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SUSTAINABLE DEVELOPMENT GOALS IN HIGHER EDUCATION A CRITICAL REVIEW

Dr.K.Murali[1*], Mr.G.Ramesh Kumar[2], Mr.K.Sambath[3], Mr.B.Vigneshkumar[4]

[1*]Professor, Department of Civil Engineering, Dr. N.G.P. Institute of Technology, Coimbatore

murali.vlb@gmail.com, 9894518182

[2]Assistant Professor (SS), Department of Civil Engineering, Dr. N.G.P. Institute of Technology, Coimbatore

[3]Assistant Professor, Department of Mechanical Engineering, Sri Ramakrishna Institute of Technology, Coimbatore

[4]Assistant Professor, Department of Civil Engineering, Dr. N.G.P. Institute of Technology, Coimbatore

***Corresponding Author:** Dr.K.Murali

*murali.vlb@gmail.com

Abstract

The Sustainable Development Goals (SDGs) have redefined the purpose of higher education and turned universities into drivers of sustainability-related innovation and social responsibility. The strategic role of civil engineering education in this paradigm is explained by the fact that the education directly influences the creation of infrastructure, environmental management, and urban resilience. This critical review will examine how SDGs are being integrated into civil engineering curricula, pedagogy, and institutional policies in the world. It denotes such new tendencies as experiential and project-based learning, competency-based assessment, interdisciplinary collaboration, and using digital tools to model sustainability. The remaining challenges like institutional inertia, fragmented curriculum implementation, faculty capacity and lack of alignment of academic standards with professional standards are also determined in the review. This shows how the policy change and transformational pedagogy and quantitative assessment systems are required to enhance sustainability integration. The paper presents a mix of best practises across the world and the results of research studies to show that the key issue is that the systemic cooperation among academia, industry, and policymakers is critical to equip future civil engineers with the skill sets that will help them address complex sustainability challenges. The article asserts that, not only is the incorporation of SDGs in civil engineering education a curricular enhancement but a transformational process is also required to encourage sustainable, equitable, and sustainable civilizations.

Keywords: Sustainable Development Goals, Civil Engineering Education, Higher Education, Curriculum Reform, Sustainability, Engineering Pedagogy, Sustainable Infrastructure.

1. Introduction

Higher education has also become a significant platform of advancing sustainability-oriented knowledge, skills, and values as a result of the 2030 Agenda of Sustainable Development of the United

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Nations. Universities are not perceived as the mere providers of technical knowledge anymore, but they are supposed to act as the drivers of the Sustainable Development Goals (SDGs) by means of education, research, and community involvement [1]. Engineering education and especially the field of civil engineering is among them and cannot be ignored in the progress of the SDGs due to its direct participation in the infrastructure, environmental management, and urban development. Civil engineering supports the development of SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action), etc. The level to which these international objectives have been effectively incorporated into civil engineering education is still skewed and disjointed in the systems of higher learning in most parts of the world.

The SDGs have also brought an ethical and operational need to change the traditional pedagogical paradigms in the context of higher education. In the past, engineering courses have focused on technical problem-solving, design, and efficiency without taking into account the social, ethical, and ecological aspects of the engineering practice. As Zhou et al. [2] note, higher education institutions are key bridges between knowledge production and societal change, and, therefore, decisive in instilling sustainability principles into professional education. Application of SDGs in curricula is not only about the introduction of courses concerned with sustainability but also involves a total re-evaluation of the learning outcomes, methods of teaching and the running of institutions to develop sustainability literacy in engineers of the future.

Civil engineering is particularly seated in the crossroads of infrastructure and sustainability. It directly affects how societies develop and execute transportation, water management, waste management, and construction industries that have compounding impact on the environmental stability and social wellbeing. The transformative potential of SDGs inclusion in civil engineering curricula, in its turn, will be the alignment of the engineering competencies to the global sustainability concerns, such as the resource scarcity, climate adaptation, and inclusive urbanisation. Structural, pedagogical and cultural barriers to the academic field restrict this change. Conventional civil engineering courses are often more discipline-based, and there is little interdisciplinary exposure or collaboration with stakeholders, and most institutions still tend to emphasize technical competence over sustainability competencies [3]. This gap can be bridged by both curriculum reform and institutional ethos and governance towards a sustainability-centred mission.

Across the world, institutions of higher learning have addressed the SDGs in diverse ways such as sustainability reporting, campus greening programs, and setting up special sustainability centers. The process of translation of these institutional commitments to the classroom practice is not consistent. Wolhuter [1] cites research output and internationalization as the main measures of university performance and rankings, which are more likely to be considered in terms of sustainable development. This lack of correspondence of global ranking standards and sustainability demands has discouraged systematic implementation of SDGs into disciplinary education, especially in such areas as civil engineering, where conventional accreditation systems and assessment paradigms prevail. This means that sustainability integration is usually done haphazardly or peripherally, and not as a part and parcel of engineering education.

The academic discussion of the SDG implementation in higher education indicates that the awareness of the SDGs has increased, yet the actual curricular change remains immature. According to Narong and Hallinger [4], the study of engineering education as a means of sustainability has developed

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considerably during the last thirty years but is still focused on the conceptual rather than the practical sphere of implementation. The majority of the research focuses on the conceptual compatibility of SDGs and engineering competencies, but there is a lack of data on the quantifiable results of student learning or graduate employability. This gap underscores the fact that there is a consistent requirement to develop pedagogical creativity and assessment models that will be able to measure the extent to which SDGs are being translated into practice in civil engineering schools.

The implementation of SDGs in civil engineering education involves dealing with various levels of complexity. At the curricular level, the principles of sustainability should be integrated in the courses instead of being limited to the elective modules. Active and experiential learning methods like project-based learning, design thinking, and community-based problem solving are needed at the pedagogical level to promote real-life knowledge of sustainability issues. The universities ought to have policies on institutional level to encourage interdisciplinary collaboration between engineering, environmental science, economics and social sciences faculties. As pointed out by Avelar et al. [3], to achieve a meaningful SDG integration, the universities must integrate teaching, research, and external partnership within reliable sustainability framework, which is backed by faculty training and incentive systems.

In spite of these, there are systematic challenges encountered during the integration process. It is important to note that Probst [5] is critical to point out that sustainability agenda of higher learning is not always coherent in nature since universities tend to seek fragmented initiatives that are more about visibility than change. The majority of institutions continue to employ the previously existing disciplinary lines and reward systems that fail to promote collaborative teaching and research. Social justice and ethical dimensions of the SDGs are sometimes misplaced in the growing focus on technological innovation in the education of engineers. This imbalance undermines the holistic concept of sustainability and inhibits the ability of the students to perceive engineering problems as socio-technical systems which are embedded within the greater ecological and social environment.

To ensure a more meaningful incorporation of SDGs into civil engineering education, the very definition of engineering competence should be changed. According to Mulder [6], strategic competences of concrete action towards sustainability are to be formulated, and the engineers must not only be told about the concepts of sustainability, but also be capable of implementing them to real life issues. This competency model requires engineering education to be changed away to problem-solving in sustainable development rather than technical optimization. The proficiencies that are needed of the future engineers to perform systems thinking, uncertainty management, and cross-disciplinary and cross-sector teamwork are the ones that are needed to implement sustainable solutions to complex and dynamic environments.

Adoption of SDGs in higher education particularly in civil engineering is both an ethical consideration and a learning opportunity of transformational learning. Civil engineering education can also be an effective tool of advancing SDGs, assuming that the universities re-evaluate their pedagogic, institutional, and assessment frameworks to advocate sustainability as a value rather than as a secondary objective. This is a critical review of the efforts, conceptual ideas, and emerging practises of teaching SDGs in civil engineering. It establishes key achievements, current challenges, and prospects that must be taken into consideration in order to make sure that civil engineering education can be employed to make a considerable contribution to sustainable development. This paper aims to

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bridge the rhetoric and the reality of sustainability in education by analysing the current studies and institutional action and finally proposing how this can be utilised to build the next generation of civil engineers who will be capable of building a sustainable future.

2. The Role of Higher Education in Achieving the Sustainable Development Goals

Higher education institutions (HEIs) occupy a central position in advancing the United Nations' Sustainable Development Goals (SDGs) through the integration of sustainability principles into teaching, research, and institutional practices. Education is not merely a goal which has been explicitly mentioned in SDG 4 (Quality Education), but also a medium by which all the other SDGs can be realised. Universities are not only producers of knowledge, but also social institutions, which can shape values, competences, and technological developments in response to global sustainability problems. According to Annan-Diab and Molinari [7], higher education is revolutionary in the creation of interdisciplinary and systemic thinking that is needed in addressing complex sustainability problems such as climate change, scarcity of resources, and sustainable infrastructure. This is a revolutionary capability that is particularly important in the civil engineering education where the professional training is responsive to the needs of socially responsible and economically viable solutions that are environmentally sound.

Education Sustainable Development (ESD) is now a conceptual model that has been applied to reorganise the curriculum in disciplines to make them more sustainable. According to Desha [8], engineering education on ESD must not be bound to theoretical awareness, but practical and project-oriented learning that can be used to model real-world sustainability problems. This approach does not only enhance cognitive knowledge of the students but also instils critical and reflective skills that are valuable in the responsible engineering practise. According to Rajabifard et al., [9], higher education institutions must consider adopting a systems approach to align institutional strategies, policies, and pedagogies with the SDGs, such that sustainability is an inherent part of higher education and not an exception. Organisational implementation of such a strategy will help close the divide between the global sustainability programmes and the local learning environment and establish a more coordinated and successful process.

Another specific area where the SDGs can be incorporated in higher education is civil engineering education, as it is a field that is associated with the concept of sustainable infrastructure, urban development, and environmental management. According to Pérez-Sánchez et al. [10], project-based learning (PBL) models are proposed to address SDG-based problem-solving in engineering education, in particular, in addressing the urban sustainability, resource-saving, and resiliency of infrastructure design issues. Coelho [11] states that the alignment of teaching in civil engineering with some goals such as SDG 11 ("Sustainable Cities and Communities") that aims at inclusive, safe, and resilient urban development is necessary. These goals can be incorporated in the curriculum to assist civil engineering students to develop sustainability skills and be able to contribute extensively in sustainability policies of the country and the world.

With its increasing popularity, the SDGs integration in higher education is still unequal in terms of disciplines and regions. Quelhas et al. [13] state that sustainability is still viewed as a peripheral subject matter in most engineering programs, instead of being a core value and a guiding principle in curriculum development. According to Álvarez et al. [14], the integration of SDGs in civil engineering

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programs needs not only curricular reform, but also faculty knowledge and institutional dedication. The barriers that still hinder are the inflexible accreditation schemes, disciplinary silos, and lack of proper assessment tools. However, the development of sustainability-based pedagogy shows a definite tendency to interdisciplinary education and outcome-based learning that is more concerned with global responsibility, ethical consciousness, and the well-being of society in the long term.

The following Table 1 summarizes key contributions of higher education to the implementation of SDGs, particularly within the civil engineering domain:

Table 1: Key Scholarly Contributions to SDG Integration in Higher Education with a Focus on Civil Engineering

Author(s)	Focus Area	Contribution to SDG Integration in Higher Education (with relevance to Civil Engineering)
[7]	Interdisciplinarity and systems thinking	Emphasized cross-disciplinary collaboration and systems-based learning for sustainability.
[8]	Curriculum renewal and pedagogy	Advocated for experiential and project-based learning to embed ESD into engineering curricula.
[9]	Institutional policy and governance	Proposed a systems approach for aligning university strategies with SDG frameworks.
[10]	Project-based learning and curriculum design	Demonstrated PBL as an effective model for integrating SDGs in civil engineering programs.
[12]	Social learning and partnerships	Highlighted the role of regional learning networks in advancing sustainability education.
[11]	SDG-specific integration	Focused on embedding SDG 11 (“Sustainable Cities and Communities”) into higher education.
[13]	Competency development	Identified challenges in developing sustainability competencies within engineering education.
[14]	Implementation challenges	Examined barriers and strategies for embedding SDGs in civil engineering curricula.

Higher education is a test tube and a catapult to the realization of the SDGs. It is not only the formal education but also the creation of professional identities and priorities within the society. In the civil engineering education scenario, the alignment of the academic objectives to the SDGs can ensure that the future engineers are not only creators of the infrastructure, but creators of the sustainable future. Operationalizing the principles of sustainability through curriculum innovation, interdisciplinary teamwork, and leadership of institutions can enable universities to make civil engineering education a driver of sustainable development of the globe.

3. The Nexus between Civil Engineering and Sustainable Development

The reason why civil engineering is fundamental to sustainable development is because it is an interface between technical innovation and social well-being. This aspect is related to the fact that the discipline is concerned with designing, building, and repairing infrastructure, which directly

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influences the quality of the environment, economic development, and social justice three pillars of the Sustainable Development Goals (SDGs). According to the Civil Engineering Body of Knowledge Task Committee [15], the present civil engineering training should not be restricted to a technical training but should be extended to encompass ethical, environmental, and sustainability-related training. Inclusion of SDGs in civil engineering courses will ensure that the graduates are prepared to meet not only the demands of the infrastructure but also the demands of the global sustainability challenges such as climate change, urban resilience and resource efficiency.

Sustainable civil engineering is a paradigm shift in the manner engineers are being trained in future. The traditional curricula are inclined to the structural mechanics, materials and hydraulics and sustainability is regarded as an alternative or a minor discipline. Chan and Lee [16] argue that positive coherence of learning outcomes and assessment in engineering education plays a critical role in instilling the sustainability in the core professional competences. It must be able to incorporate the curricula that would explicitly link engineering theory and society to applied sustainability projects and interdisciplinary work. In this respect, SDGs offer an international reference framework that can help to align technical education with environmental stewardship and social responsibility so that engineering graduates can be able to design infrastructure that can be used to achieve long-term sustainability.

Sustainability in civil engineering is not just environmental awareness but should be considered as building the ability to think about systems, interact with stakeholders, and make ethical decisions. Brundiers et al. [17] note that sustainability education must cultivate the following competencies, which are anticipatory thinking, normative understanding, and integrated problem-solving. In the case of civil engineers, they are the capability to assess the environmental footprint of building materials, optimise the energy and water systems, and create resilient infrastructure to natural and anthropogenic stressors. According to Bae et al. [18], engineering graduates need to close the divide between the academic training and the industry requirements by learning skills related to sustainability as required by employers and regulatory authorities.

Basu et al. [19] emphasize that sustainability in geotechnical and structural engineering must be viewed in a holistic approach that balances the technical performance with the environmental protection. This integrated perspective resembles the spirit of SDGs, especially SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities) that focus on the idea of innovation, resiliency, and inclusivity in the process of infrastructure creation. These objectives in education require a restructuring of pedagogical strategies. El-adaway et al. [20] suggest that problem-based and service-learning pedagogies are effective strategies to incorporate sustainability in civil engineering courses. These practical methods enable the students to have practical experience of the real life issues, which promotes the practical application of sustainability concepts in engineering designing and construction.

The systematic review shows that the incorporation of sustainability in civil engineering among institutions across the world is yet to be consistent (Kiani Mavi et al. [21]). Even though some universities have implemented the SDGs throughout their teaching and research missions, some have adopted a fragmented approach, limiting interdisciplinary learning. This gap means that there are broader problems of matching accreditation requirements, industry requirements, and academic curriculums. To bridge this gap, there should be institutionalization of sustainability competencies as

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measurable learning outcomes of civil engineering programs and there must be establishment of stronger ties with industry and policymakers.

One of the key players in the process of sustainable development that translate the abstract SDG goals into a real infrastructure product is civil engineering. With sustainability incorporated into the education of civil engineers, one could ensure that the future professionals are not merely technically competent, but also ethically and environmentally aware enough to create a sustainable world. This amalgamation of SDGs, thus, transforms civil engineering into a technical and ethical project one that is neither wanton nor careless, neither wasteful nor unsustainable, nor retrogressive or unequal.

Table 2: Key Contributions Linking Civil Engineering to Sustainable Development

Author(s)	Focus Area	Contribution to the SDG–Civil Engineering Nexus
[15]	Professional standards and competencies	Defined sustainability, ethics, and leadership as core civil engineering outcomes aligned with SDGs.
[16]	Curriculum alignment and assessment	Advocated for constructive alignment to integrate sustainability outcomes into engineering curricula.
[17]	Sustainability competencies	Identified key competencies systems thinking, anticipatory, and normative skills relevant to engineering practice.
[18]	Industry expectations and employability	Highlighted the need for bridging academic learning and sustainability skills demanded in industry.
[19]	Geotechnical sustainability	Proposed holistic design principles balancing technical and environmental performance.
[21]	Construction sustainability review	Identified global trends and disparities in sustainability integration within engineering projects and curricula.
[20]	Pedagogical innovation	Demonstrated the value of problem-based and service-learning models in sustainability education.

Table 2 summarises the main literature sources highlighting the relationship between civil engineering education and sustainable development and focuses on competencies, alignment of curricula with the industry and innovative pedagogical tools that will promote SDG integration.

4. Integration of SDGs into Civil Engineering Curricula

The introduction of the Sustainable Development Goals (SDGs) in civil engineering education is a game changer to the traditional technical teaching methodology to a comprehensive educational process incorporating engineering competencies with the international sustainability demands. It needs to change at a multiplicity of levels: at the curriculum level, at the pedagogy level, at the level of mathematical modelling, and also at the institutional policy level. This section is a critical analysis of these arguments, which identifies innovative frameworks and persistent challenges that characterise the orientation of SDGs in civil engineering education on the diverse world.

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4.1 Curriculum and Course Design

The reform of the curriculum is the key to SDG integration in civil engineering education. According to Shah and Gillen [22], universities are also restructuring engineering courses to incorporate the principles of sustainability in both core and optional courses. It is not only environmental science that is incorporated by such integration, but also ethical reasoning, social equity and long-term resilience in infrastructure design. Christiansen et al. [23] disclose that cross-institutional partnerships have been especially successful in enhancing sustainability performance through knowledge sharing and collective curriculum development between the academia and industry.

Nakad et al. [24] conducted a systematic review of different assessment techniques of sustainability integration and found that curriculum design should be able to connect SDG learning outcomes with quantifiable competencies, such as systems thinking, ethical awareness, and project evaluation. Birdman et al. [25] also show that project-based learning (PBL) models enable the acquisition of sustainability competencies by providing practical, collaborative problem-solving activities that reflect the practice of professional engineering. Sanchez-Carracedo et al. [26] suggested SDGs mapping tools and rubrics in engineering programs, which provide effective ways of continuous improvement and accountability.

In addition to single courses, Brunell [27] mentioned the possibility of incorporating frameworks like the Envision Rating System a sustainability assessment tool into capstone courses, which would strengthen the relationship between classroom education and sustainable infrastructure design. The background views, including those of Feder et al. [28], highlight the importance of instilling sustainability as early as K-12 education to instill sustainability-focused attitudes prior to joining university.

4.2 Pedagogical Strategies

The working force of sustainability integration is pedagogy. Sabri [29] posits that the education of civil engineers needs a paradigm shift that incorporates the learner-based and experiential pedagogies. Espinoza-Ramos and Capucci-Polzin [30] report the development of sustainability in multidisciplinary projects as a way of fostering innovation and ethical accountability in engineering students. Cebrián and Junyent [31] argue that sustainability education must focus on competency-based learning and not rote knowledge and encourage critical reflection and participation in problem solving.

According to Cotton and Alcock [32], institutional culture and perceived relevance frequently affected student engagement with sustainability; therefore, teachers need to develop contextualized learning experiences that can show real benefits to society. Shahtaheri et al. [33] introduce a powerful model in which sustainability assessment techniques are integrated into the initial design stages, allowing the students to consider environmental trade-offs systematically. Salari and Bhuiyan [34] present the models of sustainable product development that reconcile economic and ecological interests and provide transferable information to construction engineering. Kandakatla et al. [35] show that project-based service-learning not only improves graduate attributes in line with national accreditation frameworks, but also integrates SDGs, which is not only pedagogically sound but also institutionally accepted.

4.3 Role of Mathematics and Quantitative Modeling

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Quantitative modeling is considered to be the key to operationalizing sustainability in civil engineering education. The analysis of sustainability through the integration of Building Information Modeling (BIM) was first introduced by Azhar and Brown [36], who gave students the computational tools to analyze the energy performance, material efficiency and environmental impact. The system of food-energy-water (FEW) nexus, explored by Tabassum et al. [37], builds on this method of analysis by providing evidence of how mathematical models can be used to simulate the interdependence of complex resource systems an important skill that is increasingly important in the process of sustainable infrastructure planning. As Bao et al. [38] note, an introduction of data-driven sustainability metrics into coursework helps students to convert SDG goals into measurable engineering results. With the help of such frameworks, mathematical modeling is turned into a tool to instill sustainability into evidence-based design and decision-making.

4.4 Institutional and Policy-Level Integration

SDG-driven curriculum innovation can only be maintained by institutional commitment. Vedhathiri [39] supports the use of assessment-based models that can be used to align the graduate attributes with the sustainability outcomes and encourages accreditation agencies to clearly identify SDG-related competencies. Nurse and Pellecuer [40] indicate the growing consciousness of the principles of the circular economy among civil engineering institutions, with a particular focus on policy and governance as the means of making sustainability institutionalized instead of a fad. Faculty development and cross-departmental collaboration (together with sustainability research funding) policies can expedite the SDG implementation and standardize sustainability education in the institutions.

Table 3: Key Dimensions of SDG Integration in Civil Engineering Curricula

Category	Author(s)	Focus Area	Key Contribution to SDG Integration
Curriculum and Course Design	[22]	Program restructuring	Integration of SDGs into engineering modules across multiple disciplines.
	[23]	Cross-institutional collaboration	Enhanced sustainability through partnerships between universities and industries.
	[24]	Assessment methods	Frameworks for evaluating sustainability integration in curricula.
	[25]	Project-based learning	Experiential learning promoting SDG-linked competencies.
	[26]	Evaluation tools	Rubrics for mapping SDG outcomes in engineering programs.
	[27]	Capstone integration	Application of Envision Rating System in final-year projects.

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	[28]	Early education	Advocated sustainability integration beginning from pre-university education.
Pedagogical Strategies	[29]	Systemic educational reform	Advocated learner-centered pedagogies for sustainability.
	[30]	Multidisciplinary collaboration	Promoted ethics and innovation through sustainability projects.
	[31]	Competency-based learning	Encouraged critical thinking and reflection in sustainability education.
	[32]	Student engagement	Linked sustainability motivation to cultural and institutional factors.
	[33]	Sustainable design assessment	Integrated environmental trade-offs into early-stage design education.
	[34]	Sustainable product development	Developed models for balancing ecological and economic priorities.
	[35]	Service-learning pedagogy	Demonstrated project-based approaches aligning with accreditation outcomes.
Mathematics and Quantitative Modeling	[36]	BIM and simulation tools	Introduced computational analysis for sustainable design.
	[37]	FEW nexus modeling	Showcased mathematical modeling of resource interdependencies.
	[38]	Data-driven analysis	Linked sustainability metrics to quantitative decision-making in engineering.
Institutional and Policy-Level Integration	[39]	Accreditation and assessment	Advocated SDG-linked graduate outcomes and institutional evaluation.
	[40]	Policy and governance	Highlighted integration of circular economy principles in institutional strategy.

Table 3 provides a systematic summary of the main academic works that exemplify the process of integration of SDGs in civil engineering education in the form of curriculum reform, pedagogical innovation, quantitative modeling, and institutional policy alignment. Inclusion of SDGs into civil engineering courses is therefore a multidimensional change one that is capable of redefining the way engineers are trained, evaluated, and empowered to drive sustainable change. Through integration of curricular innovation, progressive pedagogy, quantitative modeling, and institutional alignment,

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universities will be able to produce civil engineers that have not just the technical capability but also have ethical foundations and be globally responsible.

5. Critical Barriers and Challenges

Although the adoption of Sustainable Development Goals (SDGs) in civil engineering education has become a growing trend in the world, there are still major obstacles in its implementation. These issues are multi-dimensional (pedagogical, institutional, cultural, and systemic issues). These obstacles to higher education are crucial to be critically valued to improve the channels through which higher education can be in line with the global sustainability requirements.

One of the most difficult barriers is the institutional resistance to the pedagogical change. Sabri [29] observes that the awareness of the problem of a large number of universities being tied down by traditional academic structure and outdated paradigm of instruction lives on. It is an institutional change that cannot be easily realised since in most instances, institutions are strained in resources, accreditation is rigid, and bureaucracy is rigid. According to Espinoza-Ramos and Capucci-Polzin [30], sustainability integration entails interdepartmental collaboration yet majority of the universities continue to operate in disciplinary trenches which restrict interdisciplinary communication. Such disaggregation renders having a general perspective of the complex sustainability problem in engineering circumstances impossible.

The other critical hindrance is the lack of alignment between the academic training and the industry requirements. Bae et al. [18] stress that engineering graduates lack the practical sustainability skills that are sought by employers, such as skills in systems thinking, ethical decision-making, and socio-environmental judgement. The lack of connection between higher education and professional practice implies that civil engineering graduates are technically skilled; they might not be sufficiently prepared to implement sustainability frameworks in practical projects. Birdman and others [25] also observe that even initiative projects based learning that aim at bridging this gap are not without challenges concerning the issue of scalability, consistency of assessments, and institutional backing.

Expertise and capacity of the faculty are also a significant limitation. According to the report of the study by the authors of the article by Álvarez et al. [14], there is a significant number of educators in engineering programs with little formal training in sustainability pedagogy or SDG frameworks. Devoid of this specific professional development, teachers will find it difficult to incorporate the idea of sustainability in technical courses like structural design or geotechnical analysis. Kandakatla et al. [35] supplement this by saying that despite the effectiveness of project-based and service-learning pedagogies in instilling sustainability-oriented graduate attributes, they are usually inconsistently administered because of excessive workloads, inadequate incentives, and institutional reward.

On top of pedagogy, the very conceptual complexity of sustainability presents its own difficulty in becoming a part of engineering education. According to Brundiers et al. [17], sustainability is a multi-faceted competency that includes many cognitive, normative, and strategic competencies that can hardly be standardized or assessed using conventional assessment systems. Narong and Hallinger [4] also note that sustainability studies as an engineering education remain fragmented with little longitudinal evidence on how curriculum alterations may be transformed to meaningful learning outcomes or professional practise. This aspect of exit subjugates institutional responsibility and obscures evaluation to SDG conformity.

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One more issue, as far as technology is concerned, is the lack of homogeneity in the usage of analytical instruments and modelling methods. Although quantitative methods have the potential to improve sustainability analysis, they are not very much integrated into the engineering curriculum. Tabassum et al. [37] state that modeling frameworks like the Food-Energy-Water (FEW) nexus have not yet been fully applied to the education of civil engineers because of the lack of computational infrastructure and faculty experience. Bao et al. [38] emphasize that the opportunities of data-based sustainability assessment tools, including Building Information Modeling (BIM) or life cycle analysis, are yet to be explored in most institutions. As a result, the civil engineering students usually end up lacking the skills in digital tools that are vital in the planning of sustainable infrastructure.

The necessity of transformative competencies is a deep issue. According to Mulder [6], sustainability in engineering needs strategic competences the capacity to turn awareness into action. Yet, most of them continue to focus more on theoretical learning rather than applied and reflective learning, thereby lacking in providing behavioral change. SDSGs integration requires the civil engineers to go beyond being problem solvers to be system thinkers who can incorporate a balance of innovation, resiliency, and ethics in their designs.

The above barriers highlight the fact that integrating SDGs into civil engineering education is not a technical or curriculum problem but an institutional and cultural change and involves leadership, cooperation, and persistence.

Table 4: Major Barriers to SDG Integration in Civil Engineering Education

Barrier Category	Author(s)	Key Insights and Challenges Identified
Institutional Inertia and Systemic Resistance	[29]; [30]	Outdated pedagogical models and rigid administrative structures hinder sustainability reform; lack of interdisciplinary collaboration.
Graduate Competency Gaps	[18] ; [25]	Disconnection between academic learning and industry expectations; limited assessment of sustainability competencies.
Faculty Expertise and Workload	[14]; [35]	Insufficient faculty training and institutional incentives to integrate sustainability teaching methods.
Conceptual and Assessment Challenges	[17]; [4]	Difficulty in standardizing and evaluating sustainability competencies; lack of longitudinal evidence of educational impact.
Technological and Analytical Limitations	[37]; [38]	Limited adoption of computational modeling and data-driven sustainability tools in curricula.
Competency and Behavioral Transformation	[6]	Need for strategic, action-oriented competencies that translate sustainability understanding into professional practice.

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Table 4 summarizes some of the main categories of obstacles that have been found in the literature to prevent the successful implementation of Sustainable Development Goals (SDGs) in civil engineering education, including institutional, pedagogical, technological, and competency-related. The solution to these problems should be a multidimensional approach that should be able to coordinate institutional policies, curriculum innovation, faculty development, and technological infrastructure with the overall framework of SDGs. It is only in such a concerted effort that the transformation of the civil engineering education into a real enabler of sustainable development can be achieved.

6. Emerging Trends and Best Practices

The introduction of Sustainable Development Goals (SDGs) in civil engineering education has been developed based on a sequence of creative pedagogical, institutional, and technological innovations. New trends focus on experiential learning, interdisciplinarity, digital transformation, and institutional collaboration as critical processes to introduce sustainability to higher education. These trends do not only improve the engineering competencies, but they are also in line with the global sustainability demands and professional requirements in the engineering learning.

Mainstreaming of interdisciplinary and experiential models of learning is one of the most important upcoming trends. According to Byrne et al. [41], the significance of project-based and experiential learning was one of the earliest to highlight the relevance of developing sustainability oriented mindsets in engineering students. This has since spread to include community-based and collaborative projects that are aimed at solving real-life problems. As Dlouhá et al. [12] emphasize, the impact of social learning networks in facilitating sustainability education by engaging stakeholders is increasing, as students are able to put into practice the SDG principles in real-life situations. These forms of experiential pedagogies are now the foundation of sustainability integration especially in the civil engineering programs where the interaction between design and implementation has a direct impact on environmental and social systems.

The other new trend is the institutionalization of sustainability based on competency-based models and accreditation models. Quelhas et al. [13] emphasize that it is important to cultivate sustainability skills like systems thinking, ethical thinking and integrated design in curricular reform and faculties education. This has been strengthened by the increased role played by the national and international systems of accreditation which have incorporated the sustainability learning outcomes in their evaluation criteria. Probst [5] notes that universities are abandoning the divided approach to sustainability to systemic approaches that institutionalize SDGs within the institutional missions and performance metrics. These strategies are contributing to meeting the sustainability standards of teaching, research, and community engagement.

Technological innovation is another trend of change in sustainability education. Simulation and evaluation of sustainable design practices are now simulated and measured with the help of digital tools, including Building Information Modeling (BIM), artificial intelligence (AI), and life cycle assessment. Tabassum et al. [37] show that modeling complex systems, such as the food-engineering-water nexus, is useful in making students realize the interdependence between natural and engineered systems. Bao et al. [38] highlight the importance of applying data-based approaches and e-resources to train sustainability-related competencies among civil engineering learners. These technological

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tools fill the gap in conceptual learning and analytical application and provide an opportunity to use evidence based methods of sustainable design and infrastructure planning.

Moreover, institutional collaboration, on a systemic level, is being linked with pedagogical reforms. Both Sabri [29] and Espinoza-Ramos and Capucci-Polzin [30] emphasize the importance of tripartite relationships between academia, industry, and government in developing sustainability innovation culture. These partnerships form ecosystems in which students can be exposed to the real-life issues of sustainability and policy-based engineering. Bae et al. [18] and Birdman et al. [25] demonstrate that these partnerships increase student employability through the development of SDG-related skills that are useful in the construction and infrastructure industry. Similarly, the authors of the studies by A. Alvarez et al. [14] and Kandakatla et al. [35] determine that the project-based service learning and community engagement are the most effective best practices in the translation of the sustainability theory into tangible competencies.

Conceptual orientation wise, developing the main sustainability competencies is at the leading edge of the new practices. Brundiers et al. [17] discuss the combination of anticipatory, normative, and strategic thinking as the key to sustainability education so that students can discuss engineering issues in a holistic system. Narong and Hallinger [4] build on this discussion by proposing longitudinal research that would assess the impact of sustainability competencies on the graduate outcomes and their professional performance. Mulder [6] recommends the creation of strategic competencies of concrete action, which would place civil engineers in the role of agents of transformational action that would translate the sustainability ideas into concrete design and policy.

These new tendencies represent the paradigm shift of the passive sustainability awareness to the active, competence-based, and data-driven engagement. The concept of SDGs being an integral part of civil engineering education has ceased to remain a theoretical construct and has become a working model that influences teaching and research, as well as practice.

Table 5: Emerging Trends and Best Practices in Integrating SDGs into Civil Engineering Education

Trend/Practice	Author(s)	Key Insights and Contributions
Experiential and Interdisciplinary Learning	[41]; [12]	Promoted project-based and community-driven learning for sustainability in engineering.
Competency-Based Education and Accreditation	[13]; [4]	Introduced sustainability competencies and institutional accountability in curriculum design.
Digital Transformation and Modeling	[37]; [38]	Utilized AI, BIM, and data analytics for sustainable design and system modeling.
Institutional and Industry Collaboration	[29]; [30]; [18] ; [25]	Fostered partnerships linking academia with real-world sustainability challenges and employability.
Project-Based and Service Learning	[14]; [35]	Enhanced sustainability competencies through hands-on, socially relevant engineering projects.

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Sustainability Competency Development	[17]; [5]; [6]	Emphasized systemic, strategic, and ethical competencies for transformative sustainability leadership.

Table 5 identifies the most dominant trends and best practice areas to make Sustainable Development Goals (SDGs) embedded in the education of civil engineering, namely experiential learning, competency models, digital innovations, institutional partnerships, and skill development oriented to sustainability. The new tendencies in the SDG integration are the evidence of the active development of the civil engineering education, the one that is both innovative and responsible. Universities are transforming the purpose of civil engineers to be more than just the creators of infrastructure through experiential learning, digital modeling, institutional collaboration and development of transformative competencies to be stewards of sustainable futures.

7. Future Directions and Opportunities

Inclusion of Sustainable Development Goals (SDGs) in education within civil engineering is not a conclusive process but a process that needs innovation, collaboration, and education transformation. As higher education institutions transition from awareness to action, new opportunities are emerging to deepen and scale sustainability integration across all dimensions of teaching, research, and professional engagement. The future of SDG-based civil engineering education is in the development of the generation of engineers who will be able to integrate technical excellence and social, environmental, and ethical responsibility.

One of the leading directions is institutionalization of transformative pedagogue. Civil engineering education needs to shift the focus of providing technical knowledge to the systems thinking, ethical reasoning and critical reflection as learning outcomes. Transformative learning helps students to perceive the interdependence of infrastructure, environment, and society so that they can tackle complex sustainability issues in their entirety. Integrating sustainability in all courses not as an option but as a core aspect will make graduates internalize the concept of sustainability to be a part of their professional identity. Such integration needs to be a constant development of the faculty and change of the culture of institutions to be able to reward interdisciplinary teaching and sustainability-focused innovation.

The other prospective path is the advancement of the quantitative sustainability indicators in curriculum assessment. Conventional course evaluations are not very effective in assessing the depth of sustainability learning. Universities can determine the success of civil engineering education programs in achieving global sustainability goals by developing data-driven measures, including sustainability literacy indices, project based evaluation framework and SDG alignment audits. These metrics may be used to standardize the best practices, increase accountability, and inter-institutional benchmarking. Moreover, adding sustainability indicators to accreditation systems may encourage departments to have sustained improvement and evidence-based review.

The technological innovation is a great opportunity in providing sustainability education. Quantitative analysis of the environmental and social effects of engineering designs through the integration of mathematical modeling, simulation, and artificial intelligence into civil engineering curricula allow students to understand the environmental and social effects of their engineering designs. The SDG-

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related learning outcomes can be more measurable and practical through the tools that can assist in simulating climate resilience, energy efficiency, and resource optimization in the infrastructure systems. During the age of digitalization of the construction and infrastructure industry, the ability to use sustainability-related modeling tools will be a mandatory professional competency.

International cooperation and online learning environments are also crucial possibilities that can contribute to the development of SDG-oriented engineering education. Democratization of knowledge on sustainability can be achieved by establishing open-source repositories and virtual laboratories, joint programs between countries, and international programs between countries. Joint projects among the universities, industry and policymakers can be used to produce shared structures of sustainability education which can be tailored to local situations. This is in line with the vision of establishing a globally networked learning ecosystem towards sustainable engineering one that will close the divide between the developed and the developing educational systems.

Inclusive and equitable sustainability approaches should be highlighted in the future of civil engineering education. By empowering the underrepresented regions, incorporating the indigenous knowledge systems, and encouraging gender equity in engineering, SDG implementation will be socially as well as environmentally responsible. When civil engineering education is informed by the SDGs, it can therefore become a game changer in that it will no longer develop infrastructure that is efficient and safe, but rather resilient, inclusive and sustainable.

Table 6: Future Directions and Opportunities for Integrating SDGs into Civil Engineering Education

Future Focus Area	Description	Expected Impact on Civil Engineering Education
Transformative Pedagogy	Shift from technical instruction to systems thinking, ethics, and reflection-based learning.	Cultivates engineers with holistic understanding and ethical responsibility.
Sustainability Across All Courses	Embed SDG principles into every engineering module rather than as electives.	Ensures sustainability becomes an integral and consistent component of all engineering training.
Quantitative Sustainability Indices	Development of measurable indicators and SDG-alignment tools for curriculum evaluation.	Enables data-driven assessment and continuous improvement in sustainability integration.
Mathematical Modeling and Simulation	Application of digital tools, AI, and simulation to evaluate sustainability performance.	Enhances analytical and problem-solving capabilities related to sustainable infrastructure.
Global Collaboration and Open-Access Platforms	Creation of digital networks and partnerships for sharing sustainability education resources.	Promotes equity, innovation, and global knowledge exchange in sustainable engineering education.

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Inclusive and Equitable Sustainability Education	Inclusion of diverse perspectives, regions, and gender considerations in curricula.	Fosters social justice and inclusivity within global sustainability practices.

The future of civil engineering education incorporates the future of making universities dynamic agents of sustainable change as illustrated in Table 6. Higher education is capable of producing engineers who can not only construct physical infrastructure, but also construct a sustainable and just world through pedagogical creativity, quantitative evaluation, technological combination and collaboration with the rest of the world.

8. Policy and Institutional Recommendations

Achieving the Sustainable Development Goals (SDGs) in civil engineering education requires a change in the structure of policy and institutional level in civil engineering education to attain meaningful inclusion. Universities, accreditation bodies, and other professional associations should work together so as to rebrand engineering education as a form of sustainable development. To bring higher education outcomes into the global sustainability agenda, policy frameworks must go beyond symbolic commitment, in order to inculcate sustainability as a core organisational value, by establishing measurable standards, which can bring into line higher education outcomes. Aligning accreditation and quality assurance systems with sustainability competencies is one of the background measures. The current civil engineers must have the capacity to lead, be ethical and sustainably literate besides being technically competent, as indicated by the Civil Engineering Body of Knowledge Task Committee [15]. Incorporation of these dimensions into national and international accreditation models like ABET and EUR-ACE would also make sure that sustainability is integrated in the learning outcome as well as the professional competencies. Vedhathiri [39] goes on to point out the need to revise the evaluation frameworks to incorporate sustainability-driven graduate attributes where universities will be able to evaluate the capability of students to solve SDG-related problems in real life scenarios.

Interdisciplinary collaboration and pedagogical innovation should also be the priority of institutional policies. According to Chan and Lee [16], positive alignment between the assessment and curriculum design is essential in order to strengthen holistic learning outcomes. This necessitates policy backing of cross disciplinary programmes, collaborative faculty courses, and inclusion of sustainability courses at all levels of the engineering training. The development of engineers who could solve complex sustainability problems with integrated solutions can be achieved by promoting the cooperation of civil engineering, environmental science, economics, and social studies in various institutions. In addition, the faculty development policies must offer ongoing professional development on sustainability pedagogy that can enable teachers to transform the global SDG frameworks into practical classroom activities.

The other important recommendation is on the institutional governance and strategic planning. According to Zhou et al. [2], universities can be central to transforming the global sustainability promises into the local through embedding SDGs into their missions, governance systems, and research directions. Avelar et al. [3] take this further and point out that higher institutions of learning need to embrace holistic sustainability policies that bridge the teaching, research, and external

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relationships. To maintain sustainability, it is possible to set up sustainability offices/committees to maintain a steady check on the progress and coordinate with the different departments as well as enhance accountability mechanisms.

The policy frameworks must also promote community and industry involvement making civil engineering education a source of sustainable innovation. Nurse and Pellecuer [40] emphasize that the introduction of the principles of the circular economy and collaboration within the industry into the academic curriculum can speed up the implementation of sustainable practices in the construction and management of resources. Through collaborations with local governments, non-profit making organizations, and business entities, universities are able to give opportunities to students to have an experiential learning experience that directly responds to SDG goals, including resilient infrastructure (SDG 9) and sustainable cities (SDG 11).

The international collaboration and knowledge sharing should be institutionalized in order to achieve global uniformity in sustainability measures. The networks among the universities in different regions can help to share best practices, promote the mobility programs, and compare research on SDG implementation. The policymakers need to facilitate funding programs on collective sustainability and access to open platforms on world curriculum materials.

The progressive SDG integration in civil engineering education is a policy that needs to be coordinated and it should include accreditation reform, institutional leadership, and stakeholder collaboration. Higher learning institutions can create civil engineers who do not just design infrastructure but also construct equitable, resilient and sustainable societies by instilling sustainability in educational standards, faculty development and governance systems.

9. Conclusion

The implementation of the Sustainable Development Goals (SDGs) in the field of civil engineering education is a paradigm shift in the harmonisation of higher education with the global sustainability requirements. The integration of sustainability in the university and professional bodies engineering curricula, pedagogy, and institutional governance has been critically analysed in the review. As it may be observed, civil engineering, as the institution, which has the mandate of designing infrastructures and cities, is at the centre of advancing such agendas as resilient cities, climate action, and responsible use of resources. Implementation of SDG principles in civil engineering curriculum does not only enhance technical competency but also moral, environmental and social awareness that are important qualities of 21 st -century engineers. Despite the great improvement, the integration remains unequal at the regional and institutional levels because of structural, pedagogical, and cultural barriers. These problems necessitate institutional reform on the basis of policy congruence, interdisciplinary collaboration, and evidence-based evaluation models. The future directions should be aimed at transformative pedagogy, quantitative assessment tools, and digital technologies that will be implemented to turn the sustainability theory into practise. The universities are also supposed to increase their cooperation with the industries and communities such that sustainability education is not just taught in the classes but also practised. The civil engineering training must be reformed to be grounded on knowledge transfer to sustainability change. Having SDGs at the heart of the academic and professional practise, engineers will be able to not only design infrastructure, but also create a sustainable and just future of the future generations.

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