Analysis of sustainability insertion in materials selection courses of engineering undergraduate programs

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Abstract

Purpose: This research aims to analyse how the materials selection courses of engineering undergraduate programs can be better aligned with the United Nations Sustainable Development Goals (SDGs).

Design/methodology/approach: Initially, a content analysis was performed in 39 materials selection course descriptions from 40 engineering undergraduate programs of Brazilian Higher Education Institutions, and subsequently, Delphi method procedures were conducted with professors that teach or have taught the course and are knowledgeable in the subject of sustainability.

Findings: Considering the analysed course descriptions, it was shown that most of the materials selection courses do not consider or present little emphasis on sustainability aspects. Regarding the Delphi method, eight items were evidenced to consider sustainability aspects in the analysed courses.

Originality/value: This study contributes to the debates about sustainability insertion in engineering undergraduate programs. More specifically, the findings presented consolidated information that professors and coordinators can use to align materials selection courses with the SDGs better.

Keywords: Sustainability; Engineering education; Materials selection; Sustainable Development Goals; HEIs.

1. Introduction

In recent decades, sustainable development has been emphasised due to the need for establishing more sustainable consumption patterns that balance economic, social, and environmental aspects (Veiga Ávila *et al.*, 2018). Aware of the existing problems and the adverse consequences caused for the planet, the United Nations (UN) established the concept of sustainable development, emphasising the need to ensure for future generations the conditions necessary to survive and develop themselves (WCED, 1987).

In 2015, the UN established the 17 Sustainable Development Goals (SDGs) to drive nations towards a more sustainable future (Lusseau and Mancini, 2019; UN, 2019; Vinca *et al.*, 2020). These 17 SDGs also include companies and institutions such as Higher Education Institutions (HEIs), which should be committed to the goals (UN, 2015). The first official action regarding the role of HEIs towards sustainability happened in 1990 in an agreement called the Talloires Declaration, in which universities worldwide promised to consider sustainability issues in their activities (Hoover and Harder, 2015; ULSF, 2015). The role of HEIs as essential partners in this commitment was also indicated in 2012, when the focus of HEIs on teaching, research, knowledge dissemination and the capacity to support green campus initiatives and local community projects was used to form the basis of the Higher Education Sustainability Initiative (HESI), an international partnership dedicated to sustainable development efforts (UN, 2021). Hoover and Harder (2015) emphasised the complexity of conducting this implementation; there is still much that HEIs need to do to properly insert sustainability into their structures (Bubou *et al.*, 2017; Veiga Ávila *et al.*, 2018).

In the 17 SDGs, higher education is mentioned in Target 4.3 of Goal 4. However, the links between SDG 4 and the other 16 SDGs was presented by UNESCO (2017). UNESCO (2017) also highlighted the critical role that education for sustainable development has in preparing students to consider the economic, social and environmental impacts of their actions. The transversal presence of education (reflected in its contribution to all the other SDGs) shows the importance of it transforming different aspects of life and society (Wals, 2014).

The Incheon Declaration and Framework for Action for the implementation of SDG 4 presents two main strategies for implementing and monitoring education: 1. access, inclusion and internalisation of higher education; 2. incorporation of sustainable development precepts in a broader teaching-learning process (UNESCO, 2015)

The real incorporation of these precepts in higher education begins with a substantive change in the policy and institutional behaviour of HEIs to enable them to transform their curricula and the teaching-learning process. HEIs, being social institutions (Turner, 1997), should attest and reiterate their commitment to sustainability. They must rectify their behaviour to act more sustainably and responsibly regarding economic, social and environmental impacts.

The modern university, named by Kerr (2001) as multiversity, is a complex organisation that has an essential role in society. It reaffirms, thus, its permanent character of safeguarding the advance of modern civilisation, but also of minimising ecosystem deterioration, both in social and ecological terms. In this sense, HEIs must play an active role in the development of a new culture that contemplates sustainability as a pillar (Sepasi *et al.*, 2019). Sustainability should be considered both in its internal conduct and in the training process of future generations of professional citizens, who will work in different segments, whether public or private and will assist society in the adoption of an agenda for sustainability (Godemann *et al.*, 2014).

Regarding the internal conduct of HEIs, there has been a growing effort in recent years to structure institutional and organisational measures that dialogue with sustainability. Several reports aim to give transparency and visibility to these measures (Sepasi *et al.*, 2019). In addition, the adhesion of a large part of the world's major universities to sustainability indicators and rankings, such as the UI Green Metric, is a sign of this commitment (Alonso-Almeida *et al.*, 2015; Marrone *et al.*, 2018). However, HEIs need to advance further in two other movements.

The first movement refers to strengthening the relationship between the university and society (government, companies and the third sector). Universities should perform a central role in promoting sustainable development. In the study conducted by Dlouha et al. (2013), they analysed the strategic challenges of the SDGs, their applicability in - and from - higher education, and the connection between HEIs and the world in which they are inserted, via university extension and/or the production of knowledge applied to different sectors of society. There is an increasing number of studies showing this relationship from different angles and/or dimensions regarding the impact of science and technology produced by universities in the productive sector, public bodies and organised civil society, as well as the effect of this relationship on university practices and in the formative process in general.

The second movement is related to creating institutional strategies of induction. These strategies should safeguard the didactic autonomy of professors and incorporate a critical and holistic approach connected to different contexts, the values of sustainability, and the implementation of social and participatory learning strategies as central to curricula, courses and interdisciplinary learning processes. These elements have been studied by several authors, such as Hayles and Holdsworth (2008), Junyent and Ciurana (2008), Jones et al. (2010), Lozano and Young (2013), Valkering et al. (2013), Barth and Reickmann (2012) and others. These authors analyse education for sustainable development in a regional context and explore university involvement and the role of curricula in relevant learning processes. Boron et al. (2017) point out that teaching programmes, when incorporating sustainability as a central element, operationally demonstrate HEIs' social connection to a global agenda, thereby providing students – who will be future leaders – with the ability to have a more responsible understanding of the world.

Focusing on engineering education, several authors (Nyemba *et al.*, 2019; Quelhas *et al.*, 2019; Veiga Ávila *et al.*, 2018) advocate an education that allows future professionals to have a more balanced analysis of economic, social and environmental aspects in the projects they will develop. However, the insertion of sustainability issues into engineering education is not easy (Rampasso *et al.*, 2018).

As previously mentioned, future engineers will develop many projects in their professional life, and they will have to deal with the choice and selection of materials. According to Bojarski et al. (1995), Östberg (2005) and Rojter (2012), materials form one of the basic determinants of technological and socio-economic development. The relevance of sustainable materials selection for sustainable development has been debated in the literature, and its importance is emphasised in different areas of the engineering field (Agrawal, 2021; Bapat *et al.*, 2021; Mesa *et al.*, 2020).

The literature shows the materials selection field's contribution to sustainable development-oriented actions, which offers opportunities for engineering education. The course of materials selection is mandatory in many engineering undergraduate programs. However, its interface with aspects of sustainability, when focused on the educational part, is still rarely debated in the literature; a few punctual examples can be of experiences can be found, such as in Ertekin et al. (2014) and Gelles and Lord (2020). Considering this reality and aiming to contribute to the debates associated with sustainability in engineering courses, this study aims to analyse how the materials selection courses can be better aligned with the UN SDGs.

In addition to this introduction, which also presents the theoretical foundation on the inclusion of sustainability in higher education in engineering courses, this article has three more sections. Section 2 is dedicated to showing the methodological procedures used to achieve the results. Section 3 presents the study findings and debates associated with them. Finally, Section 4 is devoted to the conclusions and final considerations. All references used are listed in the end.

2. Theoretical background

2.1 Engineering Education for Sustainable Development

As previously mentioned, the need of implementing changes in engineering education towards sustainability insertion has been debated in the literature (Nyemba *et al.*, 2019). In this sense, researchers worldwide are addressing the topic to contribute to this necessary change.

For Bubou et al. (2017), engineering curricula must be structured in such a way to enable future professionals to work without borders and with technical, educational and sustainability skills. The curricular matrices must be constantly revised to contemplate the new demands of society and the market. However, as Bubou et al. (2017) mentioned, this does not always occur due to the technological dynamism and bureaucracy in the university environment, among other issues.

For Quelhas et al. (2019), engineering training aligned with sustainable development should consider normative competence, systemic thinking, critical thinking, problem-solving ability, self-knowledge competence, strategic competence, teamwork ability, contextualisation and future vision. However, Quelhas et al. (2019), Rodríguez-Chueca et al. (2020) and Leifler and Dahlin (2020) recognise that many of these characteristics are complex to develop in undergraduate engineering education. In this sense, approaches alternatives can be sought.

As summarised by Janakiraman et al. (2021), there are interesting approaches to improve engineering education, developing students essential skills for their professional life. Among these approaches, the authors mention “Collaborative teaching”, “Collaborative learning”, “Project-based learning”, “Problem-based learning”, “Game-based learning”, “Systems Approach”, and “Attitudinal Learning” (p. 2-3). All these approaches can be helpful for the insertion of sustainability into engineering education, supporting students to be more proactive and have a holistic and systemic vision of their tasks as professionals. In an analysis of the necessary sustainability indicators to access engineering education, Al-Bahi et al. (2021) verified that, if well designed, most of the SDGs can be addressed by engineering education, especially when the quality of education and continuous improvement are emphasised. However, despite the potential of this insertion, it can be verified that an essential dilemma in teaching sustainability in engineering courses is not just teaching the concepts of economic, social and environmental aspects but integrating these concepts through learning techniques that make students interested and motivated by the subject. The difficulties to incorporate sustainability in engineering curricula are numerous, and it is necessary to make a well-designed plan to avoid problems during the execution (Rampasso *et al.*, 2018).

2.2 Sustainability in materials selection

The relevance of materials selection for engineering projects is evidenced in the literature. In this sense, the increasing concern about sustainability issues affected materials selection, as it is presented in the literature (Ma *et al.*, 2018; Mousavi-Nasab and Sotoudeh-Anvari, 2018).

In Jeya Girubha and Vinodh (2012), Multicriteria Optimisation and Compromise Solution (VIKOR) was used to support sustainable materials selection decisions for an instrument panel to be used in an electric car. Besides technical and economic aspects, environmental impacts were also considered in the decision. In Mousavi-Nasab and Sotoudeh-Anvari (2018), the authors propose a new multicriteria decision making (MCDM) approach to support selecting the most sustainable material, avoiding ranking reversal issues.

Agrawal (2021) analyses different materials to be used in additive manufacturing processes. Considering various additive manufacturing technologies (Fused Deposition Modelling, Stereolithography, and Selective Laser Sintering), the author verified that TPU Elastomer, Duraform EX and Accura HPC0 were the best material options. In Mesa et al. (2020), the authors created a Material Durability Indicator to support materials selection that considers durability and environmental impacts for products and components development. In the automotive sector, Cecchel (2020) highlights that an important reduction in vehicles' carbon footprints can be achieved using lighter materials in the production of the component.

Studies related to the construction sector are also presented in the literature. Bapat et al. (2021) present a method for comparing materials used for building facilities for public transports to consider the materials' feasibility and sustainability. The changes they simulated in Building Information Modelling for building process strategies and materials presented an energy savings of 73%, on average, compared with the existing facility. Still in the construction sector, Luhar et al. (2020) emphasise the advantages of using natural fibre composites in 3D printed concrete. Among these advantages, the reduced negative environmental impact is highlighted.

In engineering education reality, there are few examples of sustainability insertion in materials selection courses. In Gelles and Lord (2020), the authors show the use of the Social Impact Audit tool as a way to make students consider – when choosing materials for products – the social impacts that products can present during their lifecycle. In their experience with a group of students, besides social impacts, the researchers verified that more attention was also given to environmental and economic aspects. In Ertekin et al. (2014), the researchers used the software Cambridge Engineering Selector and SolidWorks® to make engineering students consider environmental aspects in the selection of the materials during products design. In their analysis, the authors verified that students were more participative and engaged in the projects.

3. Methodological procedures

This research was developed based on the four steps presented in Figure 1 and detailed below.

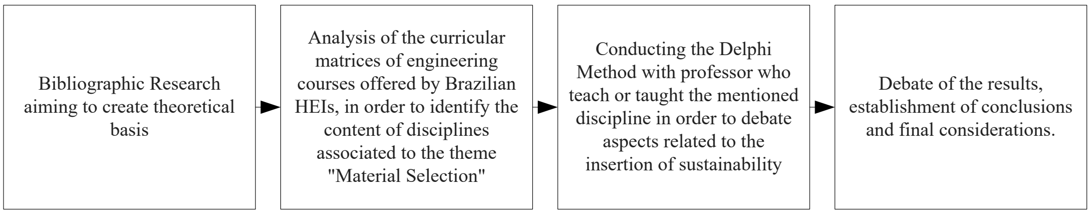

Figure 1. Steps of the research (Source: authors)

The bibliographic search (step 1) was carried out in the following scientific bases: Emerald Insight, Science Direct, Springer, Taylor & Francis and Wiley. First, to understand the importance of the sustainability theme in higher education, particularly in engineering education, the following terms were used: ‘sustainability’, ‘engineering education’, and ‘sustainability in engineering’. Subsequently, to refine the search within engineering and materials sciences, the following terms were used: ‘materials’, ‘materials selection’, ‘engineering’, and ‘materials science’. These terms were also combined with the terms used in the previous searches. Several articles were found and analysed in detail, part of which was used to develop the previous section.

Regarding step 2, an analysis was performed to consider 39 courses associated with materials selection offered by 40 undergraduate engineering programs of Brazilian public HEIs. The initial search was conducted on the institution’s websites. The 40 engineering undergraduate programs mentioned are classified in the following types: Mechanical Engineering, Metallurgical Engineering, Materials Engineering, Mechatronic Engineering, and Metallurgical Engineering and Materials.

It should be noted that the latest version of the descriptions in the HEIs’ website was considered. The content analysis of the information provided by the HEIs was based on the guidelines of Elo and Kyngäs (2008). The inductive analysis was used since categories were created during the reading of course descriptions.

According to Elo and Kyngäs (2008), content analysis can be performed in three phases: (a) preparation phase, (b) organisation phase, and (c) analysis and results reporting phase. Researchers must define the unit of analysis in the preparation phase, which can be a word or a phrase. In this study, the unit of analysis was the theme: 'sustainability insertion into materials selection courses'. In the sequence, the collected data was organised inductively, as previously mentioned. The categories to group the information were created during the content analysis. In the third phase, an overview of the theme under analysis should be provided, which in this research was the overview of sustainability insertion into materials selection courses, considering the 39 course descriptions.

Elo and Kyngäs (2008) mention that content analysis is a flexible process. Therefore, the researchers should describe in detail the steps performed in their analysis to enhance the study's credibility. This phase is called by Elo and Kyngäs (2008) as the analysis and results reporting phase.

Besides analysing the 39 course descriptions, mentioned in the previous paragraph, a Delphi method was used with professors that teach or have taught (in the last ten years) the course and are knowledgeable in the sustainability field (step 3). This step aimed to promote a debate about how materials selection courses can better address sustainability aspects and align with the UN 17 SDGs.

The Delphi method is used in several areas of knowledge. It is a process carried out through a systematic communication structure controlled by the researcher. This structure allows the specialists to express their opinions and receive feedback about them. From this, they can rethink their points of view, maintain, complement or even replace their initial opinions. It is expected that a consensus will be reached in the end. The anonymity of the participants in this kind of research is characterised as an important factor for Delphi method success (Belton *et al.*, 2019; Carneiro Caneda and Chapado Fernadez-Ardavin, 2011). Considering the lack of previous research on the subject addressed by this study and its complexity, Delphi method is justified, as evidenced by Linstone and Turoff (2002).

Regarding the consensus, Gbededo and Liyanage (2020) argue that it does not always mean unanimity in Delphi. There are several research examples in which the consensus is related to a defined percentage of agreement. In the literature, percentages of 75%-80% are commonly used, but there are cases in which this range can be from 51%-80% (Gbededo and Liyanage, 2020).

In the Delphi method developed in this study, 18 respondents participated in the first round. All these respondents fit the criteria required (professors with experience in teaching materials selection courses in the last ten years and knowledge of sustainability aspects); therefore, they were experts in the addressed subject. As it will be evidenced, 3 respondents did not answer in all rounds. In the third and last round, 15 respondents participated. It is worth highlighting that the number of participants is characterised as adequate, according to Belton et al. (2019), since according to these authors, an amount ranging from 5 to 20 participants in Delphi enables a debate with a diversity of opinions.

All the findings obtained were debated with the literature, and conclusions were established. It also should be mentioned that before the data collection (for the Delphi method), this research was approved by the Ethics Committee of the university (CAAE: 29828920.4.0000.5404).

4. Results and discussion

As mentioned in the previous section, a content analysis was initially carried out on the 39 materials selection course descriptions from 40 engineering undergraduate programs offered by public HEIs in Brazil. Figure 2 shows the percentage of engineering programs in which these courses are offered, considering the analysed sample.

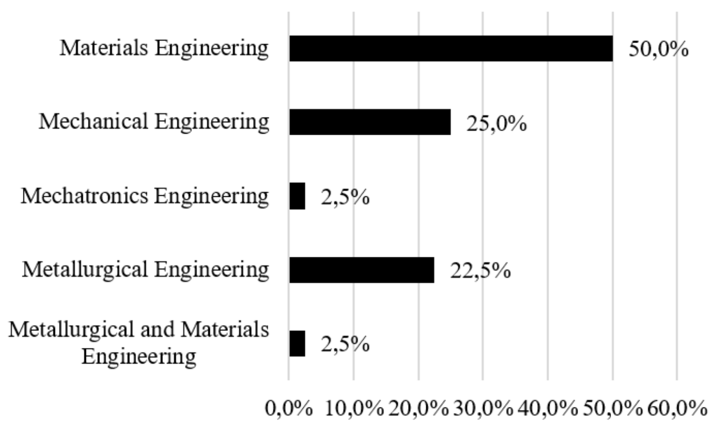

Figure 2. Distribution of the engineering programmes from which materials selection course descriptions were analysed. Source: Authors

In the content analysis carried out inductively, the information was classified into categories throughout the reading of the course descriptions, and in the end, 6 categories were obtained, namely: category 1 = presentation of criteria and methods for materials selection; category 2 = presentation of properties or property maps associated with traditional material classes; category 3 = additional emphasis on the selection of specific materials or for application in specific segments or sectors; category 4 = additional presentation of introductory content to material sciences or revision of this content; category 5 = additional presentation of introductory content to the manufacturing processes or review of this content; category 6 = emphasis on teaching methods for selecting materials in multicriteria projects / conflicting criteria; category 7 = emphasis on environmental and/or social issues or mention of sustainability aspects as components of selection criteria in a broadway.

Once the seven categories were identified, the authors of this article analysed the course descriptions again to determine the percentage of them that could be grouped in each category. For categories 1 and 2, it was found what was already expected, which is that the main core of the disciplines lies in the presentation of criteria and methods for the selection of the materials (category 1) and the display of the properties or property maps of the traditional material classes (category 2). All the analysed course descriptions (100%) fall into these two categories.

For category 3 (additional emphasis on selecting specific materials or for application in specific segments or sectors), 43.59% of the courses analysed fall into this category. For category 4 (additional presentation of introductory content to material sciences or revision of this content), 5.13%; and for category 5 (additional presentation of introductory content to the manufacturing processes or review of this content), 2.56%.

Category 6 was associated with the emphasis on the teaching methods for selecting materials in multicriteria projects/conflicting criteria. Even though the term 'sustainable' does not appear in the information in this category, we consider it important to account for it, since sustainability in its broad form is characterised by the dynamic balance between the economic, social and environmental dimensions. A total of 15.38% of the courses clearly showed the selection of materials in multi-criteria projects/conflicting criteria.

Finally, category 7 mentioned sustainable aspects, or the combination of all of them, clearly and directly in the course description. Only 17.95% of the analysed courses mentioned the environmental, social or sustainability aspects in their broad form. It should also be noted that only one course considered the social dimension when describing 'the social impacts of the use of materials.

Therefore, the main finding of this content analysis (named by Elo and Kyngäs (2008) as abstraction) is that few materials selection courses consider the sustainability aspects. Thus, there are several opportunities for improvement in this sense. Logically, our analysis was carried out on public information of course descriptions. In this sense, it is complex to measure the reasons for not including sustainability in these disciplines or even if extra activities are carried out. However, we understand that the analysed material, from the pedagogical perspective, guides professors in their teaching of materials selection courses. In this sense, if sustainability is not considered at its core, an important message is not being transmitted to the professors who will teach the discipline.

Regarding the Delphi method conducted in this research, it was composed of three rounds. The first one comprised an open question for respondents to freely express their opinion: 'How can Materials Selection courses be adjusted to align with the 17 Sustainable Development Goals?'. Table 1 presents the results of the first round. Similar responses were grouped. A total of 8 items were presented.

Table 1. Results of the Delphi Method first round (Source: Authors)

How can Materials Selection courses be adjusted to align with the 17 Sustainable Development Goals?
1. Contextualise the integration of man and ecosystem, in order to reinforce the importance of sustainability in the correct selection of materials.
2. Improve the alignment of Materials Selection courses with the concepts of Eco-design and Product Research and Development.
3. Improve the alignment of Materials Selection courses with topics covered in Energy and Environment courses.
4. Discuss sustainable issues with Materials Selection methodologies such as Ashby's maps. Insert in this context the relevant Sustainable Development Goals.
5. Emphasise the eco-properties of materials and their correlation with aspects of the Life Cycle Assessment (LCA), which allow for measuring the impacts provided by a product or service from its conception to final disposal. These results can be useful for public policy elaboration.
6. Develop projects within the themes of Materials Selection courses that enable the debate on existing regional problems in which students should consider, based on materials engineering, aspects related to sustainable development.
7. Discuss with students the innovations in terms of sustainable materials that enable less energy consumption, less environmental and social impacts, etc. Such as: biodegradable plastics, easily recyclable materials, etc. Thus, students will be able to explore alternatives to traditional materials.
8. Emphasise how the correct selection and rational use of materials can contribute to different SDGs, such as: 6) Clean water and sanitation; 7) Affordable and clean energy; 9) Industry, innovation and infrastructure; 12) Responsible consumption and production; 13) Climate action; among others. And

present practical examples of direct or indirect benefits provided to SDGs by the correct selection and rational use of materials.

Based on the answers, it was possible to verify that all professors understand the importance of aligning materials selection courses with the 17 SDGs, mentioning important aspects for establishing this integration. Of course, in this first round, some guidelines focus on different lines, but all the respondents demonstrate that sustainability is an essential factor in the content to be taught.

The responses from the first round were used as the basis for the second round. In this second round, the participants' opinions were shared (without knowing the participant's identity, in an anonymous process), and respondents were asked to verify if the synthesis carried out by the moderator was coherent or not (regarding their answer in the first round) and critically analyse their point of view. Complements to the answers or even total changes were allowed in this second round. Some participants wished to complement their answers and make some adjustments; thus the information presented in Table 2 was obtained.

Table 2. Results of the Delphi Method second round (Source: Authors)

How can Materials Selection courses be adjusted to align with the 17 Sustainable Development Goals?
1. Contextualise the integration of man and ecosystem in order to reinforce the importance of sustainability in the correct selection of materials. Evidence to students that sustainability is more than environmental aspects, and social issues also need to be considered.
2. Improve the alignment of Materials Selection courses with the concepts of Eco-design and Product Research and Development.
3. Improve the alignment of Materials Selection courses with topics covered in Energy and Environment courses.
4. Debate sustainability issues with Materials Selection methodologies such as Ashby's maps. Insert the relevant Sustainable Development Goals in this context. From this reflection and trained in the methodologies, students will be able to make more balanced decisions.
5. Emphasise the eco-properties of materials and their correlation with aspects of the Life Cycle Assessment (LCA), which allow for measuring the impacts provided by a product or service from its conception to final disposal. These results can be useful for the public policies' elaboration.
6. Develop projects within the themes of Materials Selection courses that enable a debate on existing regional problems in which students should consider, based on materials engineering, aspects related to sustainable development.

7. Discuss with the students the innovations in terms of sustainable materials that enable less energy consumption, less environmental and social impacts, etc. Such as: biodegradable plastics, easily recyclable materials, etc. Thus, students will be able to explore alternatives to traditional materials.
8. Emphasise how the correct selection and rational use of materials can contribute to different SDGs, such as: 6) Clean water and sanitation; 7) Affordable and clean energy; 9) Industry, innovation and infrastructure; 12) Responsible consumption and production; 13) Climate action; among others. And present practical examples of direct or indirect benefits provided to SDGs by the correct selection and rational use of materials.

To refine the responses from the second round, the third round can be carried out more objectively since now the participants should indicate their agreement for each item presented. To consider an item as valid for the group, a consensus level of 80% was adopted, the same level considered by Gbededo and Liyanage (2020) in their study. Table 3 shows that all the items were validated, therefore being useful for aligning the materials selection courses with the SDGs.

Table 3. Percentage of agreement for the analysed items. (Source: Authors)

Analysed items	Agreement quantity	% of agreement
1	14	93.3%
2	14	93.3%
3	14	93.3%
4	15	100.0%
5	14	93.3%
6	14	93.3%
7	15	100.0%
8	13	86.7%

5. Discussion

When considering the courses description analysis, it should be emphasised that Raoufi et al. (2019) argue that engineer training needs to be increasingly aligned with sustainability aspects. However, in several engineering undergraduate programs, the authors highlight that students do not learn methods and tools that enable them to debate economic, social and environmental aspects in a balanced manner, considering the products' life cycles. Akeel et al. (2019) highlight that engineering education should present a better balance among sustainability aspects to prepare future professionals to contribute to sustainable development. For Tejedor et al. (2019), the sustainability insertion into engineering education must use innovative educational techniques and real learning experiences.

When analysing the validated items through Delphi method, it is possible to verify that the professors' suggestions for aligning the Materials Selection courses with the SDGs go in multiple directions, generating guidelines for professors in the field. Some are broader in relation to understanding human and ecosystem interaction and discussing the concept of sustainability (item 1). Others are more specific and outlined within the topic, such as when the suggestion of using Ashby maps for sustainability is made (item 4) or in the exemplification of materials such as biodegradable plastics, easily recyclable materials, etc. (item 7).

Information such as those presented in the study of Kandziora et al. (2013) can be useful for the debates about the interaction between humans and ecosystems. Regarding the Ashby maps, it should be noted that they are maps in which materials' properties are presented against another, and it is possible to evidence different classes of materials on the same map (Ashby, 1999). Idealised in the 1980s by Michael F. Ashby, Ashby maps are useful in materials selection teaching. Some maps, for example, can present the recyclability factor of materials according to their cost, thereby being useful in the discussion of issues related to the environmental aspect of sustainability. Indeed, Ashby (1999) emphasised the need to consider the recyclability and reuse of materials. There are renowned academic journals about sustainable materials to disseminate related information, such as 'Sustainable Materials and Technologies' (Elsevier, 2021).

Items 2 and 3 focus on a multidisciplinary and transdisciplinary line, proposing alignments between different engineering fields. Multidisciplinary and transdisciplinary are outstanding themes in the insertion of sustainability in higher education, as Tejedor et al. (2019) emphasised.

Item 5 is dedicated to considering products' lifespans and analysing the impacts they can generate for society and the environment. This perspective is aligned with the Life Cycle Assessment (LCA) literature and authors such as Piekarski et al. (2019), who show that LCA can be an interesting tool for sustainability insertion into engineering education.

Item 6 explores the aspect of developing projects that consider themes from the local or regional community. In this sense, the study of Rampasso et al. (2020) can be useful for this debate. Item 8, in turn, has a direct approach, showing the contribution of materials selection courses to selected SDGs. For Aleixo et al. (2020), the SDGs are relevant drivers for teaching in higher education institutions.

For Desha et al. (2019), there is still a long path to be crossed to insert the knowledge related to the SDGs in engineering education; however, actions in this direction are already occurring, mainly in Australia and the United States. The debates within the academic community on how to align the content of the disciplines with the SDGs are essential, and in this sense, the results from this research can contribute greatly to this transition. Additionally, the studies of Ertekin et al. (2014) and Gelles and Lord (2020) present interesting and punctual examples of sustainability insertion in materials selection courses. However, as this research evidence, there are several opportunities to prepare better engineering students to perform sustainable materials selection.

6. Conclusion

The study presented in this article aimed to investigate how the materials selection courses offered in engineering undergraduate programs can be better aligned with the UN Sustainable Development Goals. This study initially carried out a content analysis on 39 materials selection course descriptions offered in engineering programs at Brazilian public institutions and subsequently proceeded with a Delphi method with specialists. In the content analysis of courses description, just 17.95% of the courses analysed mentioned sustainability issues in their description, evidencing the need to improve the current way that most courses are taught. In the Delphi methods, eight different items were highlighted to contemplate sustainability aspects in the course, with different approaches. Considering the findings presented, it can be observed that the main objective was achieved.

Theoretically, the main implication of this study is the base of knowledge provided from the Delphi method, that is, the eight validated items address manners of different magnitudes to insert sustainability aspects in the courses, considering the use of practical examples and innovation, linking the knowledge from other courses, considering lifecycle aspects of products and regional problems in activities of the course, as well as addressing specific SDGs and the contribution that materials selection can have to achieve them. The link between these items and sustainable materials selection education is unprecedented and provide interesting insights for future studies and can be basis for proposition of roadmaps to guide HEIs. For practice, the main contribution of this study is the guidelines that professors and coordinators can use to insert sustainability aspects in their materials selection courses and, consequently, enhance the engineering education for sustainable development. We understand that professors and coordinators should use the guidelines proposed here, considering their reality and teaching practices.

Due to the scarcity of literature on sustainability insertion on materials selection courses, with only punctual examples of experiences, this study has an exploratory character and, as any study of this kind, has limitations. The analysis of the courses descriptions was carried out considering the publicly available content and utilising the Delphi method with 18 specialists. However, as mentioned, we understand that the analysed contents are characterised as pedagogical guidelines for professors who will teach the subjects, and in this sense, they must transmit the main messages to be passed on to the students. About the professors who participated in the Delphi method, they are experienced in teaching the topic and are knowledgeable about sustainability. In addition, we highlight that this research does not present a roadmap to perform the mentioned insertion, but to present guidelines for engineering professors to do it, according to their reality

As suggestions for future work, resulting from the findings of this research, it is recommended to structure dynamic and pedagogical projects that can be used in the materials selection courses. Also, it would be interesting that researchers replicate this study in other countries to enable comparisons between countries and enhance the literature on the subject. In addition, experiences based on the eight different items identified in the Delphi to allow the teaching of sustainable materials selection could be published as research action studies, showing their benefits and challenges.

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