three pillars of sustainability is frequently acknowledged as a guiding principle, its practical application is often challenged by industry pressures. In particular, the demands for cost efficiency, timely delivery, and quality frequently overshadow sustainability concerns, which are seen as secondary in project prioritization. Despite these obstacles, respondents recognized the three pillars of sustainability paradigm as essential for addressing the complexity of sustainability in civil engineering and called for stronger advocacy within the profession to ensure these dimensions are properly accounted for in project planning and execution. Direct quotes are listed below:

*1, Linking **environmental, social, and economic aspects** into the entire life cycle of a project to ensure that the resources needed for the project don't impact the availability of resources for future generations.*
*2, Sustainability is the **social, economic, and environmental components** of a civil engineering project. I think civil engineering education sometimes overemphasizes the environmental focus for sustainability with much less consideration for the social and economic dimensions of sustainability.*
*3, The **triple bottom line** needs to be considered in all designs.*

4, Durability

A dominant theme that emerged was the recognition of sustainability as a principle of intergenerational responsibility, where respondents emphasized the need to balance meeting today's needs without compromising the ability of future generations to meet theirs. Many respondents referenced long-term planning frameworks, such as the seven-generation theory, underscoring the

importance of making decisions that preserve environmental resources for future use. This theme suggests that sustainability, as conceived by practicing engineers, transcends immediate project outcomes and involves consideration of broader temporal impacts. The following quotes are some of the examples:

1, *We would use the **seven-generation theory** most commonly. Designing infrastructure in a way to meet the needs of today without compromising the ability of **future generations** to meet their needs.*
*2, The selection of materials, design approaches and construction methods to minimize environmental impacts, reduce energy consumption and increase **longevity and resilience** of infrastructure and structures.*
*3, The quality of being – or the ability to be – **sustained over an extended period of time**. It relates to the consumption and production of resources – if you consume more than you produce, eventually you will run out.*

5, Meeting societal needs

Many respondents highlight the fundamental role of CCE in addressing the requirements and challenges faced by communities. They also highlight the necessity of engaging with stakeholders to ensure that projects align with societal values and priorities, such as:

*1, **Meeting the present needs of society** without infringing upon future societal needs. As well as, striking a balance between environmental, societal, financial requirements.*
*2, I think sustainability is important for the environment. But also I think students benefit from learning about sustainability as **Market trend** as well.*
*3, CE has the potential to **create and connect communities**, but without considering the environmental impact…, we can(and have) really messed our air, soil, and water.*

6, Need for improving

Responses emphasized the need for improvement in how sustainability is positioned within civil engineering education and practice. Educators noted that sustainability should move from a secondary consideration to a central guiding principle, placed alongside or even above client needs, serving as the keystone of the discipline, and fully reflecting its societal and environmental impacts:

*1, We need to do **better** and put sustainability **at the front along with (perhaps higher than?)** our clients need.*
*2, It should be the **keystone** of civil engineering/construction management practices.*
*3, Sustainability **is a critical element** in both design and construction because of the impact that these built environment aspects have on both society and the natural world around us.*

7, Life cycle

The life cycle theme highlights the importance of accounting for a project's entire lifespan, spanning planning and design through construction, operation, and eventual decommissioning. It serves as a critical lens for evaluating both environmental and economic impacts of materials and design choices over time. By adopting this approach, engineers can better assess the cumulative consequences of their decisions, from resource extraction to the end of a building's or infrastructure's service life.

Respondents particularly emphasized the importance of integrating sustainability considerations at every stage of the CCE projects. Example quotes are the following:

*1, We should really focus on **life cycle analysis** and how small changes across a sector can add up to significant gains in sustainability.*
*2, Giving consideration to the environmental, social, and economic impacts of CE projects at **all stages of project planning, implementation (e.g., construction), and operation**.*
*3, To me, sustainability in civil engineering involves **designing, constructing, and maintaining infrastructure** that does not compromise the ability of future generations.*

8, Ethics and Stewardship

Several respondents emphasized the role of civil engineers as stewards of both the built and natural environments, noting that sustainability should be regarded as a core ethical responsibility of the profession. Stewardship in this sense involves not only avoiding harm but also ensuring that infrastructure contributes positively to environmental and social well-being. As respondents described, sustainability is "inseparable" from the professional duty of civil engineers and represents "the difference between minimal competency civil engineering and good civil engineering." The actual quotes are as follows:

*1, Inseparable! It is our **responsibility as stewards** of the natural and the built environment.*
*2, The difference between minimal competency civil engineering and **good civil engineering**.*
*3, It is **our responsibility in CM** to use construction materials and methods, construction site planning and execution, and waste management that incorporate sustainability principles, including environmental, social, and economic aspects of sustainability.*

5 Discussion

The integration of sustainability into civil engineering education and practice has become a critical priority for preparing future engineers to address pressing challenges such as resource scarcity, social justice, environmental degradation, and climate change. The survey results revealed that educators do think sustainability is an important component in CCE education, but the obstacles and challenges are not few.

Key themes in sustainability

The content analysis of civil engineering professionals' responses highlights several key considerations for both academia and industry in advancing sustainable infrastructure development. While civil engineering design has traditionally emphasized meeting societal needs and market demands, the increasing urgency of climate change, urban sprawl, and aging infrastructure highlights the importance of embedding sustainability more systematically within curricula.

Themes identified in this study, including efficient use of resources, minimizing environmental impacts, balancing the three pillars of sustainability, durability, meeting societal needs, and life cycle assessment, align with the Sustainability Definition Framework (SDF) proposed by Wang et al. [9]. However, our analysis also revealed more nuanced themes, such as ethics, stewardship, and the need for improvement, underscoring the multifaceted nature of sustainability in civil engineering education

and practice. These findings highlight the growing recognition that sustainability must be integrated throughout the curriculum rather than treated as an isolated or secondary concern.

Challenge for integrating sustainability into curriculum:
Despite broad agreement (94%) on the importance of sustainability, significant challenges remain in its integration as 28% of respondents reported not incorporating sustainability into their teaching. Notably, 87% indicated there is substantial room for improvement, pointing to an urgent need to strengthen sustainability education in CCE. Several barriers hinder progress. Previous research shows that while many faculty members attempt to integrate sustainability, they struggle with effective methods to revise curricula and overcome institutional barriers [35]. Specific obstacles include limited institutional flexibility, time constraints to revise syllabi [37], an already crowded curriculum, lack of faculty training, alignment with industry needs, assessment methods [14], resource limitations [38], and student engagement. Accreditation systems also play a significant role; for instance, sustainability integration often depends on detailed requirements in discipline-specific courses and capstone projects. Current ABET standards are broad and less outcome-driven, suggesting a potential need for updated accreditation guidelines to better support sustainability integration [39].

A notable challenge is students' pessimism regarding their ability to make an impact on global sustainability issues. Some students perceive the scale of problems such as climate change as overwhelming, which may reduce engagement with sustainability topics. Addressing this requires not only technical instruction but also fostering an optimistic, solutions-oriented mindset [40]. Educators can more effectively demonstrate the practical implications of sustainability in engineering design by leveraging industry partnerships [41], incorporating case studies of successful implemented sustainable projects [42], [43], [44], [45], and engaging professionals through mentorship or guest lectures who can speak directly to the challenges and opportunities of applying sustainability principles in practice.

In addition, open-ended responses from participants emphasized the need for cohesive and interdisciplinary teaching approaches. Some respondents referenced frameworks and tools for integrating sustainability, such as Envision [46] and Engineering for One Planet [47], indicating the importance of systematically embedding sustainability principles into the core curriculum rather than presenting them in a fortuitous way.

Sustainability integration should be early
Although sustainability is addressed at all student levels—from freshmen to graduate courses—most curricula emphasize it during junior and senior years. This approach risks framing sustainability as an advanced topic rather than a foundational principle. Research suggests that sustainability should be introduced at the freshman level, allowing students to engage with the topic throughout their academic journey [48]. Early exposure fosters critical thinking, promotes deeper understanding, and enables students to apply sustainable practices in later coursework and projects. It also cultivates a holistic mindset, preparing future engineers to address complex societal and environmental challenges.

Respondents also highlighted the importance of practical application, emphasizing the need for case studies, real-world examples, and hands-on experiences. Bridging the gap between theoretical knowledge and practical application is crucial for equipping students with the skills and confidence to

implement sustainable practices in professional contexts.

Overall, the findings from this study highlight both the progress made and the challenges that remain in embedding sustainability into civil engineering education. While many educators recognize its importance and are making efforts to incorporate sustainability concepts, persistent gaps in curriculum design, faculty training, institutional support, and student engagement highlight the need for more intentional and systematic approaches. By integrating sustainability early, reinforcing it across all levels of education, and connecting it to real-world applications, civil engineering programs can better prepare students to become leaders who design and manage infrastructure that is not only functional and resilient, but also equitable and environmentally responsible [49]. These steps are essential to ensure that future civil engineers are equipped to address the urgent and complex challenges of climate change, resource scarcity, and social equity.

6 Discussion

This study represents one of the first investigations of sustainability education in the civil engineering discipline across multiple institutions in the U.S. By mapping the current state of sustainability teaching, the research establishes a baseline benchmark for assessing progress in engineering education. In addition, it identifies gaps in current practices and provides actionable directions for enhancing sustainability education and preparing future civil engineering graduates to address evolving social, environmental, and technical challenges. Building on these identified gaps, literature offers concrete, evidence-based strategies that directly address areas for improvement. Effective instruction extends beyond isolated content delivery, with case-based and project-driven learning engaging students in solving real-world engineering problems, thereby filling the gap in experiential learning [50], [51], [52], [53]. Embedding sustainability across multiple courses, rather than confining it to a single elective, addresses the lack of continuous exposure and promotes systems thinking throughout the curriculum [54]. Interdisciplinary collaboration and reflective exercises further strengthen students' understanding of the interconnectedness among natural, engineered, and social/governance systems, directly responding to gaps in holistic understanding [55]. Successful implementation also requires faculty development and institutional support, ensuring consistency and effective assessment of learning outcomes [54], [56], [57]. Together, these strategies form a coherent framework for addressing the shortcomings identified in this study and advancing sustainability education in civil engineering.

7 Conclusion

Sustainability has become an essential framework for addressing the growing pressures of resource use and societal demand, making it particularly relevant to civil engineers engaged in designing and developing the built environment. Unlike safety standards, however, sustainability lacks universally accepted definitions or measures, making it more difficult to teach and standardize. To better understand how it is addressed in higher education, this study surveyed 64 civil engineering professors across 17 subdisciplines, most of whom (81%) had more than five years of teaching experience. This survey enriches traditional curriculum evaluations, which are often limited by the availability of course syllabi. Results show that while the vast majority of educators (94%) consider sustainability a critical component of civil engineering education, most (87%) would like to improve how it is currently taught. Among respondents, 49% reported integrating sustainability concepts throughout their courses, 32% taught sustainability as a specific unit or module, and 19% identified it

as the primary theme of their course. Additionally, through systematic content analysis with high interrater agreement, eight themes emerged that reflect both common values and diverse perspectives on sustainability. These themes highlight the importance of minimizing environmental impacts, using resources efficiently, adopting life cycle thinking, and embracing stewardship as a professional responsibility. Together, they provide a clearer picture of how sustainability can be more consistently articulated and integrated across engineering education, research, and practice. Looking ahead, this research reveals opportunities to embed the identified sustainability themes into curricula, professional training, and project evaluation frameworks. Integrating these themes can enhance engineers' capacity to design and develop the built environment in ways that support social environment and harmonize with natural environment [58]. Engaging with industrial professionals through surveys or interviews could further guide curriculum development, ensuring that educational content aligns with current industry practices and emerging sustainability challenges. Future research should focus on developing curricula that systematically integrate sustainability principles and leverage case studies to demonstrate their practical application, equipping students to incorporate sustainability into design decisions, professional practice, and adaptive responses to emerging challenges. By establishing a coherent and actionable approach to sustainability education, this study positions future civil and construction engineers to lead in creating resilient, equitable, and environmentally responsible infrastructure.

Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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