sustainability

MDPI

Article

A Social Assessment Framework to Derive a Social Score for Green Material Selection: A Case Study from the Sri Lankan Cement Industry

Ashani Fernando [1,2], Chandana Siriwardana [3,*], Chamila Gunasekara [1], David William Law [1], Guomin Zhang [1] and J. C. P. H. Gamage [2]

[1] Civil and Infrastructure Engineering, School of Engineering, RMIT University, Melbourne, VIC 3000, Australia; s3934276@student.rmit.edu.au (A.F.); chamila.gunasekara@rmit.edu.au (C.G.); david.law@rmit.edu.au (D.W.L.); kevin.zhang@rmit.edu.au (G.Z.)
[2] Department of Civil Engineering, University of Moratuwa, Moratuwa 10400, Sri Lanka; kgamage@uom.lk
[3] School of Built Environment, Massey University, Auckland 0632, New Zealand
* Correspondence: c.siriwardana@massey.ac.nz

Abstract: Assessing the sustainability of material-based products now encompasses social sustainability, a vital aspect often overlooked. Even though the existing frameworks provide a starting point, they do not often differentiate between the assessment criteria when making comparisons within one specific material category, which has made sustainability assessments more focused on environmental and economic aspects. This study addresses this critical gap by pioneering a social assessment framework curated to help practitioners to choose the most sustainable cement type out of the standard cement types used in the industry. Utilizing the Fuzzy Analytic Hierarchy Process (FAHP) and linear-scoring method, criteria weights were systematically assigned based on scoring by industry and academic experts. The findings highlight the importance of integrating social sustainability with environmental and economic factors in cement selection. Unlike traditional material selection, which primarily considers cost and performance, green material selection emphasizes the holistic impact of materials, including social factors. Variations in weightage decisions among experts highlight the influence of practical experience, research interests, and context. Functionality emerges as a crucial criterion. The ranking of cement types based on social scores places CEM II/B-M at the top, followed by CEM IV/A, CEM II/A-S, CEM II/A-V, CEM I, and CEM II/A-LL. The evolving nature of sustainability necessitates ongoing research to refine and expand existing frameworks for a more sustainable construction industry.

Keywords: sustainability criteria; cement; material selection; FAHP; scoring method; social aspects; social impact

Citation: Fernando, A.; Siriwardana, C.; Gunasekara, C.; Law, D.W.; Zhang, G.; Gamage, J.C.P.H. A Social Assessment Framework to Derive a Social Score for Green Material Selection: A Case Study from the Sri Lankan Cement Industry. *Sustainability* **2024**, *16*, 6632. https://doi.org/10.3390/su16156632

Academic Editor: Antonio Caggiano

Received: 29 June 2024
Revised: 25 July 2024
Accepted: 28 July 2024
Published: 2 August 2024

1. Introduction

The requirement for choosing sustainable materials becomes more and more important as construction projects continue to grow in number. Cement, being one of the most widely used construction materials, and with a high amount of global greenhouse gas (GHG) emissions, holds significant potential for improving the overall sustainability of the industry. However, existing methods of material selection frequently give priority to technical and financial aspects while ignoring vital social aspects of sustainability [1,2].

Social sustainability often encompasses a range of factors, including, but not limited to, product acceptance, community well-being and awareness, expected functionality, local development, and resource availability [3]. The inclusion of these factors in material decision-making can have significant effects on workers', a community's, and societal well-being. A positive trend, in recent years, has been the growing awareness of the need to integrate social considerations into material selection processes in the construction industry [2]. Figure 1 presents the co-occurrence analysis of keywords in 30 selected, recent studies from 2004 to 2024, which are related to various selection criteria based on social sustainability. It conceptualizes the interconnectedness and frequency of the use of the following terms: life cycle assessment, sustainability, environmental impact, socioeconomic impact, social life cycle assessment, etc. However, consideration of social factors has been lacking when it comes to material selection-related applications [4,5]. To address this critical gap, a social assessment framework for material selection in the construction industry, with a specific focus on cement, is considered essential. This would offer decision-makers a systematic and complete method for assessing the social sustainability performance of various cement types and for making informed choices.

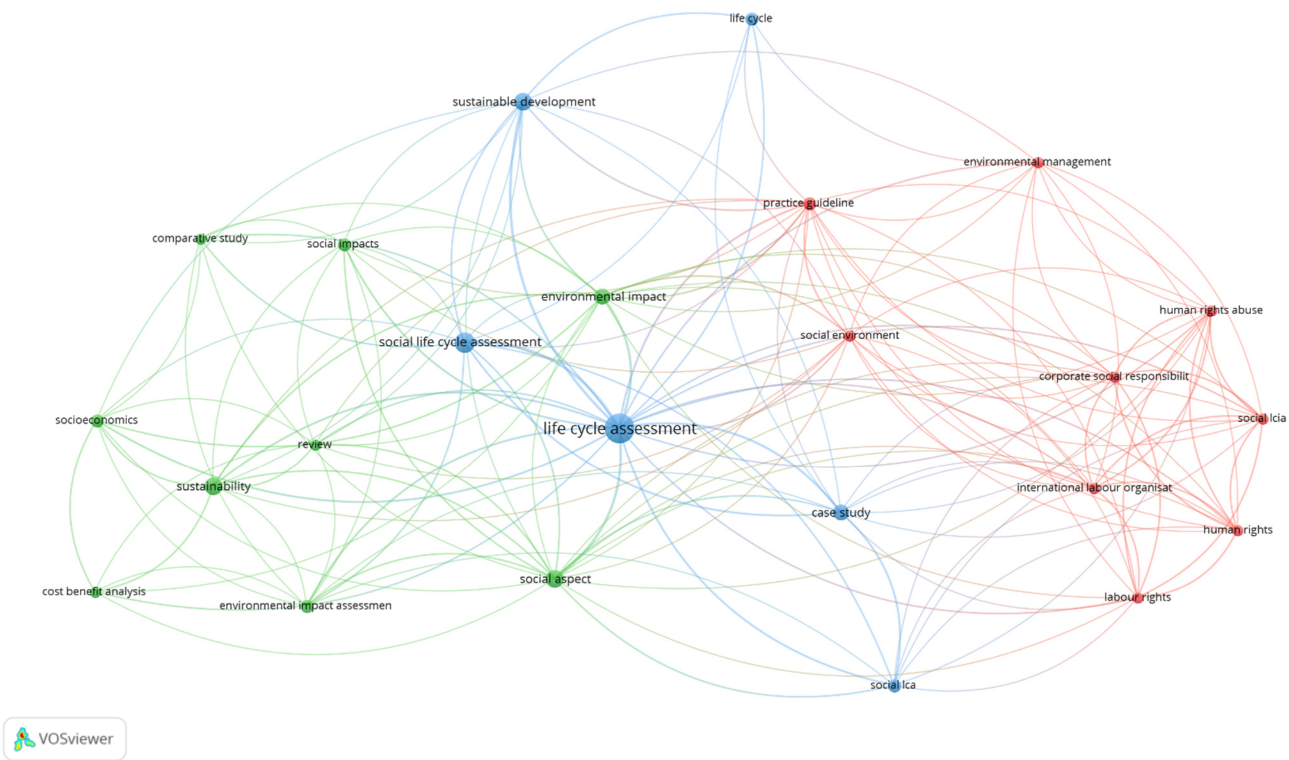

Figure 1. Keyword analysis using VOSviewer version 1.6.20.

To meet the growing demands of concrete production, currently 4–4.1 billion tonnes of cement is produced globally, which account for 8% of global CO_2 emissions [6]. Similarly, the construction industry in Sri Lanka, like any other developing nation in the world, heavily relies on the cement sector to meet the growing demand for building materials. Cement is mainly needed for infrastructure development, such as the construction of roads, bridges, buildings, etc. [7]. Sri Lanka's cement industry has grown significantly in recent years, owing to urbanization and ambitious government measures aimed at strengthening the country's physical infrastructure [8]. As a result, cement production and consumption have constantly expanded, making it an essential component of the country's economic development. As of 2020, the domestic production had reached 3.94 Mt in addition to 2.23 Mt being imported [9]. The sector has taken steps to fulfill the increasing demand for cement, which is being driven by urbanization, housing construction, and infrastructure development. Cement consumption in Sri Lanka is currently trending at around 6–6.5 Mt, with growth predicted to have returned somewhat in 2021 following a 2% fall in 2020 to 6.2 Mt [6]. This increased consumption has started raising concerns both locally and on a global basis around sustainability-related issues [10]. According to experts, failure to mitigate this environmental damage could lead to irreversible harm to the planet in the future. Aligning the cement industry with the Paris Climate Agreement requires a minimum 16% reduction in annual emissions within the built environment by 2030 [11].

In response to worldwide concerns about environmental sustainability, Sri Lanka's cement industry has made attempts to lessen its environmental footprint. In this context, blended cement (BC) has emerged as a more sustainable alternative, combining traditional cement with supplementary cementitious materials (SCMs) such as fly ash, slag, or silica fume [12]. Blended cement manufacture reduces not just the use of limited natural resources, but also GHG emissions and energy consumption during manufacturing processes. Following global trends, there has been an increase in the use of blended cement in Sri Lanka, representing a favorable shift in the industry's environmental standards [13,14]. This is evinced by the increase in local research studies focusing more on the use of cement and its sustainability aspects, demonstrating the recent emergence of attempts to address the problems related to the use of cement in Sri Lanka [12,15]. However, with the availability of a variety of cement types in the market, Sri Lankan cement consumers are made to choose from a range of cement types from different manufacturers. Even though attempts have been made to address the environmental and economic concerns, social sustainability remains the least explored area [12]. This has meant certain choices relating to material selection have lacked input from a social outlook point of view. Hence, the present study focuses on developing a social assessment framework targeting the comparison of several standard cement types used in the industry. To achieve this, the study employs the Fuzzy Analytic Hierarchy Process (FAHP) and a linear scoring method. The FAHP is utilized to assign weights to various criteria based on the inputs from industry and academic experts. This method allows for the incorporation of expert judgments in a structured and quantifiable manner, accommodating the inherent uncertainties and subjective nature of the assessment process. The criteria weights determined through FAHP are then used in a linear scoring method to rank the cement types. By developing and proposing this social assessment framework, this study aims to contribute to the evolving discourse on sustainability in the construction industry, promoting a more comprehensive and inclusive approach to material selection.

The structure of this paper is as follows: after the introduction, Section 2 reviews the relevant literature on sustainability assessment frameworks and the specific role of social sustainability. Section 3 details the methodology, including the FAHP and linear scoring method. Section 4 presents the findings and discusses the implications of the results. Finally, Section 5 concludes with a summary of the key points, limitations of the study, and recommendations for future research.

2. Theoretical Background

2.1. Need for a Social Assessment Framework

While the increased use of blended cement represents an increase in environmental sustainability awareness, it is equally important to take social sustainability into account within the cement sector. The review of recent studies related to social assessments in Figure 1 reveals what has been done to date. Represented in Figure 2 is an extraction of the same figure showing the enlargement of the node termed 'social life cycle assessment'. It encompasses areas discussed together with social life cycle assessment. A showcase of terms such as environmental impacts, social impacts, and social aspects illustrates how studies have incorporated such aspects together with social lifecycle assessment. In addition, it is seen that these applications have mainly taken the form of simple and comparative case studies, which is confirmed by the occurrence of terms, comparative studies, and case studies of keyword analysis. Few of the efforts reported in the literature are included in Table 1.

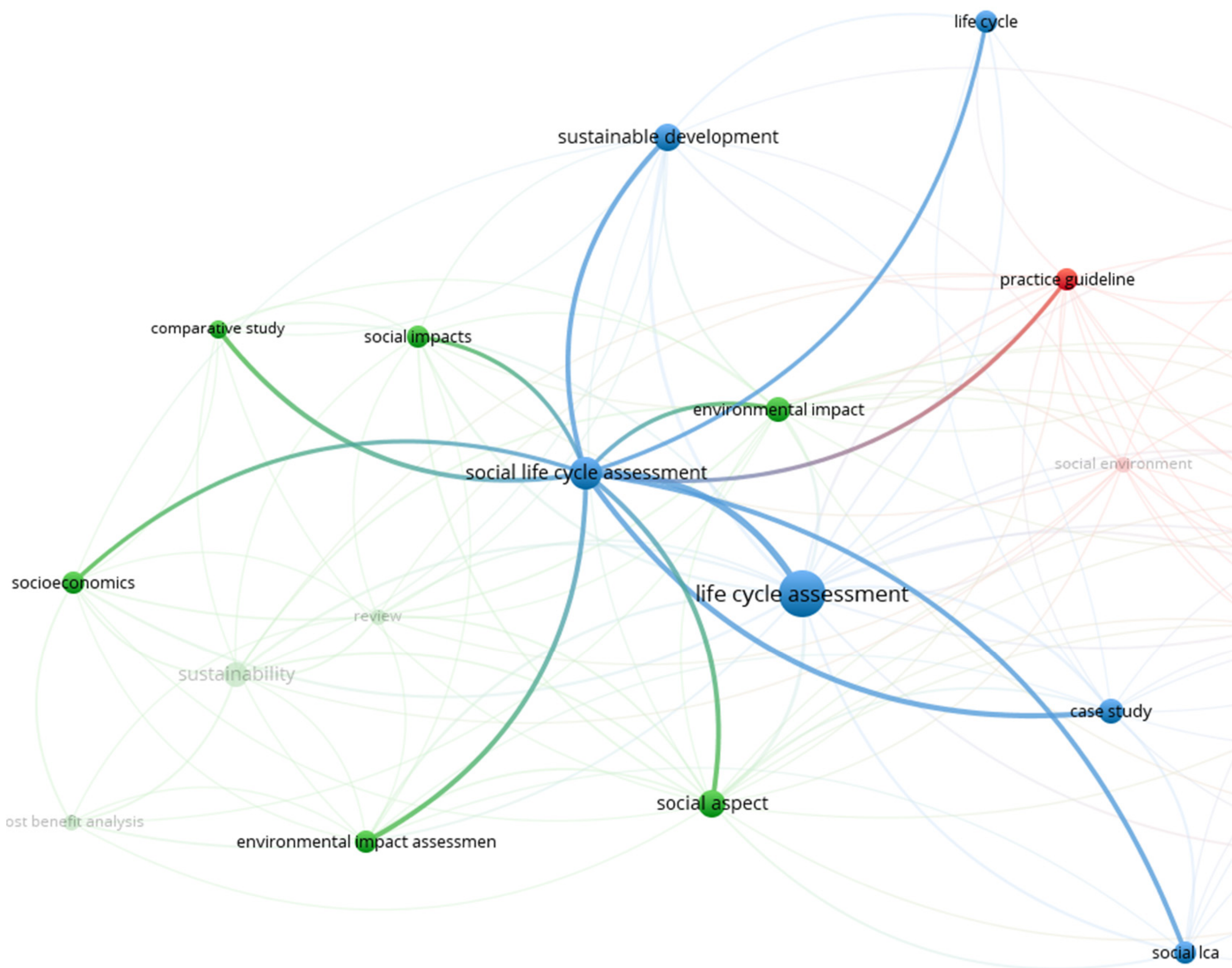

Figure 2. Co-occurrence of keywords with social assessment.

Table 1. Reported literature on social assessment.

Reference	**Case Study/Application**	
	Simple	Comparative
[16]		A laptop in several countries
[17,18]		Manufacturing processes
[19]	Plastic family materials in EU countries	
[20]	Food production system	
[21]	Chinese electronics industry	
[22]		Oil and gas; agricultural biotechnology
[3]		Concrete and steel as building materials in Iran

To analyze the general sustainability of building materials, a number of social evaluation frameworks, including the Social Life Cycle Assessment (S-LCA) and the Social Impact Assessment (SIA), have been established [3]. SLCA extends the traditional Life Cycle Assessment (LCA) to include social dimensions, assessing impacts on stakeholders such as workers and local communities throughout the product's life cycle, using a mix of qualitative and quantitative indicators. However, it faces challenges in standardization, data availability, and integration with environmental LCA [3]. SIA, on the other hand, focuses on predicting and managing social impacts of planned interventions through a participatory approach, emphasizing continuous monitoring and mitigation measures. Despite its strengths, SIA often struggles with project-specific scopes, complexity in predicting social outcomes, and resource-intensive processes [23]. Both frameworks frequently lack the level of detail required to fully distinguish sustainability within one material type due to the complex nature of the social systems. Furthermore, the social aspects of cement manufacturing and use have not received enough attention in the literature, which has mostly concentrated on environmental sustainability [5]. To measure the social sustainability of cement in Sri Lanka, however, there are currently no comprehensive metrics or assessment frameworks available. The only existing frameworks used by the industry are the green rating systems for buildings and green labelling system for materials introduced by the Green Building Council in Sri Lanka [24,25]. In that, the criteria in material assessment are not seen to fully account for the unique social potential and challenges connected to various types of cement in order to differentiate between the types. Hence in order to facilitate a comprehensive approach to the sustainability of cement, a solid social evaluation framework that is customized to the Sri Lankan context is seen as a vital requirement.

2.2. Social Assessment Criteria and Indicators

In developing a social assessment framework for cement, it is essential to identify the appropriate criteria and indicators that capture the specific social challenges and opportunities within the considered context of application. For this purpose, similar to the approaches followed in other studies [26], a thorough literature survey was conducted to identify the social indicators applicable to the context based on adequate reasoning, after which, expert opinion was utilized to further refine the criteria based on applicability to the local context. In the literature, it is well documented that social criteria should be considered in concrete/cement applications due to their impact on overall sustainability. Comparatively to environmental and economic factors, measuring and evaluating social indicators is reported to be a difficult task [27–29]. Due to this reason, several authors highlight the fact that social criteria are frequently neglected when it comes to material selection for concrete [27,30]. However, despite these challenges, it is crucial to address the social aspects in order to achieve sustainability. Among the various indicators employed, public opinion, social networks, stakeholder needs, local materials, and customer satisfaction are frequently used in numerous social assessments related to materials [15]. According to Kumar et al. (2020) [29], understanding the level of acceptance of the product among customers is crucial, as it is the end customers who ultimately drive the demand and enable the manufacturing process. Ensuring that customers are well informed and confident in using the product enhances its social sustainability. In terms of the indicator related to social network, Fatourehchi and Zarghami et al. (2020) [27] report that addressing the various difficulties faced by consumers and the development of the product to address consumer needs and expectations is important. Additionally, addressing false assumptions and misconceptions, and incorporating important product characteristics sought by consumers such as health and safety requirements, can positively influence social aspects from a material-selection point of view. Concrete/cement materials must satisfy the needs of users, including contractors, builders, and construction workers [27]. According to Al-Atesh et al. (2023) [31], considering stakeholder needs ensures that the materials selected align with their requirements, leading to improved social sustainability. The same study recognized the consequences and potential benefits of using local materials, which is seen to strengthen the social aspect of material selection. Locally sourced materials contribute to job creation and economic development within the region. Moreover, as found by Hosseinijou et al. (2014) [3], customer satisfaction is vital for long-term success and positive social impact. Thereby, addressing these factors ensures the overall satisfaction and well-being of stakeholders, and promotes sustainable construction practices.

The ultimate goal of the current study being to facilitate more informed and socially responsible decision-making in the selection of cement in the construction industry, this study utilizes popularly adopted multi-criteria decision-making methodologies, such as the Analytic Hierarchy Process (AHP), to assign appropriate weightages to the social criteria within the framework, and uses a linear scoring system to assign scores to, and rank, the cement types considered in the case study. By doing so, a criterion is developed to assign a social score to the cement types available on the local market. Table 2 represents the evaluation criteria developed through the literature review and they were refined to suit the local context through expert consultation in the industry. Accordingly, the assessment criteria include five main criteria and several sub-criteria under each main criterion.

Table 2. Social criteria for cement selection.

Main Criteria	Sub-Criteria
M1. Consumer Acceptance (Consumer awareness and acceptance to use the product which determines the viability of the product)	**1.1 Eco-friendliness with Conformity to Standards** (is extra assurance for the consumers and is a positive attribute for protecting the environment)
	1.2 Market Reputation (Depending on the brand service and brand knowledge, consumers' preferences differ with the brand and type of cement)
	1.3 Affordability (Price that the users can afford)
M2. Functionality (The role that the product plays for its customers in terms of providing the desired strength and other properties of the product)	**2.1 Ease of Use for the Intended Purpose**
	2.2 Material Strength and Durability
	2.3 Visual Quality
M3. Technology (Use of green technology assessment is vital)	**3.1 Use of Renewable Energy** (Sustainable development needs evaluating the use of renewable resources)
	3.2 Use of Alternate Fuel (Sustainable development needs evaluating the use of green technologies)
	3.3 Reuse Content (Industrial/other byproducts used)
	3.4 Environmentally Friendly Production (Quantification of embodied energy)
M4. Local Development (Creation of value to local resources and jobs)	**4.1 Local Material Use** (Important for prioritizing purposes given the current economic situation and restrictions on importing products)
	4.2 Use of Locally Available Waste Materials (Sustainable development needs evaluating the use of green technologies involving local development)
M5. Resource Availability (Feasibility to produce sustainably)	**5.1 Short-term Resource Availability** (confirms the longevity of the product)
	5.2 Long-term Resource Availability (Sustainability concerns for future generations)

3. Research Methodology

This study aims to develop a social assessment framework to rank the available cement types in the market to help consumers make informed decisions when making the optimum selections of materials [29,31,32]. For this to happen, a mixed technique with two parts was adopted in this study. The first part comprised an extensive literature review of the related studies to identify the social criteria to rank different cement types, along with interviewing experts to refine the identified criteria, and conducting questionnaire interviews to derive weightages for the main and sub-criteria by means of AHP pairwise comparison. In the second part, the five-point scoring system was utilized in compliance with available local standards, and was adopted in ranking the cement types considered for the study. A similar use of linear scoring methodology applied to other areas is reported in studies conducted by [33,34]. In this study, combining it with FAHP to derive weightages is expected to result in more reliability [35]. By combining the overall methodology and results, an assessment framework was developed to enhance the selection of sustainable cement materials. The developed framework was then used to rank the considered cement types using the five-point scoring system. Figure 3 depicts the research framework for the current study, which consists of the development of the assessment framework and the ranking of the cement types as an outcome of the assessment process.

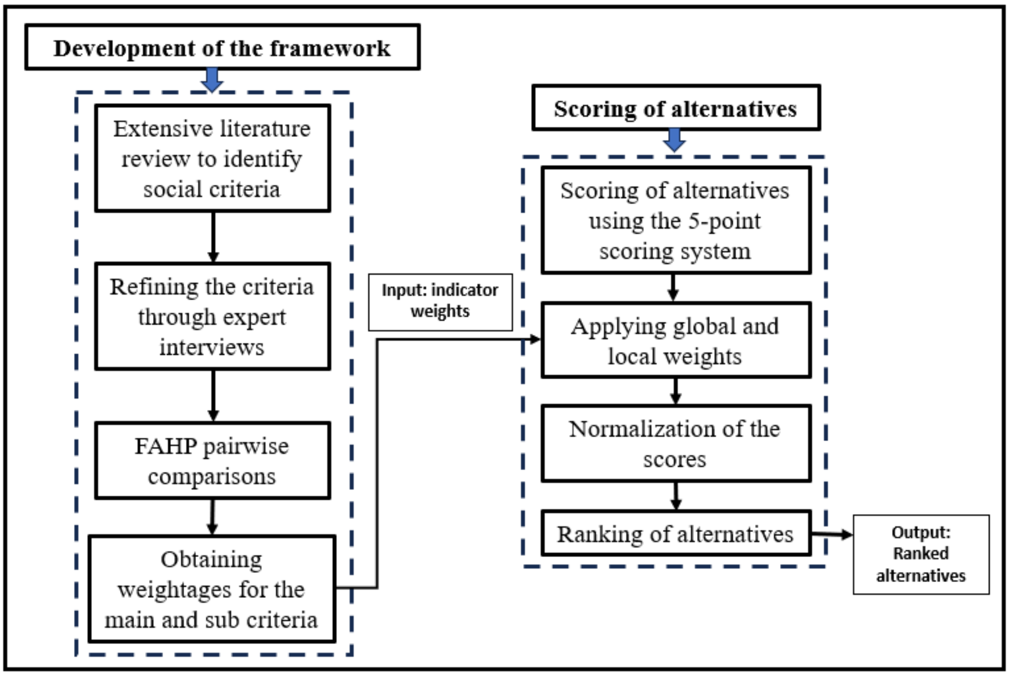

Figure 3. Research framework.

3.1. Weighing of Criteria

The process of deriving a score/index comprises a weighting and aggregation method [36]. To give each indicator a weight during the measurement and evaluation of the overall variable (synthetic score), it is advised that a weighting scheme be devised before moving on to the indicator aggregation [37]. Addressing stakeholder requirements is a key component of decision-making assessments and, as a result, in addition to indicator selection, allocating weight is another key step in the process that should account for the diversity of stakeholder viewpoints [38]. This is still one of the features that has not been fully covered in research conducted so far [15]. Hence, this study takes into account the perspectives of the decision-makers by assigning weightages accordingly. A total of 10 experts were considered to represent both industry and academia involved in concrete constructions in the Sri Lankan construction industry. Depending on factors such as complexity of the decision problem, the heterogeneity of expert opinions, and the desired level of accuracy and precision, it was decided to have a diverse group of experts (from different areas of expertise related to construction), with 10 deemed to be a sufficient number of participants, as confirmed by previous studies [39]. Information on the experts is illustrated in Table 3. Furthermore, how much weight is assigned depends on the context of the application and the needs of the user [40]. To achieve this, the purpose of the social assessment, together with the goal and scope, were relayed to the experts prior to conducting the interviews. The goal of the assessment being to derive a social index for different cement products, initially the experts were asked to refine the selected indicators which, in their opinion, would consist of the factors affecting the different social groups in the manufacturing, purchase, and use of a particular cement type.

Table 3. Data on expert profiles.

Expert No.	Professional Field	Area of Expertise	Years of Experience
1	Lecturer—Structural Engineering	Civil/Structural Engineering	8 years
2	Senior Professor/Lecturer—Structural Engineering	Civil/Structural Engineering	14 years
3	Head of Products and Solutions—Cement Manufacturing	Concrete and Cement Technology	38 years
4	Quality Assurance Manager	Ready-mix Concrete	10 years
5	General Manager	Green Certification Green Materials	6 years
6	Project Manager	Building Construction	7 years
7	Structural Engineer	Building Construction	15 years
8	Quality assurance Manager	Building Materials	8 years
9	Director	Cement Manufacturing	20 years
10	Senior Professor/Lecturer	Civil/Sustainable Engineering	12 years

When a weighting system cannot be implicitly identified, a criterion should define it [41,42]. Each sub-score's contribution to the synthetic score should be accurately replicated by the weighting method [38]. Although González et al. (2021) [43] argued that weight selection should be objective, it often involves complex issues, making objective selection difficult. Therefore, processes to manage differential subjective weights are recommended [42]. Statistical methods have traditionally been used in decision-making studies [43,44], but recent developments show the widespread use of Multicriteria Decision-Making Methods (MCDM). These methods, including Analytical Hierachy Process (AHP), Interpretive Structural Modeling (ISM), Elimination and Choice Translating Reality (ELECTRE), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Analytical Network Process (ANP), provide more stable weights than direct evaluation [45]. AHP, in particular, is popular for its simplicity and advantages over other MCDM tools, making it the chosen method for this study. AHP allows decision-makers to assess the relative importance of criteria through pairwise comparisons. While it can rank alternatives, some studies use AHP solely to derive weightages for indicators, proving this approach's validity [46]. AHP's transparency and structure facilitate the effective evaluation of complex decision problems, leading to more targeted decision-making.

To further enhance the accuracy and flexibility of the decision-making process, fuzzy logic was applied. Fuzzy logic is especially beneficial for dealing with uncertainty and imprecise information, both of which are common in real-world decision-related problems [35,37]. The application of fuzzy logic in sustainability assessments, particularly those involving multiple variables and expert opinions, provides for a better representation of uncertainty and vagueness in the decision-making process [47]. The procedure used is described as follows.

Step 1: The experts were initially asked to rank the indicators in the main and sub-criteria based on the AHP nine-point scale (see Table 4 [48]).

Table 4. Saaty AHP scale and Fuzzy triangular scales.

Saaty Scale	Definitions	Triangular Fuzzy Scale (L,M,U)
1	Equally important	(1,1,1)
3	Weakly important	(2,3,4)
5	Fairly important	(4,5,6)
7	Strongly important	(6,7,8)
9	Absolutely important	(9,9,9)
2	Intermittent values between two adjacent scales	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

Step 2: The Triangular Fuzzy Numbers (TFN) were configured as in Table 4. The FAHP scale contains three values: the lowest (lower, L), the middle (median, M), and the highest (upper, U). Triangular fuzzy logic was used to convert the crisp number to fuzzy numbers.

Step 3: After converting the AHP comparison value to the F-AHP scale value, the geometric mean method was used to aggregate all responses of the 10 experts. Following that, the fuzzy synthesis value was computed. The process to obtain the fuzzy synthesis value is shown using Equation (1) below.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} X \frac{1}{\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]} \quad (1)$$

S_i = fuzzy synthesis value

$\sum_{j=1}^{m} M_{gi}^{j}$= summing the cell value in that column starting from column 1 in each row matrix

i = row

j = column

Step 4: The defuzzification ordinate value was obtained by comparing fuzzy synthesis values. We may calculate the values of v from the foregoing calculation. To compute these, Equation (2) was utilized.

$$V(M1 \geq M2) = \begin{cases} 1, \text{ if } m2 \geq m1 \\ 0, \text{ if } m2 \geq m1 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - u_1)}, \text{ etc} \end{cases} \quad (2)$$

Step 5: Fuzzy vector weight was calculated (W) and the equation yields the normalization of vector weight values (given by Equations (3)–(5)).

$$d'^{(Ai)} = \min V(S_i > S_k) \quad (3)$$

$$\sum W' = (\text{vsl1}, \text{vsk2}, \ldots\ldots., \text{vskn}) \tag{4}$$

$$W' = \left(d'(A1), d'(A2), \ldots\ldots, d'(An)\right)T \tag{5}$$

Step 6: After defuzzification, consistency checks of the pairwise-comparison matrix of individual responses and final aggregated values were conducted using Equations (6)–(8) [49].

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} = \frac{(AW)_1}{nW_1} + \frac{(AW)_2}{nW_2} + \ldots.. + \frac{(AW)_i}{nW_i} \tag{6}$$

$$CR = \frac{CI}{RI} \tag{7}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{8}$$

The consistency check ensures the reliability and validity of experts' judgments, and that the derived weightages are reasonable. In this study, the geometric mean method was used to aggregate experts' opinions, as it is suitable for values on a multiplicative scale like AHP's pairwise comparisons [47]. This method mitigates the influence of extreme values, providing a balanced aggregation approach. Previous studies, such as that by Wang Chen et al. (2016) [37], used fuzzy AHP and geometric mean to prioritize sustainability criteria, highlighting the method's effectiveness in handling ambiguity and aggregating expert opinions in multi-criteria decision-making.

3.2. Scoring System

To rank the cement alternatives, assigning a score was necessary. As the first step, it involved defining the scoring scale for each criterion. The scoring scale was designed to reflect the varying levels of social sustainability performance for each criterion. For instance, a score of 1 indicates a low level of social sustainability, while a score of 5 indicates a high level of social sustainability for a particular cement type under the specified indicator. Bakhoum and Brown (2012) [33] adopted a similar approach in their study, which was based on evaluating structural materials.

The score system was developed based on the available scoring system used for green material assessment developed by the Green Building Council of Sri Lanka (GBCSL) and also in consultation with industry specialists [24,25]. Indicators were assigned to evaluate each sub-criterion within each main criterion, as illustrated in Table 5. The score for each alternative is given on a scale of 0–5, based on the defined indicators under each sub-criterion. Thereby, with the application of assigned weights, each alternative can attain a minimum and maximum of 0 and 5 points, respectively, under each main criterion to result in a final score out of 5 points. Finally, linear normalization was used to obtain the final scores and thereby the ranks of the alternatives. This is in compliance with the study by Vafaei et al. (2016) [50], which showed that linear normalization is the best normalization technique to be used with decision-making techniques like AHP.

Table 5. Indicators assigned to evaluate main and sub criteria.

Main Criteria	Sub-Criteria	Indicators
M1. Consumer acceptance	1.1 Eco-friendliness with conformity to standards	Clinker factor specified, per SLS standards
	1.2 Market reputation	1. Years in business 2. Customer engagement for brand 3. Customer engagement for cement product
	1.3 Affordability	Price

Table 5. *Cont.*

Main Criteria	Sub-Criteria	Indicators
M2. Functionality	2.1 Ease of use for the intended purpose	1. Workability of the mix experienced by users 2. Early strength
	2.2 Material strength and durability	1. Expected strength achievement experienced by users 2. Durability properties
	2.3 Visual quality	Color of cement
M3. Technology	3.1 Use of renewable energy	1. ≥50% renewable energy (both thermal electrical) 2. ≥30% renewable energy 3. <30% renewable energy
	3.2 Use of alternate fuel	1. % of alternate fuel ≥ 25% of conventional fuel use 2. % of alternate fuel < 25% of conventional fuel use
	3.3 Reuse content	1. % reused content ≥ 25% of conventional material use 2. %reuse content < 25% of conventional material use
	3.4 Environmentally friendly production	Embodied energy
M4. Local development	4.1 Local material use	1. % local material use< 50% conventional raw materials and distance from raw material source to manufacturing facility ≥ 50 km 2. % local material use ≥ 50% conventional raw materials and distance from raw material source to manufacturing facility ≥ 50 km 3. % local material use < 50% conventional raw materials and distance from raw material source to manufacturing facility < 50 km 4. % local material use ≥ 50% conventional raw materials and distance from raw material source to manufacturing facility < 50 km
	4.2 Use of locally available waste materials	1. % alternate material usage < 25% conventional materials 2. % alternate material usage ≥ 25% conventional materials
M5. Resource availability	5.1 Short-term resource availability	Availability for next 5 years
	5.2 Long-term resource availability	Availability for next 50 years

3.3. Alternatives for Ranking

The aim is to consider industry-used standard cement types as alternatives for ranking. Table 6 presents the commercially available cement types in the market, each complying with European cement standards: traditional Portland cement (CEM I), Portland fly ash cement (CEM II/A-V), Portland slag cement (CEM II/A-S), Portland composite cement (CEM II/B), Pozzolanic cement (CEM IV/A), and Portland limestone cement (CEM II/A-L). These were ranked using the scoring system based on the criteria and indicators developed.

Table 6. Cement types considered for the study as alternatives for ranking.

Cement Type		Composition %				
Designation	**BS EN 197-1 Cement Notation**	**Slag**	**Fly Ash**	**Limestone**	**Gypsum**	**Clinker**
Portland cement	CEM I	-	-	-	5	95
Portland slag cement	CEM II/A-S	5	-	21	4.5	69.5
Portland fly ash cement	CEM II/A-V	-	18	3	5	74
Portland limestone cement	CEM II/A-L	-	5	18	5	72
Portland composite cement	CEM II/B-M	10.5	7	12	4.5	66
Pozzolanic cement	CEM IV/A	-	28.5	2	4.5	65

In ranking the alternatives, the scores were assigned based on industry-collected data and a survey questionnaire. A sample of the questionnaire utilized is given under Supplementary Information. Primary cement users in Sri Lanka categorized as individual users, industrial users, and suppliers were considered, and responses from a representative sample of 50 people were used for obtaining the scores. For criteria M1, M2, and M5, the responses were collected using a general questionnaire, where users were given the opportunity to assign a score to the cement types, and the mean score was considered in the ranking. For criteria M3 and M4, industry-collected data were utilized in assigning the scores.

4. Results

4.1. Sample Characteristics

The experts represented both academia and industry, encompassing fields such as structural engineering, cement manufacturing, concrete and cement technology, green certification, building construction, and building materials. This diversity ensured a comprehensive evaluation of the social sustainability aspects related to cement from various perspectives. In consideration of a more representative sample, the industry-to-academic expert ratio was taken as 70% to 30%.

Here, a higher number of industry experts is justified for several reasons. First, because the construction industry is the primary domain of application for the social assessment framework and, thus, industry specialists have direct, hands-on expertise and insights into the practical aspects of cement usage, production, and societal implications. Their knowledge and expertise in real-world challenges and opportunities make their inputs highly relevant to the study's objectives. Furthermore, industry specialists understand the dynamics of the local construction market, regulations, and prevailing practices in Sri Lanka. Their expertise guarantees that the social evaluation framework is tailored to the specific environment and needs of the construction industry in the country. Moreover, including a substantial number of industry experts helps to capture a wide range of perspectives and diverse viewpoints within the sector.

In terms of years of experience, the distribution allows for a balanced consideration of the perspectives of both early-career professionals and experienced experts with extensive industry knowledge. Experts with fewer than 10 years of experience can bring fresh insights and innovative ideas, while those with over 15 years of experience offer valuable expertise accumulated over a longer duration in the industry. Combining the views of experts with different experience levels ensures a comprehensive evaluation of the social sustainability aspects related to cement, and accounts for the evolution of practices and trends in the construction industry over time.

4.2. Relative Importance of Social Criteria

The main categories and their criteria were compared by each expert through pairwise comparisons. Table 7 contains the main criteria weights according to each participant. The weightages obtained from each expert for main criteria 1 to 5 provide valuable insights into how experts from different areas of expertise within academia and industry perceive the importance of each criterion.

Experts P4 and P10, both from the cement-manufacturing industry, assigned the highest weightage (41.57% and 50.23%, respectively) to consumer acceptance. Their emphasis on this criterion suggests a strong consideration for consumers' awareness and acceptance of cement products, which greatly influences the product's market viability and success. Experts P1, P2, P5, P6, P7, and P8 assigned higher weightages to functionality, with experts from both academia and industry recognizing its importance. This criterion relates to the role cement plays in providing desired strength and other properties to meet customer requirements. The consistency in prioritization indicates its significance in determining the suitability of cement products for various construction applications. Experts P1, P3, P6, and P7, with backgrounds in structural engineering and sustainable engineering, gave relatively higher weightages to technology. Their expertise reflects the focus on incorporating green technology assessment, ensuring that cement production aligns with environmentally friendly practices. Experts P3, P4, P7, P8, P9, and P10, predominantly from the industry, emphasized local development. This criterion involves creating value for local resources and generating employment opportunities. Their high weightages indicate a recognition of the social and economic impact of cement production on local communities. Expert P5, representing green certification, assigned the highest weightage (16.88%) to resource availability. This criterion evaluates the feasibility of sustainable cement production concerning resource utilization. This emphasis reflects a concern for resource-efficient practices in cement manufacturing.

Table 7. Main criteria (M1–M5) weights according to each participant (P1–P10).

Participant Category		**Academia**			**Industry**						
Participant Number		**P1**	**P2**	**P10**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
Criteria weights(%)	Crit M1	7.64	15.47	32.40	41.57	39.75	12.27	13.21	16.44	38.09	50.23
	Crit M2	54.01	56.02	29.92	41.57	28.04	62.70	57.36	54.79	22.07	20.17
	Crit M3	10.74	6.79	12.02	5.68	6.06	7.46	9.99	7.09	10.86	11.18
	Crit M4	17.91	6.72	18.40	7.04	9.27	6.45	14.37	15.92	16.39	12.11
	Crit M5	9.70	15.00	7.26	4.14	16.88	11.12	5.07	5.76	12.59	6.31

Experts from the same category, such as those from academia or industry, display varying levels of consistency in their opinions. For instance, among the academic experts (P1, P2, and P10), there is consistent prioritization of functionality, technology, and resource availability. However, their views diverge when it comes to consumer acceptance and local development, indicating that individual expertise and research interests play a role in shaping their perspectives.

Similarly, experts from industry (P3, P4, P5, P6, P7, P8, P9, and P10) show some consistency in their prioritization of consumer acceptance and local development, likely influenced by their practical experience in the cement-manufacturing and construction sectors. However, there are variations in their views on functionality, technology, and resource availability, reflecting diverse industry perspectives.

The consistency check was performed at each level, and it was made sure all pairwise comparison matrices were consistent. Table 8 represents the resulting consistencies under each main category. The consistency ratio (CR) is acceptable if it is equal to or less than 0.1 (CR 0.10) [51]. Accordingly, it can be concluded that the results are consistent and can be used to derive reliable conclusions related to this particular context of material selection. On confirming the consistencies, the overall matrix of pairwise comparisons for the main categories and subcategories were generated, and the corresponding weights were identified. Figure 4 summarizes the local weight (L) and global weight (G) of the overall criteria. The overall consistency of $0.00662 < 0.1$ confirms the internal consistency of the resulting criteria weights.

Table 8. Consistency ratio obtained for each main category.

Main Criteria	**Consistency Ratio**
M1	0.00011
M2	0.00425
M3	0.01027
M4	0.00007
M5	0.00005

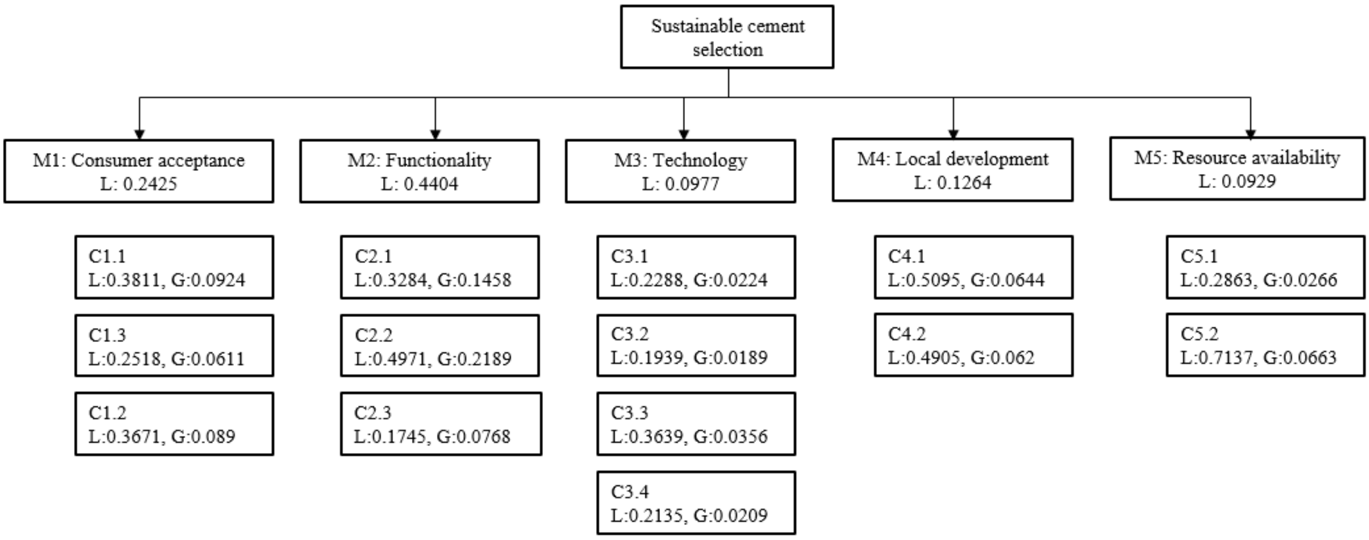

Figure 4. Hierarchy model with overall priorities.

In consideration of the main criteria, functionality has the highest weight (44.04%), followed by consumer acceptance (24.25%), local development (12.64%), technology (9.77%), and resource availability (9.29%). Among the consumer acceptance criteria, 'eco-friendliness with conformity to standards' has the highest weight of 0.3811, followed closely by 'affordability' with a weightage of 0.3671. 'Market reputation' is weighed the least among the three with a weightage of 0.2518. In the functionality criterion, 'material strength and durability' has the highest weight of 0.4971. 'Ease of use for the intended purpose' and 'visual quality' follow in rank with weights of 0.3284 and 0.1754, respectively. Under technology criteria, 'reuse content' exhibits the highest weight (0.3639). Next is 'renewable energy' and 'environmentally friendly production' with close values of 0.2288 and 0.2135, respectively. 'Use of alternative fuel' is weighed the least (0.1939). In the criterion of local development, both 'local material use' and 'use of locally available waste materials' have somewhat similar weights of 0.5095 and 0.4905, respectively. With regards to resource availability, experts seem to value 'long-term material availability' more, as reflected by its high weightage (0.7137) compared to 'short-term material availability' (0.2863).

4.3. Scoring and Ranking of Alternatives

Awareness of cement types under the consumer acceptance criterion, workability, strength, and color under the functionality criterion, and short-term and long-term availability under the resource criterion were scored using the questionnaire responses. A total of 40 responses from the general population of cement users were considered when deriving the mean score under each indicator. The final score for each cement type was derived from the weighted main and sub-criteria scores, providing an indication of their social sustainability.

The criterion of consumer acceptance evaluates how well each cement type is accepted by consumers, considering factors like eco-friendliness, market reputation, and affordability. Notably, CEM IV/A and CEM II/A-S scored the highest, indicating that they are perceived more favorably by consumers in terms of these social aspects. Functionality assesses the ease of use, material strength, durability, and visual quality of the cement. CEM II/A-S scored the highest in this category, signifying that it excels in terms of these functional attributes. The technology criterion evaluates the use of renewable energy, alternate fuel, reuse of content, and environmentally friendly production methods. Here, CEM II/A-S again received the highest score, suggesting its superior adoption of environmentally friendly practices. Under the local development criterion, which focuses on the utilization of local materials and locally available waste materials, CEM I and CEM II/A-L perform well, indicating their contribution to local development and sustainable practices. Resource availability is assessed in terms of short-term and long-term availability. CEM IV/A and CEM II/A-S scored the highest in short-term resource availability, while CEM II/B-M and CEM II/A-L scored the highest in long-term resource availability.

To draw final conclusions, deriving an overall score for each alternative was required. Table 9 illustrates the overall score, together with the normalized score for each cement type. Considering all criteria and sub-criteria, CEM II/A-S emerges as the cement type with the highest overall social sustainability score, followed closely by CEM IV/A and CEM I. CEM II/B-M and CEM II/A-L score slightly lower in terms of overall social sustainability, while still showing strong performance.

Table 9. Overall score and normalized score for cement types.

Cement Type	Overall Score	Normalized Score
CEM I	2.945	0.676
CEM II/A-LL	2.836	0.650
CEM II/A-S	3.666	0.841
CEM II/A-V	3.567	0.818
CEM II/B-M	4.360	1.000
CEM IV/A	4.099	0.940

These findings indicate that different cement types exhibit varying levels of social sustainability performance. Cement types like CEM II/B-M and CEM IV/A demonstrate strong social sustainability attributes, possibly due to their eco-friendliness, local development practices, and technology adoption. On the other hand, CEM II/A-S and CEM II/A-V, while still performing well, may have specific areas where improvements can be made to enhance their social sustainability.

5. Discussion

As pointed out in the literature, choosing green building materials, particularly materials used in concrete production, is a crucial strategy in the design and construction of building projects [31,52]. The process of prioritizing and aggregating data into a framework, as well as the concepts and principles of green construction with sustainable development, make it difficult to identify assessment criteria [32,53]. Strategies that provide a clear perspective on choosing appropriate materials, while taking into account numerous environmental, social, and economic variables, are necessary to accomplish the sustainability of construction projects [54]. However, the social criterion remains one of the domains not properly incorporated into the selection framework for green materials [3,27]. On most occasions, material selection in the production of sustainable concrete lacks the consideration of social aspects [31,55]. In addition, the availability of a range of materials in the market, particularly different cement types, makes it difficult for the users to come up with an optimum selection. Hence, consideration of only performance, along with environmental and economic factors, is seen to be insufficient.

Previously developed, related models have highlighted that social criteria are less important than environmental and economic criteria. For instance, the study by Al-Atesh et al. (2023) [31] illustrated how environmental criteria achieved the highest weightage, followed by economic and social criteria. This is particularly because materials are taken to impact the environment the most, and it is becoming a challenge to manage the environment safely while meeting urban demands. In most cases, selecting environmentally sustainable materials has predominanted. Similar findings have been reported in other studies, while stressing the investigation of social aspects when it comes to material selection [3,56]. As a result, this study offers a social assessment framework to score cement materials so that stakeholders may find it useful when choosing the cement type for their construction purposes.

The findings of this study provide valuable insights into the social-sustainability aspects related to cement, with a particular focus on the Sri Lankan context. The inclusion of experts from both academia and industry, along with their diverse backgrounds, ensures a comprehensive evaluation of these aspects. Expert consultation revealed that factors such as availability, price, sustainability issues, and quality seem to concern the consumers, which is in agreement with the findings in the study by [15]. The emphasis on consumer acceptance, functionality, technology, local development, and resource availability highlights the multifaceted nature of social sustainability in the cement industry.

Consumer acceptance: The prioritization of consumer acceptance aligns with existing literature, emphasizing the importance of market reputation and affordability in material selection [32]. The weightage assigned to consumer acceptance criteria highlights the significance of market reputation, affordability, and eco-friendliness. Experts from the cement-manufacturing industry placed a strong emphasis on this criterion, acknowledging its pivotal role in shaping consumers' perceptions and driving market success. Cement types that scored well in this category, such as CEM IV/A, CEM II/B-M, and CEM II/A-S, are likely to have attributes that resonate with environmentally conscious consumers. This finding aligns with a global trend where consumers increasingly seek sustainable and eco-friendly construction materials [57].

Functionality: The recognition of functionality, including material strength, durability, and visual quality, is consistent with previous research emphasizing the role of materials in meeting customer requirements [56]. This reflects the understanding that the performance of cement in providing structural integrity and aesthetic appeal to construction projects is paramount. CEM II/B-M received the highest score in this category, indicating its excellence in meeting these functional requirements.

Technology: The weight assigned to the technology criterion reflects a growing interest in green technology assessment within the construction industry [54]. Academic experts with backgrounds in structural and sustainable engineering notably emphasized this criterion. CEM IV/A received the highest score, suggesting its adoption of environmentally friendly production methods. This aligns with global efforts to minimize the environmental footprint of cement manufacturing [58].

Local Development: The prioritization of local development, including the use of local materials and locally available waste materials, is in line with research highlighting the socio-economic impact of construction materials on local communities [58]. It signifies a recognition of the need to create value and employment opportunities at the local level. All cement types except CEM I demonstrate a higher score in this category, indicating their contribution to local development and sustainable practices through the use of locally available materials and waste materials.

Resource Availability: The consideration of resource availability in terms of short-term and long-term perspectives reflects a concern for resource-efficient practices, reflecting global discussions of sustainable resource utilization in the construction sector [52]. Cement types like CEM IV/A and CEM II/A-S were identified as top performers in short-term resource availability, while CEM II/B-M and CEM II/A-L excelled in long-term resource availability. This could be due to the scarcity of raw materials like fly ash and slag that may occur in the future. CEM II/B-M contains a mix of these materials, which in turn reduces the effect of scarcity on its production. CEM II/A-LL only requires locally available, crushed limestone fines, which are widely available and have fewer processing and handling requirements compared to other waste materials, hence giving it a greater score for its long-term resource availability. Similar findings were reported in the studies by Lovecchio et al. (2020) [59] and Rhaouti et al. (2023) [60], where comparative assessments conducted between the available blended cement types and the SCMs demonstrated that slag as a waste raw material was more resource-intensive than fly ash and limestone fines.

Overall, the weightages assigned by experts from both academia and industry demonstrate the importance of incorporating a wide range of expertise in the development of the social-assessment framework. Each expert's unique perspective contributes to a more comprehensive and well-rounded evaluation, ensuring the framework's relevance and applicability to the context of sustainable cement practices in Sri Lanka. The study benefits from a diversity of opinions and expertise, enhancing the overall validity and robustness of the findings. The observed variation in weightage decisions between industry practitioners and academics in this study is a noteworthy aspect that reflects the diversity of perspectives and priorities within the field of cement production and construction. This diversity can be attributed to several factors, including practical experience, research interests, and the context in which these experts operate.

Practical Experience vs. Research Focus: Industry practitioners, with their hands-on experience in the construction and cement-manufacturing sectors, assigned higher weightages to consumer acceptance criteria (41.57% and 50.23%), compared to academics. This divergence suggests that industry experts place significant importance on how cement products are perceived by the market. They are acutely aware of the practical implications of consumer preferences and the role of market reputation in cement sales. In contrast, academics, while recognizing the importance of consumer acceptance, may prioritize other research areas such as technology or sustainability assessment.

Both industry practitioners and academics assigned substantial weight to functionality criteria, indicating a consensus around the importance of material strength, durability, and visual quality. However, the specific weightings within this category varied slightly, reflecting differences in their perspectives. Industry experts may emphasize functionality because they deal with real-world construction projects, where performance matters greatly. Academics, on the other hand, may consider a broader range of research topics related to functionality.

Contextual Understanding: Industry practitioners, who are deeply embedded in the local construction market and community dynamics, emphasized local development criteria (38.09%). They recognize the impact of cement production on local economies and employment. In contrast, academics, while acknowledging the significance of local development, assigned relatively lower weightings to these (16.44%). Academics might focus on broader sustainability issues and may not always have the same level of direct engagement with local communities as industry experts do.

Academics, particularly those with backgrounds in structural engineering and sustainable engineering, assigned relatively higher weightings to technology criteria (12.27% to 16.44%). This reflects their research interests in green technology assessment and environmentally friendly production methods. Industry practitioners, while recognizing the importance of technology, assigned lower weightings to these (9.77% to 13.21%), possibly because their expertise lie more in practical application than in the development of new technologies.

The study's consistency checks, with consistency ratios well below the acceptable threshold [51], reinforce the reliability of the results. This ensures that the derived criteria weights accurately represent the preferences of experts in the specific context of cement-material selection. Based on the overall social sustainability scores, the cement types were ranked as follows: CEM II/B-M ranked at the top, followed by CEM IV/A, CEM II/A-S, CEM II/A-V, CEM I, and CEM II/A-L in that order. These rankings indicate that CEM II/B-M emerged as the top-performing cement type in terms of social sustainability, closely followed by CEM IV/A. While CEM II/A-S and CEM II/A-V also performed well, they received slightly lower scores in overall social sustainability due to the comparatively lower score in the technology criteria.

The above findings of the current study provide valuable guidance for stakeholders in the cement industry, including manufacturers, builders, and policymakers. Cement manufacturers can use these insights to improve their products and align them with sustainability principles. Builders and construction professionals can make more informed decisions about the materials they select for their projects, considering not only structural requirements but also their social and environmental impacts. Policymakers can use this information to shape regulations and incentives that promote the adoption of socially sustainable cement materials.

As for the limitations, the study predominantly relied on experts from the Sri Lankan context, both from academia and industry. This limited geographic focus may reduce the generalizability of the findings to other regions with different construction practices, regulations, and social priorities. While a diverse set of experts participated, there may still be a bias towards specific disciplines or specialties, potentially overlooking valuable insights from other areas related to cement sustainability. In addition, the study primarily utilized the Analytic Hierarchy Process (AHP) for expert evaluations. Although AHP is a robust method, relying on a single evaluation approach might exclude alternative methods that could offer different perspectives or enhance result validity. The study's evaluation of awareness of cement types and their social impact was solely based on expert opinions and questionnaire responses from the general population of cement users. Public input and awareness might be influenced by factors beyond the study's control, such as media coverage or marketing efforts. To overcome the limitations, we could consider more diversification in the expert group, the use of other mixed-method approaches with AHP, broader public engagement to obtain preferences, regional variations, and further stakeholder involvement with validation.

6. Conclusions

This study addressed the critical issue of incorporating social sustainability aspects into the selection of cement materials for construction, with a specific focus on the Sri Lankan context. Recent attempts at sustainable material selection have lacked the incorporation and quantification of social sustainability. The findings of the study contribute to the growing body of knowledge on sustainable construction-material selection. They highlight the multifaceted nature of social sustainability in the cement industry and emphasize the need for a balanced consideration of consumer preferences, functionality, technology adoption, local development, and resource efficiency. Based on the findings, the following conclusions can be drawn:

- The research demonstrates that social aspects, such as consumer acceptance, local development, and resource availability play a significant role in shaping the sustainability of cement materials. This highlights the need for a more comprehensive approach to material selection that encompasses these social dimensions;
- The observed variation in weightage decisions highlights the need for a multidisciplinary approach to cement sustainability. Industry practitioners' practical insights are crucial for ensuring that sustainability measures are feasible and effective in real-world scenarios. Academics, on the other hand, play a vital role in advancing sustainable technologies and conducting research that aid industry practices;
- This diversity of perspectives can lead to a more comprehensive and balanced approach to sustainable cement production. Collaboration between academia and industry can bridge these differences and foster innovation, leading to more sustainable and socially responsible cement products;
- Industry specialists put more focus on consumer acceptance. On the other hand, academics, while recognizing the importance of consumer acceptance, prioritize other research areas such as technology or sustainability assessment. This divergence in priorities suggests that academics prioritize broader research areas, including green technology assessment and sustainable production methods. They bring attention to the long-term sustainability and environmental implications of cement materials. In addition, it shows that factors such as practical experience, research interests, and the context in which these experts operate influence this decision-making.
- One notable area of convergence among both industry practitioners and academics is functionality criteria. The consensus on the importance of material strength, durability, and visual quality underscores the universal significance of these functional attributes in cement materials. Cement types that excel in functionality are well-positioned to meet construction project requirements effectively.

- The overall weighting of the criteria functionality emerged as the most important criteria, with the highest weightage (44.04%), followed by consumer acceptance (24.25%), local development (12.64%), technology (9.77%), and resource availability (9.29%).
- The consistency checks in this research, yielding consistency ratios well within the established threshold, attested to the soundness of the methodological approach adopted. By ensuring that the experts' pairwise comparisons aligned with a high degree of consistency, the study effectively mitigated the potential for subjectivity or inconsistencies in the data.
- The study ranked the cement types according to the overall social sustainability scores. CEM II/B-M took the top position, followed by CEM IV/A, CEM II/A-S, CEM II/A-V, CEM I, and CEM II/A-L. These rankings serve as a valuable guide for stakeholders in the cement industry, enabling them to make informed decisions that align with sustainability principles.

The approach taken in the current study can be considered as a first step in forming a criterion to evaluate social sustainability and to quantify it using a score to select the most sustainable material. The presented case study indicates the ranking of different cements in terms of social sustainability. This result can be combined with environmental and economic sustainability to make more informed decisions. Furthermore, policymakers can use the framework to test the applicability for other material types when it comes to comparing within one single material category when developing regulations and guidelines that encourage the use of more sustainable construction materials, ensuring that social sustainability is considered in building projects. Future studies can focus on involving a broader geographic representation. Additionally, considering a more diverse set of experts and alternative evaluation methods can enhance the robustness of the framework. Furthermore, public input and awareness, influenced by external factors, should be considered in future studies.

In conclusion, the framework established in this study represents a significant step forward in the quest for more sustainable construction materials. The results of the case study applied in the present study comply with expert knowledge of what is deemed to be socially acceptable and demonstrate the feasibility of adopting the framework in practical applications. However, the study's limitations could be remedied, and its wider adoption achieved, by considering a more diverse expert group, broader geographic factors, and public input with other external factors. The study empowers stakeholders in the cement industry to make choices that consider not only structural requirements but also the socio-economic and environmental impact of their decisions. While acknowledging the valuable insights gained from this research, it is essential to recognize that sustainability is an ever-evolving concept. Future research should continue to explore new dimensions and refine existing frameworks, ensuring that the construction industry continues to progress towards a more sustainable and responsible future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16156632/s1, Supplementary file S1.

Author Contributions: Conceptualization, A.F., C.S., and C.G.; methodology, A.F., C.S., and C.G.; investigation, A.F., C.S., and C.G.; validation, A.F. and C.S.; formal analysis, A.F. and C.S.; writing—original draft, A.F.; writing—review and editing, A.F., C.S., C.G., D.W.L., G.Z., and J.C.P.H.G.; visualization, A.F.; supervision, C.S., C.G., D.W.L., G.Z., and J.C.P.H.G.; project administration, D.W.L., G.Z., and J.C.P.H.G.; funding acquisition, C.S. and C.G. All authors have read and agreed to the published version of the manuscript.

Funding: We would like to acknowledge the Royal Melbourne Institute of Technology (RMIT), Australia and the University of Moratuwa, Sri Lanka (RMIT-UoM) joint PhD program, which facilitated this collaboration. The research presented in this paper has been supported by the Australian Research Council projects IH200100010 and DE230101221. And the APC was funded by MDPI Sustainability journal and Massey University, New Zealand. Also, would like to thank Sri Lanka Siam City Cement (Lanka) Ltd. for the support and financial aid given in support of this research.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ahmed, M.; Qureshi, M.N.; Mallick, J.; Ben Kahla, N. Selection of Sustainable Supplementary Concrete Materials Using OSM-AHP-TOPSIS Approach. *Adv. Mater. Sci. Eng.* **2019**, *2019*, 2850480. [CrossRef]
2. Arukala, S.R.; Pancharathi, R.K.; Pulukuri, A.R. Evaluation of Sustainable Performance Indicators for the Built Environment Using AHP Approach. *J. Inst. Eng. India Ser. A* **2019**, *100*, 619–631. [CrossRef]
3. Hosseinijou, S.A.; Mansour, S.; Shirazi, M.A. Social Life Cycle Assessment for Material Selection: A Case Study of Building Materials. *Int. J. Life Cycle Assess.* **2014**, *19*, 620–645. [CrossRef]
4. Yasantha Abeysundara, U.G.; Babel, S. A Quest for Sustainable Materials for Building Elements in Sri Lanka: Foundations. *Environ. Prog. Sustain. Energy* **2010**, *29*, 370–381. [CrossRef]
5. Fernando, A.; Siriwardana, C.; Law, D.; Gunasekara, C.; Zhang, K.; Gamage, K. A Scoping Review and Analysis of Green Construction Research: A Machine Learning Aided Approach. *SASBE* **2024**. *ahead-of-print*. [CrossRef]
6. Global Cement Report, 14th ed.Tradeship Publications Ltd.: Dorking, UK, 2020.
7. Keshani, N.; Sathsara, A.; Asanka, L.; Arachchige, U.; Anjalee, S. Cement Industry in Sri Lanka. *JRTE* **2020**, *1*, 16–27.
8. Wijayasundara, M.; Crawford, R.H.; Mendis, P. Comparative Assessment of Embodied Energy of Recycled Aggregate Concrete. *J. Clean. Prod.* **2017**, *152*, 406–419. [CrossRef]
9. International Cement Review 2022. Available online: https://www.carbonclean.com/hubfs/International%20Cement%20Review/Carbon%20Clean%20-%20International%20Cement%20Review%20September%202022.pdf (accessed on 28 June 2024).
10. Yosef, F.A.; Jum'a, L.; Alatoom, M. Identifying and Categorizing Sustainable Supply Chain Practices Based on Triple Bottom Line Dimensions: Evaluation of Practice Implementation in the Cement Industry. *Sustainability* **2023**, *15*, 7323. [CrossRef]
11. Coffetti, D.; Crotti, E.; Gazzaniga, G.; Carrara, M.; Pastore, T.; Coppola, L. Pathways towards Sustainable Concrete. *Cem. Concr. Res.* **2022**, *154*, 106718. [CrossRef]
12. Kulasuriya, C.; Vimonsatit, V.; Dias, W.P.S. Performance Based Energy, Ecological and Financial Costs of a Sustainable Alternative Cement. *J. Clean. Prod.* **2021**, *287*, 125035. [CrossRef]
13. García-Segura, T.; Yepes, V.; Alcalá, J. Life Cycle Greenhouse Gas Emissions of Blended Cement Concrete Including Carbonation and Durability. *Int. J. Life Cycle Assess.* **2014**, *19*, 3–12. [CrossRef]
14. Jóźwiak-Niedźwiedzka, D. Influence of Blended Cements on the Concrete Resistance to Carbonation. In *Brittle Matrix Composites 10*; Elsevier: Amsterdam, The Netherlands, 2012; pp. 125–134. ISBN 978-0-85709-988-4.
15. Kulasuriya, C.; Dias, P.; Vimonsatit, V. Investigation of Social Concerns Regarding a Sustainable Cement. *J. Eng.* **2024**, *30*, 1–20. [CrossRef]
16. Ekener-Petersen, E.; Finnveden, G. Potential Hotspots Identified by Social LCA—Part 1: A Case Study of a Laptop Computer. *Int. J. Life Cycle Assess.* **2013**, *18*, 127–143. [CrossRef]
17. Dreyer, L.C.; Hauschild, M.Z.; Schierbeck, J. Characterisation of Social Impacts in LCA: Part 1: Development of Indicators for Labour Rights. *Int. J. Life Cycle Assess.* **2010**, *15*, 247–259. [CrossRef]
18. Dreyer, L.C.; Hauschild, M.Z.; Schierbeck, J. Characterisation of Social Impacts in LCA. Part 2: Implementation in Six Company Case Studies. *Int. J. Life Cycle Assess.* **2010**, *15*, 385–402. [CrossRef]
19. Lopez, A.D.; Razza, F.; Slimani, D.; Ramos, M.H.; Gordillo, P.C.; Pastor, M.C. Report on the Current Situation Analysis: Recyclability, Social and Economic Requirements Evaluation and How It Can Affect New Developments. 2009.
20. Kruse, S.A.; Flysjö, A.; Kasperczyk, N.; Scholz, A.J. Socioeconomic Indicators as a Complement to Life Cycle Assessment—An Application to Salmon Production Systems. *Int. J. Life Cycle Assess.* **2009**, *14*, 8–18. [CrossRef]
21. Manhart, A. Key Social Impacts of Electronics Production and WEEE-Recycling in China. 2007.
22. Matos, S.; Hall, J. Integrating Sustainable Development in the Supply Chain: The Case of Life Cycle Assessment in Oil and Gas and Agricultural Biotechnology. *J. Oper. Manag.* **2007**, *25*, 1083–1102. [CrossRef]
23. Barbhuiya, S.; Das, B.B. Life Cycle Assessment of Construction Materials: Methodologies, Applications and Future Directions for Sustainable Decision-Making. *Case Stud. Constr. Mater.* **2023**, *19*, e02326. [CrossRef]
24. GBCSL. *Green Labelling System*; GBCSL: Colombo, Sri Lanka, 2012.
25. GBCSL Green Rating System for Built Environment 2013. Available online: https://www.srilankagbc.org/green-rating-system-for-built-environment/ (accessed on 28 June 2024).
26. Escorcia Hernández, J.R.; Torabi Moghadam, S.; Lombardi, P. Sustainability Assessment in Social Housing Environments: An Inclusive Indicators Selection in Colombian Post-Pandemic Cities. *Sustainability* **2023**, *15*, 2830. [CrossRef]
27. Fatourehchi, D.; Zarghami, E. Social Sustainability Assessment Framework for Managing Sustainable Construction in Residential Buildings. *J. Build. Eng.* **2020**, *32*, 101761. [CrossRef]
28. Rashid, K.; Rehman, M.U.; De Brito, J.; Ghafoor, H. Multi-Criteria Optimization of Recycled Aggregate Concrete Mixes. *J. Clean. Prod.* **2020**, *276*, 124316. [CrossRef]

29. Reddy, A.S.; Kumar, P.R.; Raj, P.A. Development of Sustainable Performance Index (SPI) for Self-Compacting Concretes. *J. Build. Eng.* **2020**, *27*, 100974. [CrossRef]
30. Bakhoum, E.S.; Brown, D.C. An Automated Decision Support System for Sustainable Selection of Structural Materials. *Int. J. Sustain. Eng.* **2015**, *8*, 80–92. [CrossRef]
31. Al-Atesh, E.A.; Rahmawati, Y.; Zawawi, N.A.W.A.; Utomo, C. A Decision-Making Model for Supporting Selection of Green Building Materials. *Int. J. Constr. Manag.* **2023**, *23*, 922–933. [CrossRef]
32. Khoshnava, S.M.; Rostami, R.; Valipour, A.; Ismail, M.; Rahmat, A.R. Rank of Green Building Material Criteria Based on the Three Pillars of Sustainability Using the Hybrid Multi Criteria Decision Making Method. *J. Clean. Prod.* **2018**, *173*, 82–99. [CrossRef]
33. Bakhoum, E.S.; Brown, D.C. Developed Sustainable Scoring System for Structural Materials Evaluation. *J. Constr. Eng. Manag.* **2012**, *138*, 110–119. [CrossRef]
34. Hossain, U.; Liu, J.-C.; Xuan, D.; Ng, S.T.; Ye, H.; Abdulla, S.J. Designing Sustainable Concrete Mixes with Potentially Alternative Binder Systems: Multicriteria Decision Making Process. *J. Build. Eng.* **2022**, *45*, 103587. [CrossRef]
35. Figueiredo, K.; Pierott, R.; Hammad, A.W.A.; Haddad, A. Sustainable Material Choice for Construction Projects: A Life Cycle Sustainability Assessment Framework Based on BIM and Fuzzy-AHP. *Build. Environ.* **2021**, *196*, 107805. [CrossRef]
36. AL-Nassar, F.; Ruparathna, R.; Chhipi-Shrestha, G.; Haider, H.; Hewage, K.; Sadiq, R. Sustainability Assessment Framework for Low Rise Commercial Buildings: Life Cycle Impact Index-Based Approach. *Clean Technol. Environ. Policy* **2016**, *18*, 2579–2590. [CrossRef]
37. Wang Chen, H.M.; Chou, S.-Y.; Luu, Q.D.; Yu, T.H.-K. A Fuzzy MCDM Approach for Green Supplier Selection from the Economic and Environmental Aspects. *Math. Probl. Eng.* **2016**, *2016*, 8097386. [CrossRef]
38. Hagerty, M.R.; Land, K.C. Constructing Summary Indices of Quality of Life: A Model for the Effect of Heterogeneous Importance Weights. *Sociol. Methods Res.* **2007**, *35*, 455–496. [CrossRef]
39. Saaty, T.L.; Özdemir, M.S. How Many Judges Should There Be in a Group? *Ann. Data. Sci.* **2014**, *1*, 359–368. [CrossRef]
40. Kurda, R.; De Brito, J.; Silvestre, J.D. A Comparative Study of the Mechanical and Life Cycle Assessment of High-Content Fly Ash and Recycled Aggregates Concrete. *J. Build. Eng.* **2020**, *29*, 101173. [CrossRef]
41. Goyal, S.; Routroy, S.; Singhal, A. Analyzing Environment Sustainability Enablers Using Fuzzy DEMATEL for an Indian Steel Manufacturing Company. *J. Eng. Des. Technol.* **2019**, *17*, 300–329. [CrossRef]
42. Franciosi, C.; Di Pasquale, V.; Iannone, R.; Miranda, S. Multi-Stakeholder Perspectives on Indicators for Sustainable Maintenance Performance in Production Contexts: An Exploratory Study. *J. Qual. Maint. Eng.* **2020**. *ahead-of-print*. [CrossRef]
43. Brescia-Norambuena, L.; González, M.; Avudaiappan, S.; Saavedra Flores, E.I.; Grasley, Z. Improving Concrete Underground Mining Pavements Performance through the Synergic Effect of Silica Fume, Nanosilica, and Polypropylene Fibers. *Constr. Build. Mater.* **2021**, *285*, 122895. [CrossRef]
44. Kubler, S.; Robert, J.; Derigent, W.; Voisin, A.; Le Traon, Y. A State-of the-Art Survey & Testbed of Fuzzy AHP (FAHP) Applications. *Expert Syst. Appl.* **2016**, *65*, 398–422. [CrossRef]
45. Odu, G. Weighting Methods for Multi-Criteria Decision Making Technique. *J. Appl. Sci. Environ. Manag.* **2019**, *23*, 1449. [CrossRef]
46. Kabir, G. Comparative analysis of ahp and fuzzy ahp models for multicriteria inventory classification. *Int. J. Fuzzy Log. Syst.* **2011**, *1*, 1–16.
47. Liu, Y.; Eckert, C.M.; Earl, C. A Review of Fuzzy AHP Methods for Decision-Making with Subjective Judgements. *Expert Syst. Appl.* **2020**, *161*, 113738. [CrossRef]
48. Saaty, R.W. The Analytic Hierarchy Process—What It Is and How It Is Used. *Math. Model.* **1987**, *9*, 161–176. [CrossRef]
49. Peng, G.; Han, L.; Liu, Z.; Guo, Y.; Yan, J.; Jia, X. An Application of Fuzzy Analytic Hierarchy Process in Risk Evaluation Model. *Front. Psychol.* **2021**, *12*, 715003. [CrossRef] [PubMed]
50. Vafaei, N.; Ribeiro, R.A.; Camarinha-Matos, L.M. Normalization Techniques for Multi-Criteria Decision Making: Analytical Hierarchy Process Case Study. In *Technological Innovation for Cyber-Physical Systems*; Camarinha-Matos, L.M., Falcão, A.J., Vafaei, N., Najdi, S., Eds.; Springer International Publishing: Cham, Switzerland, 2016; Volume 470, pp. 261–269. ISBN 978-3-319-31164-7.
51. Saaty, T.L. Decision Making with the Analytic Hierarchy Process. *IJSSCI* **2008**, *1*, 83. [CrossRef]
52. Švajlenka, J.; Kozlovská, M. Perception of User Criteria in the Context of Sustainability of Modern Methods of Construction Based on Wood. *Sustainability* **2018**, *10*, 116. [CrossRef]
53. Kayani, S.A.; Warsi, S.S.; Liaqait, R.A. A Smart Decision Support Framework for Sustainable and Resilient Supplier Selection and Order Allocation in the Pharmaceutical Industry. *Sustainability* **2023**, *15*, 5962. [CrossRef]
54. Lee, W.J.; Mwebaza, R. The Role of the Climate Technology Centre and Network as a Climate Technology and Innovation Matchmaker for Developing Countries. *Sustainability* **2020**, *12*, 7956. [CrossRef]
55. Suchith Reddy, A.; Anand Raj, P. Developing a Material Sustainable Performance Score (MSPS) to Select an Alternative Cementitious Material. *Cem. Wapno Beton* **2019**, *24*, 68–76. [CrossRef]
56. Mathiyazhagan, K.; Gnanavelbabu, A.; Lokesh Prabhuraj, B. A Sustainable Assessment Model for Material Selection in Construction Industries Perspective Using Hybrid MCDM Approaches. *JAMR* **2019**, *16*, 234–259. [CrossRef]
57. De Luca, P.; Carbone, I.; Nagy, J.B. Green building materials: A review of state of the art studies of innovative materials. *J. Green Build.* **2017**, *12*, 141–161. [CrossRef]
58. Akadiri, P.O.; Olomolaiye, P.O. Development of Sustainable Assessment Criteria for Building Materials Selection. *Eng. Constr. Arch. Manag.* **2012**, *19*, 666–687. [CrossRef]

59. Lovecchio, N.; Shaikh, F.; Rosano, M.; Ceravolo, R.; Biswas, W. Environmental Assessment of Supplementary Cementitious Materials and Engineered Nanomaterials Concrete. *AIMS Environ. Sci.* **2020**, *7*, 13–30. [CrossRef]
60. Rhaouti, Y.; Taha, Y.; Benzaazoua, M. Assessment of the Environmental Performance of Blended Cements from a Life Cycle Perspective: A Systematic Review. *Sustain. Prod. Consum.* **2023**, *36*, 32–48. [CrossRef]