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Barriers to Effective Sustainable Development Education for Civil Engineering Students

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The urgency of sustainable development has led educational institutions to incorporate sustainability principles into engineering curricula. However, questions remain about whether this approach effectively instills a sustainability-oriented mindset in graduates. Given the pivotal role of education in achieving sustainability goals, it is essential to optimize the impact of sustainable development education. This study explores key barriers to effective sustainability education based on literature review findings and survey results from 48 civil engineering students at Washington State University. The survey measured student perspectives on seven primary barriers: (1) insufficient instilment of commitment to sustainability, (2) inadequate program structure for comprehensive understanding, (3) limited integration of sustainability in decision-making processes, (4) weak program policies supporting sustainability, (5) non-binding declarations lacking accountability, (6) overly crowded curricula, and (7) lack of faculty collaboration. The results showed that "insufficient instilment of commitment" and "inadequate program structure" were perceived as the most critical obstacles. These findings highlight the need for targeted curriculum reforms and institutional support to strengthen sustainability education. Addressing these barriers can better equip future engineers with the values and knowledge needed to support sustainable practices, ultimately advancing educational institutions' contribution to global sustainability goals.

Keywords: Sustainable development, engineering, education, barriers

Introduction

As the alarming impacts of development on the environment, society, and economy are more widely understood compared to the past decades (Jackson, 2009), a global effort has been initiated to mitigate the risks of development and push it toward more sustainable approaches (Lafferty, and Eckerberg, 2013). Multiple guidelines, industry standards, and regulations have been developed by the United Nations (2007), the European Commission (2016), and other organizations to mitigate the negative impacts of development. However, the research indicates that without a global determination to contribute to sustainability, rules and standards cannot effectively enhance the sustainability of development (Salomaa & Juhola, 2020). A paradigm shift is required to happen in people's mindsets that warns them about the negative impacts of unsustainable decisions and motivates them to contribute to sustainability at all times. Higher education plays a central role in fostering this paradigm shift.

Although higher education has evolved in incorporating sustainability in its curricula, there are still significant opportunities in higher education that indicate a demand to reinforce its contribution to sustainable development. For instance, research findings show the institution's commitment to sustainability can be observed by the students (Lozano et al., 2015). The role of engineering education in contributing to sustainable development can be attributed to the significant roles that engineers play in the industry. Engineers' knowledge, priorities, and decisions they make as industrial professionals have roots in their academic backgrounds. For instance, in the classes, they learn how to do an economic appraisal to select between different possible solutions. However, considering sustainability in decisions is commonly less emphasized in engineering education (Rosen, 2012). The construction sector significantly contributes to various environmental challenges, including high energy (Ortiz et al., 2009) and water consumption (Tafazzoli, 2016), greenhouse gas emissions, material waste, and alterations to natural runoff patterns (Tafazzoli, 2018a & 2018b). Many construction professionals remain reluctant to adopt sustainable practices, often due to a lack of awareness or other industry constraints (Tafazzoli, 2018c). This paper explores strategies to enhance the effectiveness of sustainability education in civil engineering, aiming to amplify its impact on industry practices.

Background

Embedding sustainable development principles into the academic systems is one of the leading solutions to enhancing the academia's contribution to sustainable development (Weber et al. 2014; Lozano, 2006). Most governments have not considered education as a primary organizing principle for economic development (Calder and Clugston, 2003). Though, many higher education institutions have voluntarily engaged themselves in this effort during the last two decades (Lozano at al., 2015). According to the findings of Lozano et al. (2013), this engagement is based on utilizing traditional paradigms that primarily rely on reductionist thinking and mechanistic interpretation (Lovelock, 2007). One of the earliest formal recognitions of the academia's impact on sustainable development was the United Nations Development Program that was issued at the Stockholm Conference in 1972 and highlighted the role of academia in contributing to environmental protection and conservation (UNEP, 1972). This led to increased engagement of academia in reflecting sustainable development in their systems. The contribution of academia to sustainability has evolved parallel to the establishment of the necessity of sustainable development in communities. Since the notion of sustainability in higher education (SHE) at an international level by the United Nations UNESCO-UNEP International Environmental Education Program in 1978, multiple declarations about environmental sustainability in higher education have been developed (Wright, 2004). These declarations have evolved to incorporate a more comprehensive approach to contribute to sustainable development. Figure 1 shows the evolutionary role of academia in sustainable development (data from Wright, 2004).

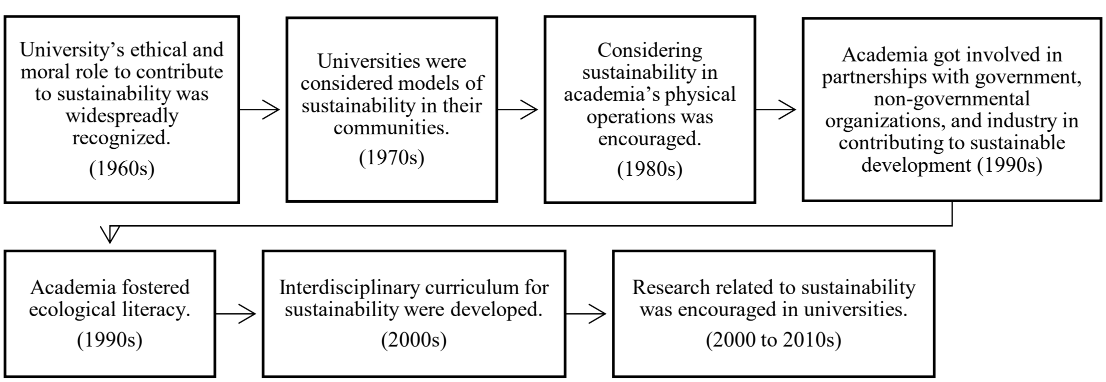

Figure 1. The evolution of academia's role in contributing to sustainable development

Several studies have focused on finding solutions for the assessment of academia's contributions to sustainable development. Klein-Banai and Theis (2013) studied the direct impact of institutions of higher education on greenhouse gas emissions for 135 colleges and universities reporting greenhouse gas emissions. The indirect impact of academia on sustainability has been widely addressed in the literature. There is a strong agreement that universities have massive potential in enhancing sustainability thinking not only among their students, but also in the hosting community, and the industry. This potential can be fostered or wasted depending on academia's performance. Dlouh et al. (2013) highlighted the regional impact of universities in establishing sustainability- oriented thinking. The author noted that "involvement in sustainability education reflects not only policy demands but also the transformation of the epistemological perspective in science and education". In another research Lee et al., (2013), it was noted that academia has the role of leadership in the hosting community by showing commitment to sustainable development. Figure 1 shows the evolutionary role of academia in sustainable development (data from Wright, 2004).

The massive impact of different industries on sustainability has been shown in several studies (Labuschagne et al., 2005). Although many industries have significantly adopted more sustainable practices in the extraction and processing of raw materials, declaration of ingredients, and delivery of products, there are significant barriers to accommodating more sustainable methods in the industry (Tafazzoli, 2017a). Table 1 shows some of the barriers to adopting sustainable practices in the industry. One of the critical issues regarding this is the fact that monetary incentives are prior to environmental protection from the lens of the real-world industry. For instance, cost savings resulting from reducing the water and energy consumption in sustainable buildings are expected to motivate industry professionals to accept the additional initial cost of sustainable construction. Though, in many cases, those who benefit from these savings are different from the investors and developers. In other words, cost savings can only compensate for the additional initial costs if the investors reside in the facility and do not sell it to other users. When the monetary factor cannot be a strong incentive, there is a need in the industry to understand the necessity of using sustainable methods even though they lead to additional costs (Tafazzoli, 2017b). Such motivation cannot be effectively created for the industry through rules and regulations. Relying on these rules can lead to greenwashing, which is misleading eco-friendly claims for marketing (Tokar, 1997). If the engineers have the knowledge and awareness from their academic background, they can potentially bring this motivation to the industry (Cook et al., 2006).

Table 1. Research findings for the barriers to adopting sustainable practices in the industry

Author	Study Area	Year published	Major barriers
Van Bueren and Priemus	Netherland	2002	Institutional factors
Studer et al.	Hong Kong	2005	Lack of a legal requirement to report sustainability, poor support from senior management, no demand from shareholders for sustainability reporting
Pinkse and Dommisse	Netherland	2009	Costs for the contractors
Sourani	England	2011	lack of funding, restrictions on expenditure and reluctance to incur higher capital cost when needed
Tafazzoli	United States	2018c	Unwillingness to pay the additional initial costs of the green buildings.

Barriers to Effective Sustainable Development Education to Civil Engineering Students

1) Poor instilment of the necessity of commitment to sustainability in students. Davis et al. (2003), studied the challenges and driving forces for institutions that are integrating sustainability concepts into teaching. The findings indicate that students' awareness of the concept of sustainability is limited as the majority of the sampled groups consider sustainability just as an ecological concern. The research of Sibbel (2009) and Birdsall (2014) supported these findings. also Establishing the broad impacts of sustainability in the industry for engineering students can help them understand why sustainable decisions are critical even though they may initially seem expensive. When this necessity is internalized in engineering graduates, it can impact the decisions they will make in their careers. This, in turn, is expected to impact the industry by modifying its benefit-oriented approach to a more sustainability-oriented approach. The engineering education has a responsibility to establish a profound understanding of how the decisions they make are connected with a broad range of ripple impacts on the triple bottom lines and how incorporating sustainability considerations into their decisions can contribute to the environment, society, and economy.

2) Inability of the Engineering Programs in Establishing a Comprehensive Understanding of Sustainable Development. As mentioned, the term sustainability is commonly associated with environmental protection, and the societal and economic aspects of it are not sufficiently considered (Wright, 2002). Engineering education creates an appropriate opportunity to fix this misinterpretation of sustainability. Engineering students must learn how their decisions can impact non-environmental aspects of sustainability such as mobility for the handicapped, reduction of property values in a project's vicinity, promoting using alternative modes of transportation, reducing absenteeism for the occupants, or improving the vitality of indoor spaces, and contributing to the health and well-being of the hosting community to name a few. Such a broad consideration of sustainability does not currently exist in engineering education (Wright, 2002). Another critical aspect of enhancing students' understanding of sustainability is instilling a comprehension of life cycle impacts in all decisions they will make as engineers (Mälkkiand Alanne, 2017). A life-cycle approach is an essential paradigm shift required in the industry to be incorporated into environmental, occupational health and safety, risk and quality management. Engineering students are traditionally taught to assess the initial costs and impacts of projects and do not focus on how these factors might change in the course of project life. Weber et al. (2014) findings indicated the misconceptions about assessment among engineering students and the need for improving their comprehension of it. This approach needs to be improved.

3) Inadequate Teaching of Integration of Sustainability into Engineering Decision Making. Traditional engineering education was primarily based on problem-solving (Mills & Treagust, 2003). Little creativity or critical thinking is involved in these methods to evaluate different possible scenarios by a comprehensive assessment of the sustainability impacts in each of the alternatives. The comprehensive assessment approach is integral in sustainable decision-making and engineering education requires to more effectively reflect it in the students' curricula. Due to the multiple aspects of a sustainable decision, it is a challenge to establish an understanding of the various potential consequences of a decision for students. For instance, in selecting construction materials for a project the following criteria must be involved to come up with a sustainable decision, 1) if the manufacturer utilizes sustainable practices in extracting raw materials, processing and shipping them, 2) If the manufacturer discloses the ingredients of the material, 3) the embodied energy of the material, 4) possibility of Co2, pollutants, or toxic emissions from the material, 5) If this purchase supports local economy or underprivileged businesses (USGBC). According to Schwarz et al. (2002), the development of metrics is a simple approach many companies take to incorporate the goals of sustainability into decision-making. Engineering students need to be provided with the education they would find beneficial in multi-criteria decision-making to maximize the sustainability goals.

4) Poor Integration of Sustainability in the Engineering Program's Policies and Strategic Plans. To systematically pursue the integration of sustainability in the engineering program's policies and plans, a useful tool is developing a declaration that clearly explains the program's sustainability commitments, objectives, and plans to meet these objectives. Sustainably declarations are one of the primary tools of academia in defining and pursuing sustainability goals. This explains why many institutions invest in developing and refining their declaration. An example of these declarations is the American College and University Presidents Climate Commitment (ACUPCC). Based on this program, institutions are required to account for their emissions and develop a climate action plan with emissions reduction goals (Klein-Banai and Theis, 2013). These declarations do not currently exist in many engineering programs or are limited to a few sustainability objectives that are listed in the University, department, or program's strategic plan (Lozano, 2013). The sustainability declaration must be developed as a comprehensive official document that encompasses different short- and long-term goals. Furthermore, the declaration must introduce guidelines (Calder and Clugston, 2003) and define the responsibilities of involved parties in achieving decided goals within the specified timeframe. The effectiveness of creating these declarations in ratifying the program's contribution to sustainability has been emphasized by several authors (Cole and Wright, 2005, Calder and Clugston, 2003, Lozano et al., 2015). In many programs that have developed a sustainability declaration, the document remains unchanged in different years. The declaration needs to be updated at specific intervals to reflect the opportunities and challenges of the engineering program that can impact its sustainability goals, approaches, or plans. Ideally, a declaration should involve all the students, faculty, and staff by defining how each of them is expected to contribute to the objectives. It is essential to maintain this statement as practical as possible. Idealistic objectives that remain unachieved by their specified deadlines demoralize the team's effort to pursue future goals.

5) Non-binding Sustainability Declarations. Bekessy et al. (2007), studied the failure of non-binding declarations to achieve university sustainability goals. The authors found that accountability can impact the achievements of these declarations. The research suggests that without scrutinizing progress, declarations deviate to greenwashing rather than leading to real accomplishments in sustainability. The examination of Wright (2004) supports these findings. The author emphasized that the themes that are pictured in the declarations should act as a constant reminder that reflects sustainability in the university in detail. Avoiding accepting the challenges of defining responsibilities and tracking them is a hindrance to the success of these declarations. The metrics for assessing and reporting sustainability declarations cover five key areas: Education, Research, Campus Life, Outreach, and Assessment and Reporting. In Education, examples include tracking credit hours in sustainability-focused courses to gauge academic integration. Research metrics emphasize financial commitment, such as the budget for sustainability-related projects, and the output in terms of funded projects and publications. Campus Life metrics address operational sustainability, including energy savings and water reduction efforts on campus. Outreach metrics assess the university's engagement beyond campus, like contributions to local sustainability projects and partnerships with other institutions.

6) Insufficient Collaboration of the Faculty. As mentioned above, an effective establishment of a sustainability paradigm in students' education can happen when the students' attention is drawn to the connection between the topics they learn in their courses with sustainability in an ongoing process. The involvement of professors and instructors in contributing to this goal is a challenge. This involvement depends on the faculty's motivation and determination to contribute to sustainability. Depending on various factors, different faculty may not have this motivation. They may have a preference to teach the students how to focus on the engineering aspects of an issue that is possibly relevant to their research interests or experiences. Garcia et al. (2008) explained why "educating the educator" has been suggested in the literature as a fundamental requirement for enhancing sustainability education. This cannot be limited to a workshop or developing handouts and providing them to the faculty. It requires establishing a systematic method for extending faculty's understanding of sustainability, teaching them how to integrate it into their courses, and evaluating their performance. Table 2 provides more details about how this method can be implemented.

Table 2. Suggested elements to include in the educators' program

Educating the educators	Broadening the faculty's knowledge about the fundamental concepts of sustainable development, its evolution, connections with engineering, potential to impacts the market and industry
	Introducing necessary tools to assess sustainability in engineering
	Introducing opportunities to integrate sustainability concepts into the course contents
	Connecting the faculty to plan a collaborative effort to share responsibilities in exposing the students to different aspects of sustainable development
	Providing support to the participating faculty
Evaluating the educators	Introducing metrics to assess the faculty's contribution to sustainability education
	Evaluating the faculty's contribution and providing feedback for enhancements

7) Overcrowded Curricula of Engineering Programs. As suggested by Lozano et al., (2015), one of the critical solutions in enhancing the contribution of academia to sustainability is to make sustainable development an integral part of the institutional framework and reflect it in the university approaches, policies, vision, and missions. Considering the multiple goals of universities in enhancing the quality of their engineering curricula the courses offered in the engineering programs do not often allow for the addition of more required courses. Additionally, bearing the age of engineering programs in many institutions in mind, the evolutionary process of their curricula is commonly progressed to a stable state. This leaves the engineering programs with limited flexibility to make changes in their curricula. Incorporating an effective sustainable development education requires integration of its fundamentals in courses, research approaches, and students' capstone or senior design. The over-crowded curricula of many engineering programs limit the capacity for the addition of sustainable development education. The findings of Velazquez et al. (2005), support that the discipline-restricted organizational structure limits the engagement of courses in incorporating sustainable development principles in students' learning. While elective courses provide a worthy opportunity for intensive teaching of sustainable development principles, it is crucial to keep in mind that sustainability education as an elective course may not be taken by all engineering students.

Survey Methodology

To understand the perceived barriers to effective sustainable development education among civil engineering students, a survey was conducted with a sample of students from Washington State University. The objective was to gather student experiences and opinions on specific factors that might hinder the incorporation of sustainable education principles within their engineering program. The survey asked students to assess various barriers, including the instilment of commitment to sustainability, integration of sustainability concepts into decision-making processes, program policies, curriculum constraints, faculty collaboration, and the impact of non-binding sustainability declarations. The survey methodology aimed to capture students' perspectives on barriers to effective sustainable development education. The survey instrument consisted of a structured questionnaire with both closed and open-ended questions. The closed-ended questions utilized a 5-point Likert scale, where participants rated the importance of various barriers from 1 (least important) to 5 (most important). The survey included questions such as: "How significant do you find the lack of faculty collaboration in integrating sustainability into the curriculum?" and "To what extent does an overcrowded curriculum hinder your ability to learn about sustainability principles?" Open-ended questions allowed participants to elaborate on their ratings and suggest additional barriers they perceived. This combination of question types ensured both quantifiable data through the Relative Importance Index (RII) and qualitative insights to provide a comprehensive understanding of the barriers identified.”.

The survey was sent to 158 students. A total of 48 civil engineering students participated, representing a diverse cross-section of academic years and backgrounds within the program. The percentage of respondents in college years was as follows: Freshman: 33%, sophomore: 27%, junior: 23%, and senior: 17%. This population provided a perspective on the sustainability challenges present in their curriculum, as students were familiar with both introductory and advanced engineering coursework. They were encouraged to rate each factor on a scale of 1 to 5, with 5 indicating the highest perceived importance and 1 the least, allowing for the calculation of a Relative Importance Index (RII) for each barrier. This structured approach aimed to quantify the collective student opinion on the obstacles to embedding sustainable principles in their education. Figure 2 shows the results.

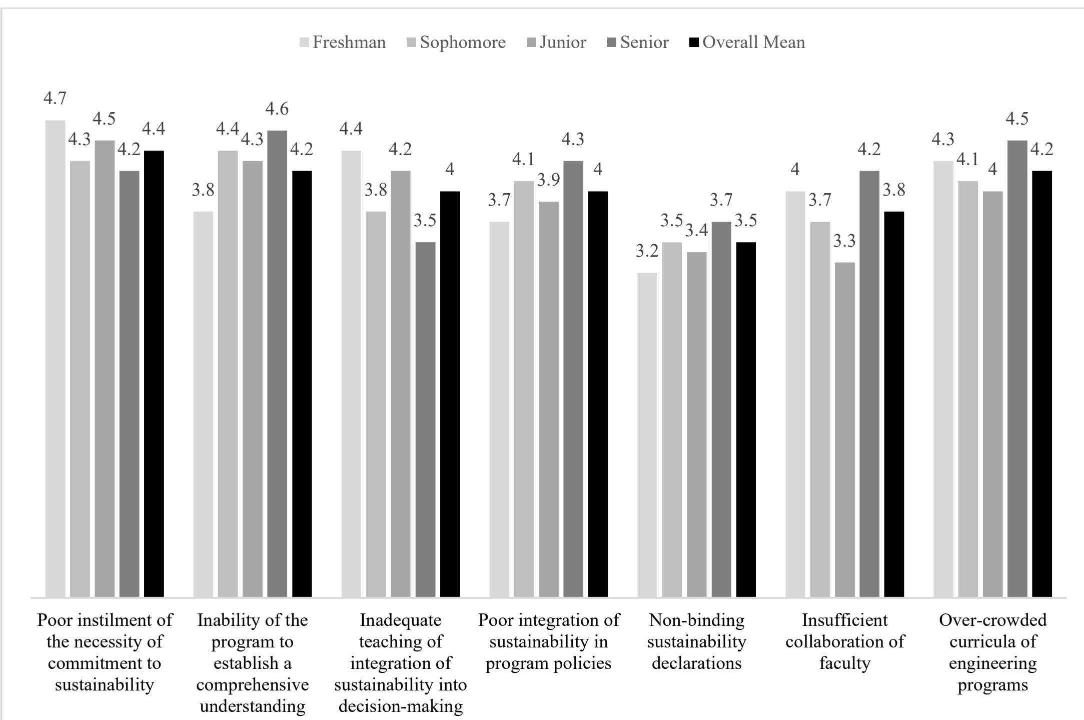

Figure 2. The mean score of each barrier among the students of each year

Upon collection, the survey responses were analyzed to determine the RII for each of the seven identified barriers. The data was aggregated and processed to calculate the mean scores, which were subsequently ranked. The Relative Importance Index (RII) method is a quantitative approach used to rank the importance of various factors based on survey data. It is widely used in the literature for ranking the contribution of multiple criteria to a significant outcome (Tafazzoli, 2018b and Tafazzoli, 2018c). It is commonly applied in fields like education, engineering, and management to identify and prioritize barriers, attributes, or features according to respondents' perceptions. The RII provides a normalized score that allows for easy comparison across factors by converting raw survey ratings into relative importance levels. The formula for calculating the RII is:

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$$\mathrm{RII} = \frac{\Sigma \mathrm{W\ A} \times \mathrm{N}}{A \times N}$$

where ΣW represents the sum of the ratings given by all respondents for a particular factor, A is the highest possible score on the rating scale (which is 5 here on a Likert scale), and N is the total number of respondents. The RII ranges from 0 to 1, with higher values indicating greater importance. By ranking factors based on their RII values, researchers and decision-makers can determine which issues are perceived as most critical, aiding in the development of targeted interventions and improvements. This ranking provided insights into which barriers were seen as the most significant impediments to effective sustainable development education, and which were perceived as less critical. The scores allowed us to establish a hierarchy, illustrating students' views on the importance of each barrier. This quantitative analysis aimed to offer a clearer understanding of where the program may need to focus its efforts to strengthen sustainable development education. The survey results, summarized in Figure 1, reveal the prioritization of barriers as identified by the participating students. This figure visually represents the students' perspectives and highlights the areas in which the program may need to implement changes to improve sustainability education. The findings from this analysis can inform program directors and faculty members about specific aspects of the curriculum or institutional policies that may require enhancement to foster a stronger commitment to sustainability among future civil engineers.

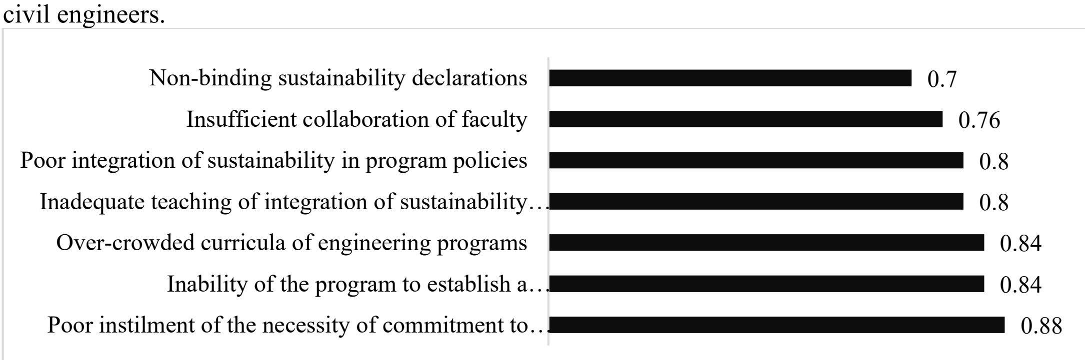

Figure 3. Relative importance index values for each of the barriers

Summary And Discussion

Sustainable development is not limited to certain practices and methods that must be applied in the industry to meet specific goals. It is a philosophy and way of thinking and decision-making that need to be internalized in the students to effectively embrace all the decisions they will make as engineers. As suggested by Lourdel et al. (2005), incorporating sustainable development should be noticed in day to day activities of the university experiences. This requires the constant consideration of sustainability in different courses and highlighting the connections of all courses' contents with the triple bottom lines of sustainability. This approach can be embedded in the current curricula and does not require significant changes to it.

The paper reviewed the findings of research to list common barriers of enhancing the academia's contribution to provide the students with effective learning of sustainable development principles. It was highlighted that establishing a sustainability paradigm requires comprehensive incorporation of sustainability in various elements of students' experience on campus including courses, research, and campus operations. The prerequisite of creating such an environment is the school's determination and collaboration of all faculty and staff. The engineering programs, and particularly civil engineering program, must broaden the students' understanding of sustainability and assist them in finding the connections of different engineering decisions on sustainability as well as establishing a life-cycle approach in the assessment of potential impacts of engineering decisions.

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