Engineering Education for a Sustainable Future A systematic literature review and a perspective

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Abstract. Education represents a fundamental pillar of society, being an important factor in shaping and building each individual for their future. It is common sense that society, like the world we live in, undergoes adaptations and modifications over time, especially due to the need to resolve issues that allow for improved comfort and greater chances of survival in these changes. Therefore, a question arises: what factor must be highlighted in order to respond to this need? Sustainability presents itself as a preponderant factor in humanity's response to building a more sober, educated, conscious and cohesive society. Educating an individual with tools and qualities based on sustainability, who in the future will have the capacity to reach many other individuals in an educational context, presents itself as a possible way to enhance and disseminate sustainability in social, academic and professional aspects. This study is based on the premise of an ERASMUS + project that aims to provide a possibility for a more sustainable education in the field of Engineering, having as its central point a holistic approach that must be the center of society: Sustainability.

Keywords: Sustainability, Education, Engineering.

1 Introduction

Society, in its global context, is faced with opportunities and challenges, with both technological progress and globalization identified in this ambiguity. The increase in the complexity of all the factors involved and the diversity of available information does not allow for a single and homogeneous solution to all the issues imposed, but rather for creative processes and properly organized actions [1]. It is a fact that this combination of sustainability aspects is crucial for the future of society. Sustainable Development (SD), in its genesis, represents the balance between society's natural cycle dynamics and progress [2]. In the aforementioned context of globalization, higher education institutions (HEIs) are significant in global procurement, international partnerships, reaching students comprehensively through mobility, as is the example of the ERASMUS Program. These characteristics enhance the development of economic aspects, strengthening communities and combating poverty [3]. In HEIs, education for sustainable development must be a priority rather than being considered an option [4]. Universities, as teaching and research institutions, as well as employment promotion entities, present themselves as opportunities for the dissemination of very comprehensive education, as they educate societies' future decision makers, offering learning opportunities, methodologies and qualities that contribute to the application of your professional path, resulting in a more sustainable and innovative future [5]. Recently, Sustainability embedded in programs has increased and demonstrated potential within society and HEIs, particularly in environmental issues as well as sustainable development [6]. There is a common convergence trend in the literature that higher education institutions play a fundamental role in achieving a sustainable development [7]. There is consensus among academics and professionals about the key principles inherent to sustainability, as if a scroll were about how to achieve sustainable development using some common rules or objectives, as is the case with the Sustainable Development Goals (SDGs) [8]. The lack of sufficient skills in teachers' curricula is a challenge for the implementation of objectives and targets within sustainability [9]. This highlights the importance of providing not only students, but also all elements of HEIs with knowledge, virtues and soft skills in the field of sustainability with the aim of making the most of each individual, as a productive element of society. Another important aspect relies on the possibility to exist a link between sustainability and resilience. Resilience is presented as the ability to absorb, recover and adapt to adverse events, while sustainability can equally be defined as overcoming the needs of the present without endangering the interests of its three pillars, namely, society, economy and the environment [10]. Therefore, a practical approach to HEI students could be to deepen the practice of resilience.

In educational institutions, such as HEIs, Knowledge is poured into subjects adapted to an academic environment in order to prepare for the professional future. The implementation of practical approaches based on interdisciplinarity allows for effectiveness in understanding complex and multipolar challenges, as it brings together different themes and programmatic contents that, despite being from different areas, are linked to each other. The alignment of sustainable development goals and their synergies highlight the need for professionals and students who master different skills and knowledge, disciplines and sectors, resulting in the need for teamwork to deliver the goals. Multifaceted issues require skills and education from different disciplines and experiences in an integrated way. The development of interdisciplinarity in education promotes the ability to understand and act on issues, aligning the solution with the desired outcome for sustainable development [11]. For Summers, Childs and Corney (2005, p. 627). It therefore becomes evident to understand which skills that students should have to better face the challenges of the future, particularly in sustainability issues. It is with this premise that the ERASMUS + Project called Engineering Education for a Sustainable Future (EESF) was born, with the following objectives:

- Develop and implement innovative learning and teaching practices in engineering education in four HEIs linked to the 2030 SDG framework;
- Ensure undergraduates (European Qualifications Framework - EQF 5-6) are better equipped to use their engineering knowledge to tackle societal challenges and make a lasting contribution to the realisation of the SDG's;
- Stimulate innovative learning and teaching. Our objectives are underpinned by our shared commitment to the environment, the fight against climate change and the SDGs;
- Challenging students to embrace sustainability and apply their engineering knowledge to real-world challenges, the stakeholders should boost their CIVIC mindset.

It is therefore important to carry out a literature review in order to understand the difficulties that the project may face.

2 Current pratical approaches to embedding SDGs in courses/programmes

Over the last decades, HEIs have been increasingly preoccupied with sustainability and sustainable development issues in engineering education[12]. The Sustainable Development Goals (SDGs), adopted by all United Nations Member States in 2015, provide a comprehensive framework for addressing global challenges such as poverty, inequality, climate change, and environmental degradation. As key drivers of innovation and progress, engineers play a critical role in achieving the SDGs by developing sustainable solutions to complex societal problems [13]. Engineering Education for Sustainable Development requires adoption of innovative strategies and adequate pedagogical approaches to support future engineers in developing adequate professional skills. Such professional skills include effective communication, critical thinking, problem-solving, teamwork, leadership, technical and non-technical skills, ethical behaviour, social responsibility, and sustainability. Therefore, engineering education must evolve to encompass a broader spectrum of skills, emphasizing the importance of developing professional behaviours and attitudes alongside technical competencies. By doing so, it aims to better prepare engineering graduates for the multifaceted roles they will play in society, ensuring they are equipped to contribute to sustainable development and the well-being of communities worldwide [12]. Embedding the SDGs in engineering courses involves integrating these global objectives into the curriculum, teaching methods, and project work within engineering programmes. This approach is aimed at equipping future engineers with the knowledge, skills, and attitudes necessary to contribute to sustainable development. Key strategies for incorporating the SDGs into engineering education are (1) curriculum design; (2) interdisciplinary projects and courses; (3) service learning and community engagement. However, these strategies are not without (4) challenges and all of these are discussed below.

2.1 Curriculum Design

One of the primary ways to embed the SDGs in engineering courses is through curriculum integration. In terms of teaching strategies, there's widespread consensus on employing active learning methods [14], [15], [16] such as problem-based learning, project-oriented learning, case-based learning, solution-oriented learning, challenge-based learning, service learning, and simulations [12], as well as study visits, games, simulations or dramatizations are considered “the most effective tools for integrating sustainability into the engineering curriculum” [14], [16].These approaches are highly recommended for fostering the necessary competencies in Engineering Education for Sustainable Development (EESD). For example, civil engineering courses may address SDG 11 (Sustainable Cities and Communities) by exploring urban planning, infrastructure development, and sustainable transportation systems [17]. Similarly, environmental engineering courses can focus on SDG 6 (Clean Water and Sanitation) by examining water treatment technologies, wastewater management, and pollution prevention strategies, topics of critical importance [18]. Overall, incorporating SDGs into engineering curricula is vital for enhancing awareness and engagement with these goals among both faculty and students. In addition to what is taught in the classroom, another aspect to be considered is how specific elements are conveyed by faculty within the classroom – or what the literature recognize as the ‘hidden curriculum’ [12]. Given that academics' beliefs significantly influence educational reform [19], faculty members must cultivate a deep understanding of SDGs to seamlessly integrate them into the curriculum and effectively teach them in the classroom.

2.2 Interdisciplinary Research Projects and Courses

Interdisciplinary research projects and courses provide valuable opportunities for engineering students to explore the interconnected nature of the SDGs and collaborate across disciplines to develop innovative solutions [14][20][21]. Sustainability encompasses various interconnected dimensions, challenging the traditional compartmentalization of knowledge within specific disciplines. The rationale for adopting multidisciplinary approaches to embedding SDGs in engineering programmes stems from the recognition that sustainability issues are complex and interconnected, transcending the scope of any single discipline [14]. Consequently, there's a pressing need for engineers who are not just technically skilled but also possess the capability to consider and address the broader social, economic, and environmental contexts of their work [21]. Such needs call for “a type of engineer who is socially connected and who can work both within and outside the boundaries of his or her own discipline” [21]and are well-equipped to contribute to sustainable development in a holistic manner[20]. For example, a multidisciplinary engineering course could bring together students from different disciplines, such as mechanical engineering, electrical engineering, and computer science, to design and build renewable energy systems for off-grid communities. Working in interdisciplinary teams enables students to address sustainability challenges and develop solutions for real-world sustainability issues [14]). Multidisciplinary project create opportunities for students to interact with a range of stakeholders and work alongside their peers, fostering a holistic understanding of sustainability and tackling the intricate challenges associated with it [14], [21], [22]. Curricular emphasis on interdisciplinary topics and skills, along with co-curricular activities like participating in non-engineering clubs, studying abroad, and engaging in humanitarian engineering projects, significantly enhance students' interdisciplinary skills. Faculty beliefs about interdisciplinarity in engineering education also play a moderating role, influencing the relationship between certain co-curricular experiences and students' interdisciplinary skills [22] .

2.3 Service-Learning and Community Engagement

Service-learning and community engagement initiatives offer another avenue for embedding the SDGs in engineering courses. Service-learning is defined as “a credit-bearing, educational experience in which students participate in an organized service activity that meets identified community needs and reflect on the service activity in such a way as to gain further understanding of course content, a broader appreciation of the discipline and an enhanced sense of civic responsibility” [23]. The literature extensively supports the idea that community engagement or service-learning, as an educational approach, yields benefits for students, staff, institutions, and the community alike [24]. Students involved in such programs often report greater satisfaction with their courses, exhibit enhanced academic outcomes and critical thinking abilities [23] , improved leadership and teamwork skills and cultural awareness [24]. By partnering with local communities, non-profit organizations, and government agencies, engineering students can apply their skills and knowledge to address real-world sustainability challenges [23].

2.4 Challenges and Considerations

While embedding the SDGs in engineering courses offers numerous benefits, it also presents challenges and considerations. One challenge is the interdisciplinary nature of the SDGs, which may require collaboration between departments and faculties to ensure comprehensive coverage across the curriculum, development of critical thinking skills, interpersonal competencies, integrated problem solving, interdisciplinary work and continuous learning [12].Yet, some faculty members may lack motivation to engage in interdisciplinary projects [25].Ensuring faculty members receive proper training and support to seamlessly weave SDGs into their courses and evaluations is essential [12], [26], [27]. Nonetheless, financial constraints and insufficient resources can hinder the ability of universities to provide this training, posing a substantial obstacle to the effective embedding of SDGs into academic programs and their delivery in the classroom [25], [28]. Additionally, integration of SDGs in alignment with accreditation mandates and industry benchmarks, requires thoughtful planning and coordination [24]. Embedding the SDGs in engineering courses is essential for preparing future engineers to address pressing global challenges and contribute to sustainable development efforts [12]. By integrating SDGs into the curriculum, offering interdisciplinary projects and courses, and engaging students in service-learning and community engagement initiatives, universities can empower students to become agents of positive change in their future careers [23]. While challenges may arise, the benefits of embedding the SDGs in engineering education far outweigh the obstacles, ultimately advancing the goal of creating a more sustainable and equitable world.

3 Barriers to Embedding SDGs in Engineering Education

Embedding SDGs in HEIs is not without challenges. A recent review of the literature distinguishes between external barriers related to the economic, political and social environment and internal barriers related to the human nature of managers, infrastructure and resource availability [26].Serafini et al. (2022) summarize the macro perspective barriers to SDG implementation into six main categories: (1) human resources; (2) financing; (3) government; (4) organizational; (5) society; (6) communication.

Regarding the human resources dimension, Serafini et al. (2022) highlight that when implementing SDG policies in institutions, projects typically involve allocating resources, forming teams, establishing assistance centers, and developing infrastructure. Initially, significant efforts are concentrated to ensure widespread dissemination within institutions. However, over time, without strong coordination from a central coordinator, the momentum diminishes, resulting in reduced dissemination and impact of post-graduation programs throughout the university. One particular issue is that in many universities, actions related to SDGs implementation are often isolated and lack coordination among research groups and alignment with management objectives, leading to project failures and eventual discontinuation. University outreach projects should uniformly educate the university community on SDGs to achieve standardized knowledge among all members. While some universities have integrated SDGs into their curriculum or specific projects, there is a lack of standardized documents guiding this institutional process at a national level. Overall, Serafini et al. (2022) underline the need for institutions to prioritize SDGs uniformly and provide active engagement opportunities for students to address social issues, thereby fostering a collective effort towards improving the environment and society.

In relation to the financial dimension, Serafini et al. (2022) identify inadequate resource availability within institutions and the lack of funding from government and private sources as a barrier to SDGs implementation. That is because the scarcity of resources often renders project execution infeasible, thereby undermining the global competitiveness of universities.

The third dimension, government, represents a barrier to SDGs implementation due to the often bureaucratic nature of processes and practices. Additional obstacles identified by Serafini et al. (2022) include variations among institutions based on factors such as university size, resource availability, and project volume; high levels of taxes and tuition fees that reduce researchers' project budgets and potentially discouraging new initiatives; lack of experience among research foundations and researchers; and insufficient awareness of proper accountability practices. Addressing these challenges requires aligning internal norms with external funding agencies, fostering cooperation networks, and promoting government support to stimulate SDG integration and research collaboration. Overall, these efforts are crucial for facilitating growth and sharing successful experiences among institutions in achieving the 2030 Agenda.

Organizational dimension has been recognized as a significant challenge, as it shapes the incentives that the work environment can offer to the entire community. Serafini et al. (2022) highlight the lack of uniformity in course content pertaining to Sustainable Development Goals (SDGs) within a single institution and suggest that universities should consider empowering departmental leaders to implement coordinated actions spanning all levels of the institution. Currently, SDGs dissemination process can be hindered by universities' lack of flexibility in their curriculum leading to rigidity in classroom dissemination (Serafini et al., 2022). Failure to integrate discussions on SDGs into classroom subjects, hinders students' awareness of and engagement with SDGs (Serafini et al., 2022).

Regarding the social dimension, discussions surrounding SDGs have gained global significance, urging companies and universities to reconfigure their production processes to align their supply chains with customer needs. Serafini et al. (2022) define social barriers as "the lack of alignment of the internal process of universities with the different organizational processes inherent to each institution". This misalignment extends to classroom teachings, which often fail to address real-world economic challenges, relying primarily on theoretical content rather than practical experience. To bridge this gap, universities are increasingly adopting active methodologies, such as case studies, to disseminate SDGs [26].

Conclusions

The transition towards integrating SDGs into HEIs, particularly within engineering disciplines, reflects a pivotal shift in educational paradigms, driven by global sustainability challenges. This shift underscores the vital role of HEIs in nurturing a new generation of engineers equipped not only with technical expertise but with a profound understanding of and commitment to sustainable development. Integration of SDGs within the engineering curriculum enhances students' awareness, understanding, and engagement with sustainability issues, preparing them to become agents of change in their professional and personal lives. However, the journey towards full integration of SDGs into HEIs is fraught with complexities, including institutional inertia, lack of resources, and the need for cultural change among faculty and students. It is possible to conclude the importance of interaction with students and members of the HEIS staff in order to interact, develop critical thinking, as well as carry out actions in order to observe, verify and measure the impact they had on these individuals. It is also concluded that projects that involve practical actions, critical experimentation and implementation of innovative methodologies increase the engagement of these individuals, promoting the improvement of the academic environment in HEIs, leaving a clear promise of success in the professional future with more sustainable practices.

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