sustainability

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Systematic Review

A Systematic Review of the Different Methods Assessing Sustainability Integration in Engineering Curricula

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Abstract: Over the last two decades, numerous studies have highlighted the significance of integrating sustainability into higher education. Consequently, there has been a growing interest in the literature on engineering education for sustainable development, emphasizing the inclusion of this concept within engineering curricula and recognizing the pivotal role that engineers play in achieving the sustainable development goals. Therefore, sporadic engineering faculties worldwide have begun acknowledging and assessing issues related to sustainability in their curricula. As several methods have been employed to assess its inclusion, the aim of this paper is to review the various methods used to gauge how sustainability is incorporated in their respective engineering curricula. We carried out a systematic review of the literature regarding sustainability as assessed specifically in engineering curricula using the Scopus and ERIC databases. We applied PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology and, as a result, 30 papers were included. The results produced 14 methods with the articles highlighting existing limitations. Therefore, the authors recommend the combination of at least two of the methods to efficiently evaluate sustainability in engineering curricula.

Keywords: sustainability; sustainable development; engineering education; EESD; curriculum; systematic review; higher education

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1. Introduction, Background, and Literature Review

In 2015, at the UN Summit (UNS), which took place in New York, the eight millennium development goals (MDGs) were extended to a set of 17 sustainable development goals, better known as SDGs [1]. These SDGs aim to play a significant role in establishing the norms that businesses, governments, and societies should pursue in order to protect the interest of future generations and build universal peace through the "2030 Agenda" [2]. Amongst all 17 SDGs, SDG4, which focusses on education, is probably the core SDG that should help promote and achieve the other 16 goals.

Since the early 1970s, primitive discussions about sustainability have existed in higher education institutions (HEIs). In this sense, there has been an increasing demand for universities to educate students to help promote sustainable development (SD) [3]. Education for sustainable development (ESD) was highlighted in declarations like "The Talloires Declaration" in 1990, "The Kyoto Declaration" in 1993, and "The UN Decade for ESD" from 2005 to 2014. Although the discussion of sustainability began with environmental education, it has eventually evolved to emphasize ESD in the second decade of the twenty-first century, providing a vast body of literature on the topic [4]. Despite this, the literature shows clearly that HEIs still face numerous challenges to achieve ESD. These challenges relate to issues caused by the absence or even inadequate implementation of ESD, which should be equally considered [3]. This reality applies especially to engineering education considering the important role that engineers can and should play in achieving SD, an issue that has gained prominence in the literature over time [5–8].

The need to expose researchers and teachers to engineering education for a more meaningful evolution towards SD, which should in turn foster environmentally aware attitudes, skills, and behavior patterns, as well as a sense of ethical responsibility, was specified [9]. Engineering students require sound design-based courses to help augment their intellectual growth. Part of this growth is to make them understand the need to use minimal resources in their designs to ascertain that future generations are not affected. This is in line with the World Federation of Engineering Organizations' (WFEO) beliefs [10] in that, for engineering, this means playing an important role in planning and building projects that preserve natural resources, which should be cost-efficient and support human and natural environments. Hence, engineering education for sustainable development (EESD) is a comprehensive topic that includes technical, social, and economic elements. EESD becomes crucial in equipping engineering graduates with the information, the will, and the abilities to handle the problems of the twenty-first century and beyond. Hence, this demonstrates the importance of embedding sustainability in engineering curricula.

Amongst all educational disciplines, undoubtedly, engineering plays a critical role in achieving the majority of the SDGs. Romero et al. (2020) further stated that "once achieved, future engineers can reduce inequalities, suppress poverty, as well as support a healthy and sustainable life" [11].

The relevance of the curriculum for realizing the objective of ESD by preparing future engineers with the technological skills and abilities to tackle sustainability challenges is acknowledged by the engineering education communities and accrediting bodies [12]. As such, it is crucial for the engineering community to adapt its educational program in order to make the transition to integrate sustainable development.

Between 1987 and 2007, a relatively small number of engineering education institutions started a process of curriculum integration of EESD. Although there was a growing interest in EESD, there has not been a significant change in engineering curriculum within countries to effect a global change [10] and no single approach or recipe for implementing ESD curriculum change has been unanimously found to be effective [13].

Therefore, a growing interest in incorporating sustainability into engineering curricula started to develop globally, with countries in the EU and the Americas taking more active roles in doing so. Several methods have been employed by institutions and researchers to assess its inclusion with no consistency in approach or method. Considering that the curricula incorporates the teaching content, the methods of its selection, the organization, and the delivery [14], the present study, which is part of wider research in educational sciences, aims to assess the scientific literature to understand the transformations in engineering education in the face of the challenges of SD. With the many assessment methods used and with no obvious information as to which method to use, this paper aims to review the various methods used to gauge how sustainability is incorporated into engineering curricula. This paper equally aims to be a guiding starting point for any scholars engaging in the assessment of their curricula for SD integration.

2. Materials and Methods

This section introduces the qualitative systematic review carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), as can be seen in Supplementary File S1, in order to adhere to the guidelines of transparency and validity.

2.1. Aim and Research Questions

This study undertook an extensive examination of the literature on sustainability in engineering education by reviewing the various methods used to assess sustainability integration in engineering curricula between 2000 and 2023 inclusively. The following research questions outline the specific areas that were explored in the articles:

(A) What are the conducted methods to analyze sustainability's incorporation into the engineering curriculum?
(B) Are there any explicitly mentioned limitations or challenges encountered in the process? And are there any mentioned advantages for the used assessment method?
(C) What kinds of findings are obtained according to each method?

2.2. Search Strategy

In this qualitative systematic review, articles from scientific journals published between 2000 and 2023 were considered. Papers that assessed the incorporation of sustainability in engineering curricula were considered in order to interpret what has been utilized. Research databases vary in their approaches on how to search for published material depending on the discipline. Scopus is considered one of the top databases to use for citation searches. When it comes to education sciences, ERIC is considered to be the top database. As such, Scopus and ERIC were utilized as they complement one another to provide a comprehensive search in this area of research. The search employed the following keywords: "sustainability", "engineering education", and "curriculum". These criteria were applied to the fields of article title, abstract, and keywords. Table 1 illustrates the combinations of these terms used in the search process.

Table 1. Search terms results.

Search Terms	**Database**	**Results**
("sustainability" AND "engineering education" AND "curriculum")	SCOPUS	1060
("sustainability" AND "engineering education" AND "curriculum")	ERIC	90

2.3. Inclusion and Exclusion Criteria

The selected articles were required to include an analysis of engineering curricula with results explicitly linked to sustainability; otherwise, they were excluded. Articles utilizing the integration approach by assessing the impact of newly added courses were equally excluded. Furthermore, the focus was solely on articles addressing curriculum assessment, excluding those focusing on a single course assessment. The selection process involved multiple stages, resulting in a final set of 30 articles. To uphold reliability and align with PRISMA guidelines, all three authors actively engaged in every phase of the process of evaluating the 30 selected articles.

2.4. Trial Flow/Selection Process

By limiting the research to articles and review articles only, this reduced the number of articles to 359, 277 from SCOPUS and 82 from ERIC. Additionally, 5 articles published before 2000 were excluded. After removing 34 duplicate articles, the abstracts of the remaining 320 were scrutinized by reading their abstracts to determine their relevance to the present systematic review. The authors conducted regular meetings to address any inconsistencies in interpreting the results. All articles were organized in an Excel sheet, with each sheet corresponding to the publication year. The three authors unanimously agreed on the selection process, leading to the removal of 37 articles unrelated to sustainability, 7 articles not related to engineering, and 246 lacking a curriculum assessment. Articles discussing approaches for integrating sustainability into the curriculum were specifically categorized under "lacking a curriculum assessment". The selection process was a bit challenging because of the lack of consistency in the articles' keywords. Ultimately, 30 papers underwent a thorough analysis. Figure 1 illustrates a flow chart summarizing the entire process.

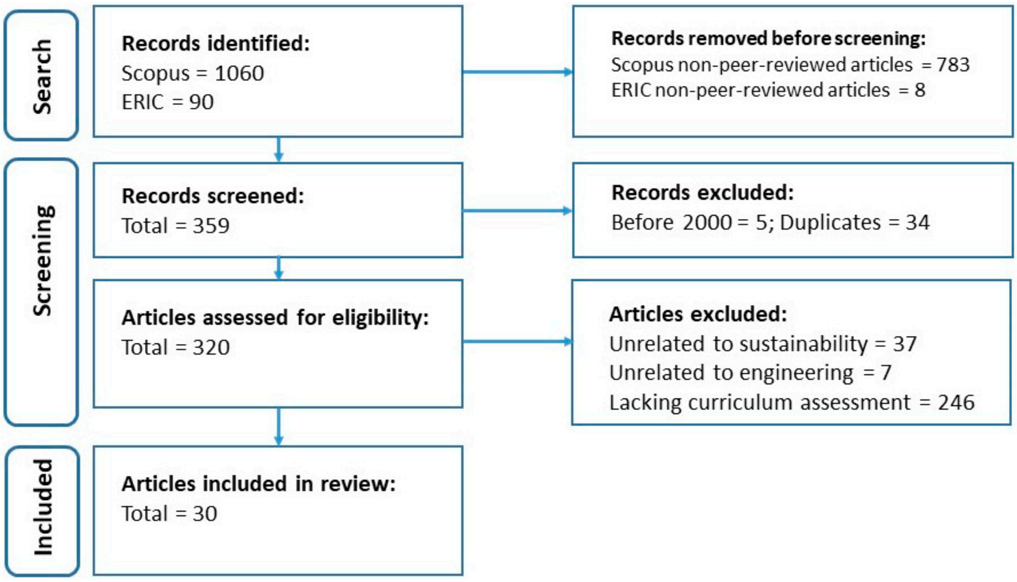


Figure 1. Flow diagram of articles' selection.

3. Results

In this section, the results of the analysis for each of the above research questions are addressed. The information is organized into charts and tables to methodically structure the most pertinent information and the conclusions derived from each article. Subsequent to the selection process, the three authors meticulously scrutinized the results of each article, assessing their relevance individually.

As evident from Figure 2, there is a noticeable increase in the number of articles after the introduction of the UN SDGs in 2015, with a surge in 2019, 2020, and 2021 with 6, 5, and 5, respectively.

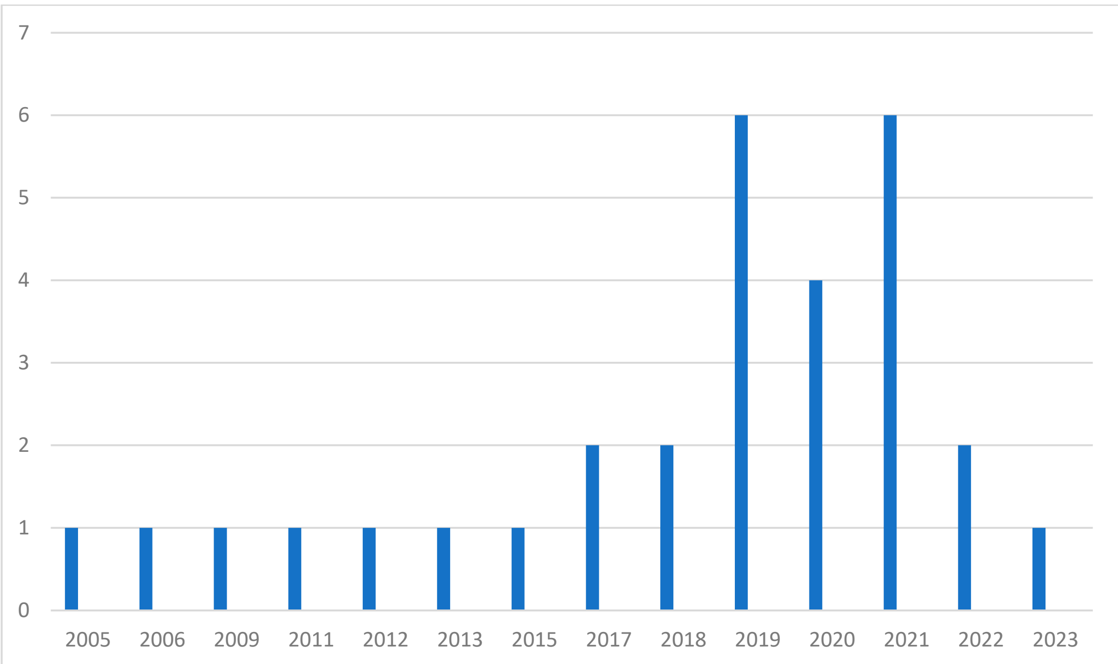
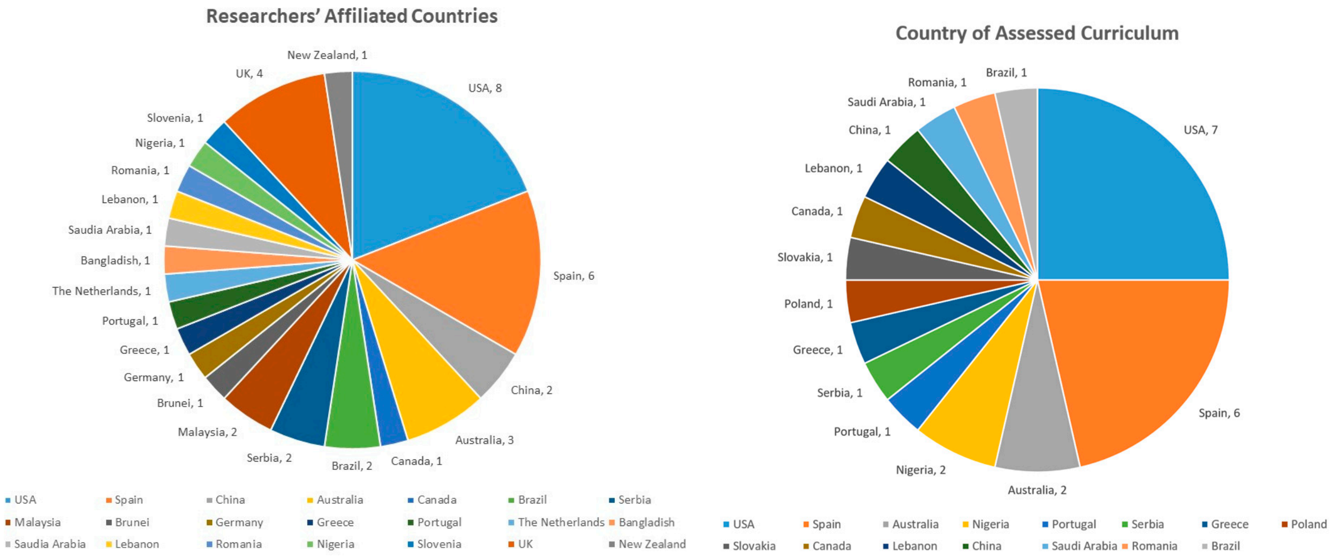


Figure 2. Number of articles by year of publication.

Table 2 and Figure 3 highlight the 30 articles in relation to the researchers' affiliated country and the respective countries where the curricula were assessed.

Table 2. Summary of the 30 articles' geographical affiliations.

Article	Researchers' Affiliated Country	University—Country of Assessed Curriculum
Sofri et al. (2023) [15]	Brunei Darussalam	From the top 300 2019 Quacquarelli Symonds ranking universities
Jahan et al. (2022) [16]	USA	Rowan University—USA
Gannon et al. (2022) [17]	USA and New Zealand	University in the USA
Gomez-Martin et al. (2021) [18]	Spain	Universitat Politècnica de València—Spain
Sánchez-Carracedo et al. (2021) [19]	Spain	Polytechnic University of Madrid (UPM), Universitat Politècnica de Catalunya (UPC-BarcelonaTech), and University of the Basque Country (UPV/EHU)—Spain
Nikolić and Vukić (2021) [20]	Serbia	University of Novi Sad, University of Belgrade, University of Kragujevac, University of Nis, and University of Pris—Serbia
Aginako and Guraya (2021) [21]	Spain	University of the Basque Country, Engineering school of Bilbao—Spain
Damigos et al. (2021) [22]	Greece	Universities in Greece, Poland, and Slovakia
Arefin et al. (2021) [23]	Bangladesh and Australia	Universities in Australia
Sánchez-Carracedo et al. (2020) [24]	Spain	Autonomous University of Madrid (UAM), University of Cádiz (UCA), University of Cordoba (UCO), International University of Catalonia (UIC), University of Seville (US), University of Salamanca (USAL), and Camilo José Cela University (UCJC)—Spain
Qu et al. (2020) [25]	Australia and China	Tongling University—China
Ashraf and Alanezi (2020) [26]	Saudi Arabia	Prince Mohammad Bin Fahd University—Saudi Arabia
Alexa et al. (2020) [27]	Romania	Polytechnic University of Bucharest (UPB), Technical University of Civil Engineering of Bucharest (UTCB), Technical University of Cluj Napoca (TUCN), Technical University "Gheorghe Asachi" Iasi (TUIASI), and Polytechnic University of Timisoara (UPT)—Romania
Akeel et al. (2019) [28]	Nigeria and UK	Universities in Nigeria
Sánchez-Carracedo et al. (2019) [29]	Spain	University of Córdoba (UCO), Universitat Politècnica de Catalunya–BarcelonaTech (UPC), and Universidad Politécnica de Madrid (UPM)—Spain
Trad (2019) [4]	Australia	University of Technology Sydney (UTS)—Australia
Onyilo et al. (2019) [30]	Malaysia	Universities in Nigeria
Rampasso et al. (2019) [3]	Brazil and Germany	Universities in Brazil
Rubio et al. (2019) [31]	Spain	Universities in Spain
Roure et al. (2018) [32]	Canada	Sherbooke University—Canada
Colombo and Alves (2017) [33]	Brazil and Portugal	A Portuguese Public University—Portugal
Thürer et al. (2018) [34]	China, Serbia, UK, and USA	N/A
Arsat et al. (2017) [35]	Malaysia	University Teknologi Malaysia—Malaysia
Nazzal et al. (2015) [36]	USA and UK	Highly ranked US universities—USA
Watson et al. (2013) [37]	USA, Netherlands, and UK	Georgia Institute of Technology—USA
Salem and Harb (2012) [38]	Lebanon	Notre Dame University—Lebanon
Becerik-Gerber et al. (2011) [39]	USA	101 AEC programs—USA
Murphy et al. (2009) [40]	USA	USA
Galvič (2006) [41]	Slovenia	The 100 top universities in Europe and the USA
Kumar et al. (2005) [42]	USA	Michigan Technological University—USA



(**A**) (**B**)

Figure 3. (**A**) Researchers' affiliated countries; (**B**) Country of assessed curriculum.

Results of the Research Questions

3.1. What Are the Conducted Methods to Analyze Sustainability's Incorporation into the Engineering Curriculum?

The various methods depicted in the 30 articles are summarized in Table 3 with the main data of each study detailed below accordingly. Their description and the details varied from one article to another with no consistency in the content. It is quite clear that the two most common methods used are "surveys" and "content analysis".

Table 3. Summary of various methods utilized.

Method	Articles
Content analysis	[15,20,27,28,33,35,36,41]
Engineering Sustainability Map	[19,24,29]
Sustainability presence map	[19,24,29]
Tracing sustainability learning outcomes within the faculty's graduate attributes, subject learning outcomes, and assessment learning outcomes	[4]
Survey/questionnaire	[3,16,17,19,21,25,26,32,36–40,42]
Fuzzy Cognitive Maps	[22]
Fuzzy comprehensive evaluation model	[25]
Systematic review	[3,4,20,23,30,34]
STAUNCH (Sustainability Tool for Auditing University Curricula in Higher Education)	[18,37]
TOPSIS	[3]
Benchmarking	[31,40,42]
Comparative analysis	[39]
Interviews	[22,35]
Students' deliverables (quizzes, projects, etc.)	[26,36]

- **Sofri et al. (2023), "Analysis of chemical engineering curriculum to improve process safety competency" [15]**

Method: The common processes of safety topics, with one of them being sustainability, were assessed in the chemical engineering programs of the top 300 universities of the 2019 Quacquarelli Symonds (QS) ranking through gathering information about syllabi. The data were then sorted in Microsoft Excel 2022. By searching the keywords in Microsoft Excel, the summation of the topics was calculated in order to obtain quantitative results.

- **Jahan et al. (2022), "Integrating inclusivity and sustainability in civil engineering courses" [16]**

Method: Within the NSF RED (Revolutionizing Engineering Departments) Grant received by Rowan University, a curriculum, integrating inclusivity and sustainability, was developed in the civil engineering department. An online student survey to assess the impact of all revised course content, for all courses that were subject to the integration, was conducted.

- **Gannon et al. (2022), "Engineering faculty views on sustainability and education research: Survey results and analyses" [17]**

Method: This paper measured engineering educators' attitudes and dispositions towards engineering sustainability education through a fully presented survey.

- **Gomez-Martin et al. (2021), "Boosting the sustainable development goals in a civil engineering bachelor degree program" [18]**

Method: The syllabi were assessed through an analysis performed by the Sustainability Tool for Auditing Universities' Curricula in Higher Education (STAUNCH), which is an educational assessment tool that was created in 2007 to evaluate the sustainability content of curricula by scrutinizing syllabi or course descriptors as data sources, focusing on 37 sustainability topics across economic, social, environmental, and crosscutting dimensions (Akeel et al., 2019) [28]. Following the latter's methodology, the authors followed the following steps: selection of the data, information gathering, information classification and program analysis, and proposals. Every course's objectives, outcomes, and assessment methods were evaluated for their contribution to the targets of the SDGs using four levels from no contribution and no evidence to contribution with evidence.

- **Sánchez-Carracedo et al. (2021), "Tools for embedding and assessing sustainable development goals in engineering education" [19]**

Methods: Three tools were introduced for assessing ESD—(1) an Engineering Sustainability Map (see definition below), which included a survey for teachers for the creation of the degree, (2) a sustainability presence map (see definition below), and (3) a survey for students on their self-perception of their sustainability training.

- **Nikolić and Vukić (2021), "Sustainable development as a challenge of engineering education" [20]**

Methods: For an international context, a systematic review was conducted to investigate the ways of integrating sustainability in foreign engineering universities' curricula. As for the national context, the engineering curricula in Serbia were analyzed by identifying the courses whose names contain sustainable or sustainability. Courses referring to one of the three pillars of sustainable development were excluded. Subsequently, the syllabi were collected to determine whether the course is mandatory or elective.

- **Aginako and Guraya (2021), "Students' perception about sustainability in the engineering school of Bilbao (University of the Basque Country): Insertion level and importance" [21]**

Method: Part 3 of their survey focused on the curriculum. It was structured and distributed to the Electrical Engineering, Industrial Electronic and Automatic Engineering and Mechanical Engineering students to assess the insertion level of sustainability in their respective programs at the engineering school of Bilbao. Students were asked about the percentage of integration of the three dimensions in their courses, trainings, projects, etc.

➢ **Damigos et al. (2021), "The factors impacting the incorporation of the sustainable development goals into raw materials engineering curricula" [22]**

Method: The method used in this study was based on a two-stage approach assessing the educational needs in Greek Raw Material engineering studies as per the mining industry's needs. A group of stakeholders consisting of academics (students and academic staff), the industry, and professionals were interviewed to discuss the educational needs and challenges of achieving the SDGs in the mining industry. Fuzzy Cognitive Maps were then utilized to evaluate the main value chain SDGs–education–innovation eco-system and its interactions.

➢ **Arefin et al. (2021), "Incorporating sustainability in engineering curriculum: A study of the Australian universities" [23]**

Method: A systematic review was conducted to evaluate what is published from the relevant literature and secondary data in order to understand the status of Australian universities in integrating sustainability in their engineering programs. The selected articles from Scopus, Web of Science, and Google Scholar were analyzed. As for the secondary data, updated university websites, program catalogues, and published university magazines were considered, then analyzed as well.

➢ **Sánchez-Carracedo et al. (2020), "Analysis of sustainability presence in Spanish higher education" [24]**

Methods: To identify the percentage presence of sustainability in the curriculum, two methods were used: a sustainability map and a sustainability presence map.

The sustainability map "consists of a matrix containing learning outcomes. The rows of the matrix contain four competencies ... The columns enable learning outcomes to be classified into three domains levels using taxonomy a simplified version of the Miller Pyramid" (p. 396).

"The sustainability presence map of a curriculum is a sustainability map in which the matrix cells contain a number greater than or equal to zero, rather than learning outcomes. This number expresses the number of subjects that develop some of the learning outcomes of the cell in the sustainability map. If a cell in the sustainability presence map contains a number greater than zero, it is assumed that the competency related to the cell is developed in the curriculum at the domain level in which the cell is located (regardless of the number of subjects and hours dedicated to this development)" (pp. 398–399).

➢ **Qu et al. (2020), "Applying sustainability into engineering curriculum under the background of new engineering education" (NEE)" [25]**

Method: Pre- and post-questionnaire surveys, as well as a Fuzzy comprehensive evaluation model, were used to evaluate the changes in the knowledge, attitudes, and behaviors of engineering students at Tongling University before and after the integration of a new curriculum.

➢ **Ashraf and Alanezi (2020), "Incorporation of sustainability concepts into the engineering core program by adopting a micro curriculum approach: A case study in Saudi Arabia" [26]**

Method: After adopting a micro-curricula approach by incorporating sustainability into the core engineering program and including a stand-alone course, quantitative and qualitative methods were used for assessment, such as surveys, peer reviews, preceptor views for design projects, employer surveys, and quizzes.

➢ **Alexa et al. (2020), "Engineers changing the world: Education for sustainability in Romanian technical universities-An empirical web-based content analysis" [27]**

Method: An empirical content analysis of Romanian technical universities was conducted to identify the courses that integrate sustainable development. A total of 25,920 core and elective courses were analyzed using exploratory empirical content analysis.

➢ **Akeel et al. (2019), "Assessing the sustainability content of the Nigerian engineering curriculum" [28]**

Method: This study considered a content analysis of three engineering documents: the Benchmark Minimum Academic Standards for Engineering Programs in Nigeria and the engineering handbooks of two Nigerian higher education institutions. These documents were converted to PDF form and uploaded to NVivo 11 Pro software.

➢ **Sánchez-Carracedo et al. (2019), "A methodology to analyze the presence of sustainability in engineering curricula. Case of study: Ten Spanish Engineering degree curricula" [29]**

Method: In this study, the methodology proposed two tools: the Engineering Sustainability Map (see definition above) and the sustainability presence map (see definition above).

➢ **Trad (2019), "A framework for mapping sustainability within tertiary curriculum" [4]**

Method: A systematic literature review identified seven sustainability competencies. The assessment of ESD competency integration into the curriculum employed a two-tier scanning mechanism. In the initial step, subject outlines (SOs) were utilized to pinpoint sustainable subject learning outcomes (SLOs) and assessment learning outcomes (ALOs). The second step involved scrutinizing ALOs and SLOs for constructive alignment with the student experience. Statistical analysis using SPSS software was subsequently employed to statistically represent the results.

➢ **Onyilo et al. (2019), "Sustainable development and sustainability in engineering education in Nigeria" [30]**

Method: A systematic review examined the literature between 2014 and 2019. It focused on sustainable development and sustainability in engineering education in Nigeria to assess the extent of awareness regarding ESD among engineering stakeholders in Nigeria and to explore various approaches for incorporating sustainability into the engineering education curriculum in the country.

➢ **Rampasso et al. (2019), "Some of the challenges in implementing education for sustainable development: Perspectives from Brazilian engineering students" [3]**

Method: To analyze the challenges of incorporating sustainability in the engineering courses in Brazil, a combined methodology of a systematic review, survey, and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was performed. A set of 10 challenges were identified from the systematic review to serve as parameters to structure a survey completed by 91 students. The gathered data were then examined using the allocated averages and the multi-criteria decision technique TOPSIS, which allowed the challenges to be ranked.

➢ **Rubio et al. (2019), "Embedding sustainability competences into engineering education. The case of informatics engineering and industrial engineering degree programs at Spanish Universities" [31]**

Method: The method used was based on benchmarking methods that are normally used in evaluating companies and institutions. It focused on best practices and continuous improvement. The typology used compared the behavior of various universities that offer the same degree. The functional approach adopted focused on two specific aspects related to a holistic vision of sustainability competencies and their systematic inclusion in the curricula. In total, 27 degrees in computer engineering (informatics) and 28 degrees in industrial engineering (industrial) were analyzed. Key dimensions (keywords) were selected: (a) ethics and professional responsibility, (b) environmental, (c) social, and (d) legal and regulatory.

➢ **Roure et al. (2018), "Systematic curriculum integration of sustainable development using life cycle approaches" [32]**

Method: A framework to systematically integrate SD concepts within an eight-semester civil engineering curriculum at Sherbooke University was applied. The framework consisted of five steps: (1) mapping the curriculum, (2) setting learning targets, (3) developing an action plan for the assessed program, (4) implementation of the action plan, and (5) assessing the final performance. In order to assess the success of the set targets, a concise student satisfaction survey was conducted including questions about demographics, perceived learning outcomes, and the learning experience.

➢ **Colombo and Alves (2017), "Sustainability in engineering programs in a Portuguese public university" [33]**

Method: This study was based on documental research from the official website of a Portuguese public university. The authors gathered the information using Excel. Then, after identifying the courses for each master's and PhD program, they interpreted and analyzed the objectives of education, key learning outcomes, and program summary. They also specified the ECTS number and the teaching assessment methods for each course. According to the number of courses related to sustainability and the corresponding ECTS number, the programs were classified as the Strongest, Medium, or Weakest, where Strongest refers to programs with more than three courses related to sustainability, Medium to those with up to three courses, and Weakest to programs without courses related to sustainability.

➢ **Thürer et al. (2018), "A systematic review of the literature on integrating sustainability into engineering curricula" [34]**

Method: A systematic review of the literature on integrating sustainability into engineering curricula was conducted. There were a total of 247 articles, of which 70 were analyzed. Whilst the review did not tackle the method of integration, it raised 12 questions that are hoped to guide the integration of SD in curricula, so we felt that it had some relevance to include in our systematic review.

➢ **Arsat et al. (2017), "Integrating sustainability in a student-centered learning environment for engineering education" [35]**

Method: This paper presented a study that aimed to evaluate teachers' experiences and the implementation of sustainability-related courses at University Teknologi Malaysia. Six engineering courses were assessed by identifying the courses' title and the synopsis offered in the programs. Then, the assessed courses were divided into three categories: models, orientation, and approach. In addition, an in-depth analysis was conducted by interviewing the instructors who taught the assessed courses.

➢ **Nazzal et al. (2015), "Introduction of sustainability concepts into industrial engineering education: A modular approach" [36]**

Method: The authors first examined the state of sustainability in industrial engineering programs. The websites, course descriptions, and syllabi were analyzed. Based on a systematic review regarding specific sustainability concepts in industrial engineering, the authors implemented a curricular modification program in which sustainability was introduced into several courses through the use of content-focused modules. After the curricular change, quantitative and qualitative methods were performed to assess the effectiveness of the sustainability modules introduced. Quantitative data included students' quizzes and their writing assignments. As for the qualitative assessment, it was based on end-of-course surveys.

➢ **Watson et al. (2013), "Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology" [37]**

Methods: In order to assess the curriculum of the civil and environmental engineering program at Georgia Institute of Technology, two complementary methods were used: the Sustainability Tool for Auditing University Curricula in Higher Education (STAUNCH) system and two student perceptions surveys, conducted as interviews.

➢ **Salem and Harb (2012), "Education for sustainable development: Assessment of the current situation at the faculty of Notre Dame University (NDU)—Louaize" [38]**

Method: The authors evaluated students' competencies in addressing ESD. To assess the current status and identify challenges and strategies for integrating sustainability into curricula, a survey was conducted based on the frameworks developed by University Leaders for a Sustainable Future (ULSF) in 2009. Subsequently, two engineering courses were chosen for a preliminary study aimed at incorporating sustainability concepts. The assessment involved measuring students' knowledge, attitudes, and skills before participating in these courses, with the intention of evaluating their learning outcomes upon course completion.

➢ **Becerik-Gerber et al. (2011), "The pace of technological innovation in architecture, engineering and construction education: Integrating recent trends into the curricula" [39]**

Method: To provide an overview of the emerging areas of BIM and sustainability, 101 AEC educational programs were assessed. The examination assessed how educational innovations, such as distance learning, multidisciplinary collaboration, and industry partnerships, are employed to cultivate essential competencies in these subject areas. The researchers categorized AEC disciplines based on accreditation bodies like ABET, NAAB, and ACCE. They also conducted a survey to identify internal factors (e.g., program resources, expertise) and external factors (e.g., accreditation requirements, sustainability initiatives) influencing pedagogical approaches. The research highlighted the challenges associated with integrating new knowledge areas into constrained curricula and explored diverse approaches adopted by university programs. A comparative analysis was conducted to identify similarities and differences, as well as the specific advantages and disadvantages of various approaches across AEC programs.

➢ **Murphy et al. (2009), "Sustainability in engineering education and research at U.S. universities" [40]**

Method: In order to have engineering programs self-identify the content that constitutes sustainability, a benchmarking study was performed and presented in two categories: (1) courses, course modules, and curricula, and (2) research.

➢ **Galvič (2006), "Sustainability engineering education" [41]**

Method: Courses and textbooks found on the internet from the top universities in countries considered "developed countries" by the authors were assessed in 2003. An in-depth analysis of the course content was conducted. The occurrence of courses in different categories and their respective titles were displayed within each category. A slight change from pollution prevention courses to sustainability was noticed, along with information on the most commonly used textbooks.

➢ **Kumar et al. (2005), "Infusing sustainability principles into manufacturing/mechanical engineering curricula" [42]**

Method: This paper evaluated the existing undergraduate mechanical engineering curriculum at Michigan Tech in terms of sustainability. It highlighted obstacles to integrating sustainability throughout the curriculum by conducting an undergraduate student survey and a benchmarking study. The survey was divided into four sections assessing the students' knowledge regarding ABET requirements, their views on the existing curriculum, on sustainability issues, and open-ended questions to identify areas of weaknesses for improvement.

3.2. Are There Any Explicitly Mentioned Limitations or Challenges Encountered in the Process? And Are There Any Mentioned Advantages for the Assessment Method Used?

Table 4 details the advantages and/or limitations as highlighted in each article.

Table 4. Advantages and limitations of the method of curriculum analysis.

Authorship	Method(s) Used	Advantages Expressed by the Authors of the Papers	Limitations or Challenges Expressed by the Authors of the Papers
Sofri et al. (2023), "Analysis of chemical engineering curriculum to improve process safety competency" [15]	Content analysis using Excel	N/A	N/A
Jahan et al. (2022), "Integrating inclusivity and sustainability in civil engineering courses" [16]	Survey	N/A	N/A
Gannon et al. (2022), "Engineering faculty views on sustainability and education research: Survey results and analyses" [17]	Survey	Effective in measuring engineering faculty support toward engineering education and sustainability education	N/A
Gomez-Martin et al. (2021), "Boosting the sustainable development goals in a civil engineering bachelor degree program" [18]	STAUNCH (SDGS targets)	Systematic method that can be carried out in different bachelor's degrees to find subjects that have the potential to incorporate the SDGs into their program	It is necessary to complete the analysis by surveying students on the degree of knowledge of the 2030 Agenda and the SDGs throughout the academic years, to be able to assess their increase in knowledge on the subject.
Sánchez-Carracedo et al. (2021), "Tools for embedding and assessing sustainable development goals in engineering education" [19]	(a) Engineering Sustainability Map Questionnaire for teachers for the creation of a degree sustainability presence map (b) Questionnaire for students on self-perception of their sustainability training	Exportable tools to other disciplines with little adaptation of the tools Not only for the improvement of the sustainability competencies but to embed the SDGs in teaching	N/A
Nikolić and Vukić (2021), "Sustainable development as a challenge of engineering education" [20]	(a) Systematic review (b) Content analysis/name related courses	N/A	N/A
Aginako and Guraya (2021), "Students' perception about sustainability in the engineering school of Bilbao (University of the Basque Country): Insertion level and importance" [21]	Survey	N/A	N/A

Table 4. *Cont.*

Authorship	Method(s) Used	Advantages Expressed by the Authors of the Papers	Limitations or Challenges Expressed by the Authors of the Papers
Damigos et al. (2021), "The factors impacting the incorporation of the sustainable development goals into raw materials engineering curricula" [22]	Interviews and Fuzzy Cognitive Maps (FCMs)	FCMs are a popular method used for studying the structure and behavior of complex systems	N/A
Arefin et al. (2021), "Incorporating sustainability in engineering curriculum: A study of the Australian universities" [23]	Systematic review	N/A	N/A
Sánchez-Carracedo et al. (2020), "Analysis of sustainability presence in Spanish higher education" [24]	Engineering Sustainability Map and sustainability presence map	As per the authors knowledge, this was conducted as the largest study to analyze the presence of sustainability in curricula	N/A
Qu et al. (2020), "Applying sustainability into engineering curriculum under the background of "new engineering education"(NEE)" [25]	(a) Pre- and post-questionnaire surveys (b) Fuzzy comprehensive evaluation model	N/A	N/A
Ashraf and Alanezi (2020), "Incorporation of sustainability concepts into the engineering core program by adopting a micro curriculum approach: A case study in Saudi Arabia" [26]	Survey and students' deliverables	N/A	N/A
Alexa et al. (2020), "Engineers changing the world: Education for sustainability in Romanian technical universities-An empirical web-based content analysis" [27]	Content analysis (empirical analysis)	N/A	This study was limited to the content of the curricula and to the information retrieved from the universities' public websites (the authors indicated that interviewing professors and students should be undertaken too to obtain better results).
Akeel et al. (2019), "Assessing the sustainability content of the Nigerian engineering curriculum" [28]	Content analysis by using NVivo 11 Pro	N/A	This study is constrained by the problem of defining sustainability content.

Table 4. *Cont.*

Authorship	Method(s) Used	Advantages Expressed by the Authors of the Papers	Limitations or Challenges Expressed by the Authors of the Papers
Sánchez-Carracedo et al. (2019), "A methodology to analyze the presence of sustainability in engineering curricula. Case of study: Ten Spanish Engineering degree curricula" [29]	(a) Engineering Sustainability Map (b) Sustainability presence map	Such a diagnosis would reveal the areas in which teachers need more training and also enable the design of a training program aimed at covering the needs of each degree	For a given cell, it is known whether or not there is a presence but not how large this presence may be. A cell in the Engineering Sustainability Map may contain several learning outcomes. However, it is sufficient for a single learning outcome of the cell to be developed in a single subject of the degree in order to define the whole presence of the cell. In addition, the cell corresponds to a single domain level of a certain competency unit, although the fact that the cell is considered as "present" leads to both the presence of the competency unit and the presence of the related sustainability competency. That is, developing a single learning outcome results in the determination of the presence of competency and a competency unit in the degree, regardless of the number of subjects and hours that the degree dedicates to developing the learning outcome. The analysis presented was conducted on the basis of the degrees' learning guides only. Therefore, activities different from those indicated in the learning guides could be undertaken by the subjects.
Trad (2019), "A framework for mapping sustainability within tertiary curriculum" [4]	Tracing sustainability learning outcomes within the faculty's graduate attributes, subject learning outcomes and assessment learning outcomes	It is an in-depth assessment method that analyzed detailed data	This method focused on tracing learning outcomes through the curriculum and did not take into consideration how learning and teaching takes place, which can promote or discourage ESD as well.
Onyilo et al. (2019), "Sustainable development and sustainability in engineering education in Nigeria" [30]	Systematic review	N/A	N/A
Rampasso et al. (2019), "Some of the challenges in implementing education for sustainable development: Perspectives from Brazilian engineering students" [3]	(a) Systematic review (b) Survey (c) TOPSIS	N/A	The data evaluated were only from 91 engineering students who completed the survey.
Rubio et al. (2019), "Embedding sustainability competences into engineering education. The case of informatics engineering and industrial engineering degree programs at Spanish Universities" [31]	Benchmarking	Breadth of data collected and detailed description of the process and derived results, make the study valid.	(a) The analysis was carried out in specific years, 2014/15 and 2015/16 only. (b) The information was from learning guides (syllabi) only. (c) This study did not cover all Spanish universities.
Roure et al. (2018), "Systematic curriculum integration of sustainable development using life cycle approaches" [32]	Survey	N/A	N/A

Table 4. *Cont.*

Authorship	Method(s) Used	Advantages Expressed by the Authors of the Papers	Limitations or Challenges Expressed by the Authors of the Papers
Thürer et al. (2018), "A systematic review of the literature on integrating sustainability into engineering curricula" [34]	Systematic review	N/A	N/A
Colombo and Alves (2017), Sustainability in engineering programs in a Portuguese public university" [33]	Content analysis by using Excel	N/A	This study was limited to the information from the official website.
Arsat et al. (2017), "Integrating sustainability in a student-centered learning environment for engineering education" [35]	(a) Content analysis (b) Interviews	N/A	N/A
Nazzal et al. (2015), "Introduction of sustainability concepts into industrial engineering education: A modular approach" [36]	(a) Before new modules: Content analysis (b) After new modules: Students' deliverables and end-of-course surveys	(a) Maintaining communication with faculty members and students through surveys ensures more effective curriculum modification (b) Effective and applicable approach	This study was limited in scope.
Watson et al. (2013), "Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology" [37]	(a) STAUNCH (b) Two surveys	Both methods can be useful and provide a holistic overview for curricula assessments	STAUNCH results were based on the course documentation. It did not include SD education delivered in the classroom.
Salem and Harb (2012), "Education for sustainable development: Assessment of the current situation at the faculty of Notre Dame University—Louaize" [38]	(a) Survey (b) Survey before and after courses	N/A	N/A
Becerik-Gerber et al. (2011), "The pace of technological innovation in architecture, engineering and construction education: Integrating recent trends into the curricula" [39]	(a) Survey (b) Comparative analysis	N/A	N/A
Murphy et al. (2009), "Sustainability in engineering education and research at U.S. universities" [40]	Benchmarking Survey	N/A	N/A
Galvič (2006), "sustainability engineering education" [41]	Content analysis	N/A	This study included limited work.
Kumar et al. (2005), "Infusing sustainability principles into manufacturing/mechanical engineering curricula" [42]	Benchmarking Survey	N/A	N/A

3.3. What Kinds of Findings Are Obtained in the Articles?

Table 5 depicts the findings from each article.

Table 5. Articles' findings.

Article	Findings from the Articles	Authors' (Our) Interpretations
Sofri et al. (2023) [15]	Sustainability was demonstrated as a new process safety topic in undergraduate chemical engineering programs. The goal of including sustainability topics in the process safety chemical engineering curriculum is to raise students' knowledge of how industrial activities contribute to environmental issues like climate change and ozone depletion.	The content analysis evaluated the presence of sustainability in chemical engineering curricula in many QS-ranked universities to raise students' awareness and knowledge to understand environmental issues.
Jahan et al. (2022) [16]	The outcomes derived from the sustainability content incorporated into specific courses displayed a consistent pattern. Among the courses, namely Statics, Solid Mechanics, Surveying, and CEE Systems, scores were below 80% when compared to the remaining courses. It is noteworthy that all these courses are at the sophomore level, with the first three carrying two credits each. Despite this, the overall findings are positive, particularly in the case of junior-level core courses, where students affirm that the curriculum effectively introduces them to sustainability and green engineering concepts.	The survey focused on one university and evaluated the presence of sustainability. It allowed the authors to assess how students perceive sustainability concepts after the introduction of courses.
Gannon et al. (2022) [17]	The survey successfully assessed the level of support from engineering faculty for both engineering education research and sustainability education. Additionally, the survey included items that contributed to gauging attitudes toward climate change, teaching methods, curriculum, and the implementation of research-driven pedagogies. The study provided statistical analyses of the survey's structure, along with recommendations for its continued development and potential applications.	The survey focused on one university and measured engineering educators' attitudes and dispositions toward engineering education research and sustainability education.
Gomez-Martin et al. (2021) [18]	Forty-five courses (75%) addressed or had the potential to address targets covering the 17 SDGs.	The STAUNCH method proved to be a useful tool to assess sustainability's presence at their university.
Sánchez-Carracedo et al. (2021) [19]	In this study, it was found that only just over a quarter of the SDG learning objectives existed in all engineering degrees. Two SDGs (SDG 2 and SDG 14) lack appropriate learning objectives within any engineering degree. To address this shortfall, the Engineering Sustainability Map incorporates certain learning outcomes that may not directly align with SDG learning objectives but are pertinent to the SDGs. Consequently, the Engineering Sustainability Map complements the UNESCO document, contributing to the fulfillment of SDGs from both engineering and technological perspectives.	This paper describes three tools that the authors developed as part of a large project on SDGs and which were validated to be used in the project.
Nikolić and Vukić (2021) [20]	From the international context, there are two main ways to integrate sustainability: designing special courses dedicated to sustainable development or an integrative approach. Challenges include a lack of space for new courses, the complexity of the issues, insufficient teaching staff knowledge, and resistance to change. In Serbia, the analysis of the engineering curricula showed that courses dedicated to sustainable development were found at all levels (undergraduate, master, doctoral), as well as within the specialist, applied, and integrated studies, and they are almost equally represented in undergraduate and master's studies. Sustainable development courses at the undergraduate level are typically studied during either the second or fourth academic year. Most courses related to sustainable development are elective.	A systematic review was conducted to explore the approaches of integrating sustainability in engineering programs globally. Furthermore, content analysis was performed to analyze sustainability's presence in the engineering curricula in Serbia.

Table 5. *Cont.*

Article	Findings from the Articles	Authors' (Our) Interpretations
Aginako and Guraya (2021) [21]	The authors found that sustainability is hardly inserted in the assessed programs. The authors showed that the environmental dimension had the highest result in being integrated in the programs.	The survey method assessed sustainability's presence at one university.
Damigos et al. (2021) [22]	The authors highlighted the importance of the various stakeholders' respective roles in forging a sustained cooperation for enhancing the curricula, which can in turn enhance cooperation and interest, leading to improved SDG fulfillment. All stakeholders agreed that it is crucial to integrate sustainability in the engineering curriculum. The stakeholders equally agreed that the existing curriculum lacks transferrable presentation skills, which should be addressed urgently to allow the integration of multidisciplinary project implementation. It became apparent that RM engineers, like all other engineers, require comprehensive knowledge of sustainability principles, presentations and transferable skills, innovative thinking, and strong professional attitudes. A number of simulations were then conducted to ascertain the correlation between industry needs and SDGs, as the external sector, and university environmental factors, as the internal sector, related to faculty knowledge about SDGs and their inclusion in courses. Internships were a critical link between both sectors and a serious improvement is needed to integrate SD in the curriculum as only a few courses provided the basics of SD principles. The latter should be actively integrated and embedded in as many technical courses as possible. The FCM method was used for the first time to evaluate SD principles, which created the possibility to assess the fifteen factors identified by the stakeholders in the RM whole value chain SDGs–education–innovation eco-system.	FCMs are a tool that needs further validation to be used widely as they provide a comprehensive assessment of sustainability in teaching. The interviews complimented the FCM to explore the educational needs and challenges of achieving the SDGs.
Arefin et al. (2021) [23]	The literature highlighted that Australian universities are taking this matter seriously. Most of them successfully incorporated sustainability and the remaining universities are in the process of incorporating sustainability in the engineering program.	The systematic review played a critical role in evaluating sustainability's presence in many universities in Australia.
Sánchez-Carracedo et al. (2020) [24]	The results of the study showed that many courses have developed sustainability courses to a given degree. The results varied from one university to another.	Through the dual methods of Engineering Sustainability Maps and sustainability presence maps, sustainability's presence was investigated in many universities.
Qu et al. (2020) [25]	The authors depicted that, following the new curriculum's implementation, there were significant changes in attitudes and knowledge.	The effectiveness of applying sustainability to the engineering curricula was evaluated using pre- and post-questionnaire surveys as well as a Fuzzy comprehensive evaluation model.
Ashraf and Alanezi (2020) [26]	The authors concluded that stand-alone courses focusing on sustainability are the most effective strategy.	Survey and students' deliverables helped in determining the effectiveness of stand-alone courses needed to promote sustainability.
Alexa et al. (2020) [27]	The results showed that there are discrepancies in the number of sustainability-related courses among universities, faculties, and degrees. For example, master's courses integrate sustainability more than bachelor's courses.	The content analysis (empirical analysis) helped in investigating sustainability's presence in many universities.
Akeel et al. (2019) [28]	The results revealed that the Nigerian engineering curricula suffer from a low sustainability content with more focus on environmental concepts versus social topics.	The content analysis helped in investigating sustainability's presence in many universities.

Table 5. *Cont.*

Article	Findings from the Articles	Authors' (Our) Interpretations
Sánchez-Carracedo et al. (2019) [29]	The findings suggested that the competency least prevalent across all degrees in terms of sustainability is "participation in community processes that promote sustainability", registering an average presence of 23.3%. Conversely, the most prevalent competency is the "application of ethical principles related to the values of sustainability in personal and professional behavior", with an average presence of 76.6%. On average, sustainability-related learning outcomes exhibit a presence of 52.1%, indicating that roughly half of the learning outcomes (cells) in the ten Engineering Sustainability Maps are not addressed in the degrees under examination.	Through the dual methods of Engineering Sustainability Maps and sustainability presence maps, sustainability's presence was investigated in many universities.
Trad (2019) [4]	From the Student Outcomes (SOs), it was found that declared education for sustainable development (ESD) outcomes comprised 22.4% of undergraduate courses within the Faculty of Engineering and Information Technology (FEIT). A more thorough investigation, which included evaluating subject content and student experiences for the seven ESD outcomes, revealed a 7.7% integration of sustainability into FEIT undergraduate courses. The tables that were generated using SPSS illustrated the distribution of individual competencies across the duration of course candidature. Lifecycle assessment was obviously absent from the curriculum.	The method used traced sustainability learning outcomes through the engineering curriculum. However, as it only involved one university used as a case study, the outcomes are limited in value and cannot be generalized.
Onyilo et al. (2019) [30]	The findings indicated a lack of awareness about ESD even among engineering stakeholders. Scholars globally have employed approaches like modular/Bolt-in, Project-Based Learning (PBL), Integrative Learning, Problem Project-Based Learning (PPBL), among others to infuse sustainability into their engineering education programs. These approaches could be implemented as stand-alone courses or integrated into existing programs. The authors suggested that institutions and faculties planning to integrate sustainability could consider adopting any of these approaches.	The systematic review was used to assess the level of awareness of SD and the approaches adopted to integrate sustainability in Nigeria.
Rampasso et al. (2019) [3]	TOPSIS revealed the following challenges: 'Sustainable issues debated only in specific disciplines in a limited extent'; 'Difficulty to integrate disciplines for the broad teaching of sustainability'; 'Lack of practical and real examples of how sustainability can be embedded in the specific context of the course'; and 'Activities and examples presented focus exclusively on environmental issues'. The authors concluded that Brazilian universities have to make a big effort to integrate sustainability in their engineering courses.	The combined methodology of a systematic review, survey, and TOPSIS was used to analyze the challenges of integrating sustainability in Brazil.
Rubio et al. (2019) [31]	The authors found great diversity in how sustainability competences had been integrated in the curricula. There were extended variations between both degrees in what they included in the relationship to the to the Key dimensions. For example, whilst informatics significantly lacks environmental dimensions, industry lacks the ethical dimension. This extended variation was equally found when the holistic and systematic integration of sustainability in the curricula was assessed by evaluating the number and type of courses offered that include them in their syllabuses. One noticeable finding is that not a single university in either discipline managed to cover all four key dimensions.	Benchmarking was used to investigate many degrees in Spanish universities.
Roure et al. (2018) [32]	The results indicated an 85% positive response rate, reflecting engineering students' appreciation for the introduced SD modules. The capstone project yielded the most favorable outcomes, highlighting the students' ability to apply their SD knowledge at this stage.	The survey helped in evaluating the curriculum in one university.

Table 5. *Cont.*

Article	Findings from the Articles	Authors' (Our) Interpretations
Colombo and Alves (2017) [33]	The authors investigated the integrated master's programs, which were then categorized as "Strongest" (comprising three programs, equivalent to 20% of the total), "Medium" (consisting of six programs, or 40%), and "Weakest" (with six programs falling into this group, making up the remaining 40%). Regarding master's programs (second cycle), 3 were designated as "Strongest" (constituting 11%), 7 as "Medium" (accounting for 26%), and 17 as "Weakest" (representing 63%). In the case of doctoral programs, 3 were classified under the "Strongest" category (making up 13%), 4 as "Medium" (17%), and 17 programs lacked any sustainability approach, placing them in the "Weakest" category (constituting 71%).	The content analysis helped in evaluating sustainability's presence in one university.
Thürer et al. (2018) [34]	The analysis led to the identification of twelve prospective research questions. The aim was to address these questions and, in turn, improve education, ensuring that engineers are well-equipped, actively involved, and empowered to address the environmental, social, and economic challenges of the 21st century.	The systematic review was used to assess the integration of SD in engineering curricula globally.
Arsat et al. (2017) [35]	The analysis of the results followed a systematic approach, categorizing them into three factors: input, throughput, and output. The study then revealed three primary findings: (1) the complete implementation of sustainability is lacking across all engineering courses, (2) a student-centered learning environment should provide a platform for integrating sustainability without compromising technical and engineering content, and (3) when implemented, the integration of sustainability is focused on one pillar, specifically the environmental aspect.	The content analysis helped in evaluating sustainability's presence in one university, which was complemented by interviews.
Nazzal et al. (2015) [36]	The authors concluded that the positive response from the students confirms that the introduced approach had indeed made a positive impact, demonstrating its effectiveness and practical applicability.	The content analysis helped in evaluating sustainability's presence in many universities before introducing SD modules. Post implementing SD modules, surveys were conducted to assess their success.
Watson et al. (2013) [37]	The STAUNCH results revealed a predominant focus on environmental issues in the courses, suggesting a potential need for enhanced depth of coverage. The results from student surveys aligned with the curriculum assessment, although discrepancies were noted specifically in relation to social issues. Employing both assessment methods offered a comprehensive perspective on the impact of engineering courses and degrees on sustainability. This dual approach helped identify disparities between the sustainability content outlined in the syllabus and its actual implementation in the classroom.	The STAUNCH method and the two conducted surveys proved to be a useful method to assess sustainability's presence at their university.
Salem and Harb (2012) [38]	The results highlighted the limited courses on offer for sustainability, of which most of them are offered by the department of civil and environmental engineering. In addition, they do not adequately educate students about the institution's role in social and ecological systems. Furthermore, the analysis of the survey completed by the students before taking the courses showed that there is a need to add a new mandatory course about environmental knowledge, values, and ideas (results after courses are not available).	The survey was used to identify the challenges and to assess the current status of SD in the curricula.
Becerik-Gerber et al. (2011) [39]	The results showed that discrepancies exist in the 101 US AEC educational programs, necessitating a reorientation to cultivate a future workforce capable of spearheading transformations in the AEC industry.	The survey was used to identify factors related to SD. Then, a comparative analysis was conducted to ascertain similarities and differences between the programs.

Table 5. *Cont.*

Article	Findings from the Articles	Authors' (Our) Interpretations
Murphy et al. (2009) [40]	Sustainable engineering is at a critical stage, with significant grassroots activity in education and research. The benchmarking was used as an inventory of what is currently available and can serve as a resource as standards develop in classifying courses under four specific categories: sustainable engineering courses, traditional engineering courses with sustainable engineering content, cross-disciplinary courses offered jointly with a non-engineering department, and sustainable engineering technology courses which address technologies viewed as enabling sustainability.	Benchmarking was used to investigate sustainability's presence in the programs in many universities.
Galvič (2006) [41]	Universities continue to uphold courses rooted in traditional approaches like pollution and control. Sustainability has been incorporated into undergraduate programs, while in postgraduate studies, it is available as a module with multiple associated courses.	Content analysis was used to investigate sustainability's presence in the curricula in many universities.
Kumar et al. (2005) [42]	This paper suggests that the ideas presented should serve as a guideline for curriculum development, with each university's culture and educational objectives determining its vision for its manufacturing/mechanical engineering curriculum. The authors believe that integrating sustainability into engineering curricula, including course development and faculty engagement, will help students to better understand the world around them.	A survey and benchmarking were used to investigate sustainability's presence and barriers in one university.

4. Discussion and Conclusions

The papers included in this study provide a general overview underlining that the concept of sustainability is crucial for engineers, making it essential to integrate SD into their profession and daily thinking. An integral step in this direction, as detailed in Table 3 and Section 3.1, is seen in the many methods used to integrate sustainability into engineering curricula and how the curriculum was evaluated in each manuscript. Whilst the curriculum serves as an optimal starting point for educational programs, it is intriguing to note that the presence of only 30 articles (Tables 3–5) assessing engineering curricula from 2000 to 2023 seems disproportionately low given the critical importance of evaluating engineering programs. Furthermore, it is evident that there is a discrepancy in the countries that are actively leading in this endeavor (Table 2 and Figure 3A,B). It is intriguing to note that no studies published in English were found, using ERIC and Scopus, in countries where sustainability plays a critical role in setting policies, for example in the UK, France, and Finland. The need for a change is still required worldwide to meet the SDGs. It is therefore imperative to infuse the concept of sustainability into education systems worldwide, particularly in engineering curricula, knowing that engineers are the key players in making achieving sustainability goals a reality.

4.1. Methods

In addressing the question "What are the conducted methods to analyze sustainability's incorporation into the engineering curriculum?", it is evident from Table 3 that 14 methods were employed in the literature to assess engineering curriculum. The literature did not provide a Gold Standard reference for curriculum analysis and as such the methods are described as mentioned in the respective articles. Upon examination of the papers, certain methods exhibited similarities and fell within the same category. It is therefore advisable for researchers to reach a consensus, to adhere to, and to uphold standardized method nomenclature. For instance, STAUNCH, an education assessment tool developed in 2007, evaluates sustainability content in curricula by scrutinizing syllabi or course descriptors as data sources. It focuses on 37 sustainability topics across economic, social, environmental, and crosscutting dimensions [28]. Thus, it aligns with the category of content analysis. Some articles exclusively employed a single method, while the majority of researchers opted for a combination of two or three methods; details were elaborated in Section 3.1. Notably, there is a variance in the level of detail provided in the listed articles regarding the methods used. For example, the implementation of content analysis is well documented in some articles, indicating specific tools such as Excel [15,33] and NVivo 11 [28], but is nonexistent in others [20,27,35,36,41]. This inconsistency makes it difficult to decide whether one approach is better than the other, or if a new assessment method is warranted.

4.2. Dissecting the Curriculum

Analyzing a curriculum is not a straightforward task. There are many methods available (Table 3), and each method allows for the analysis of a specific aspect of the curriculum. Some methods offer quantitative insights into the courses (e.g., [15,28,33]), while others help identify the key competencies targeted by the programs. Whilst some methods focus on the objectives expressed by teachers [35], others concentrate on the experiences of students [26,36]. Since a curriculum encompasses both the teaching content and the methods of selection, organization, and transmission [14], it is necessary to cross-reference and employ multiple methods for a comprehensive curriculum analysis, as is the case with Damigos et al. [22] and Qu et al. [25]. The latter approach allows us to capture potential differences between the prescribed curriculum and the actual curriculum [43], highlighting the variance between what is intended to be taught and what actually is being taught.

Our review allows us to note that the approach taken by most authors is predominantly didactic. Their objectives are to grasp changes in the form and content of curricula by focusing on the following: what is taught, what the pedagogical practices employed are, and their efficiency. This holds true for all articles that focus on the titles and content of courses, the sought-after competencies, and keywords in the programs. Consequently, these articles generally address the formal and explicit curriculum and not what is informal, implicit, or hidden in the curriculum. It is equally shown in the synthesis about higher education for sustainable development by Rickinson et al. (2015) what works and what does not work well, in an axiological purpose [44].

There are also fewer articles with approaches falling under the sociology of the curriculum. Such articles delve into the curriculum in its interactions with social, cultural, and political realities and the connections between the curriculum and these external transformations, as was the case with Gomez-Martin et al. [18], Rubio et al. [31], and Watson et al. [37]. Research that conceives of the curriculum as a social construct [14] places emphasis on the actors involved in the curriculum (teachers, educational leaders, students, businesses, etc.), their representations, and the meaning they attribute to their practices. This approach, which is more comprehensive, has deep roots in Weberian sociology.

4.3. Advantages, Limitations, and Access to a Precise Type of Result

Regarding the questions “Are there any explicitly mentioned limitations or challenges encountered in the process? Are there any mentioned advantages for the used assessment method?”, the findings indicate that each method gives one kind of limited result (Table 4), which is why employing multiple methods is preferable for obtaining more robust results. As previously noted, by relying solely on content analysis, for instance, the study may then lack accuracy, especially when instructors incorporate sustainability approaches in their classes with such information lacking from the official course syllabus [32,37]. STAUNCH [18,37] and other auditing tools, using software, are useful to identify what the curriculum offered but did not reflect in the quality of the content. Therefore, the selection of methods should encompass a comprehensive approach to ensure accuracy in the results. It seems, then, more appropriate to combine at least two of the methods in Table 3.

As can be seen from Table 3, the two most independently used methods are “survey/questionnaire” and “content analysis”. These two methods can in fact complement one another and may produce a comprehensive evaluation in assessing the curricula. It is our recommendation that these two methods are used in future analysis, allowing a platform of similarities to compare engineering curricula worldwide. Adding a third method is surely advisable to further strengthen the analysis.

The results from the question "What kinds of findings are obtained in the articles?" underscored the importance of aligning the choice of method with the respective research objectives but, more importantly, the findings highlighted that there is no agreement as to which method is best to use. Tables 4 and 5 provide a comprehensive overview of the findings from each article and their respective limitations or challenges, if any. The findings prove that the choice of method might have skewed the results one way or another, and with no one system used to assess the curricula, it is quite difficult to create a benchmark to do so across all engineering courses worldwide as it stands. If we take into account the variety and richness of engineering curricula offerings around the world, one might argue that there is a need for a common set of methods to be used to standardize the process of evaluation.

At the end of this analysis, we do not think it is necessary to harmonize either the curricula or the analysis methods. We are convinced that it is important to provide educators and researchers with a wide choice of evaluation and analysis tools, thus allowing them to choose the one or the ones that best suit their institution, their program, and their teaching and research objectives.

The knowledge of the variety of these methods is very useful for academics to define the approach that will suit their needs best. This was one of the main objectives of our review.

5. Limitations

A major limitation of this paper is its focus on purely the scientific literature and those published in English only. Future research could extend this study to other databases, if it seems justified, accreditation bodies, and their methods to assess the curriculum.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16114549/s1, File S1: PRISMA checklist [45].

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