sustainability

MDPI

Article

A Comparative Analysis of the Criteria for Choosing Sustainable Materials for Façades in Turkey and the European Union

Haney Başak Daskin [1], Alina Bărbulescu [2,*], Radu Muntean [2,*] and Emre Caner Akcay [3]

[1] The Graduate School of Natural and Applied Sciences, Atilim University, 06830 Ankara, Turkey; h.basakdaskin@gmail.com
[2] Department of Civil Engineering, Transilvania University of Brașov, 5 Turnului Str., 500152 Brasov, Romania
[3] Department of Civil Engineering, Atilim University, 06830 Ankara, Turkey; caner.akcay@atilim.edu.tr
* Correspondence: alina.barbulescu@unitbv.ro (A.B.); radu.m@unitbv.ro (R.M.)

Abstract: One of the primary contributors to energy consumption is the construction industry. To address the urgent demand for eco-friendly approaches in this field, this study conducted an investigation on Scopus and Web of Science databases to identify the criteria for selecting sustainable materials for façades. Three groups of criteria were derived after a systematic review: Environmental, Social/economic and Technical. The main goal of the research was to answer the question of whether there are differences in these materials' selection between Turkey and European Union countries. After applying statistical tests, it was found that there are significant differences in selecting eco-friendly material only from the social/economic perspective. The most important sub-criterion is the economic cost. Comparisons with results from China and US confirm this finding.

Keywords: sustainable materials; façade; statistical tests

check for updates

Citation: Daskin, H.B.; Bărbulescu, A.; Muntean, R.; Akcay, E.C. A Comparative Analysis of the Criteria for Choosing Sustainable Materials for Façades in Turkey and the European Union. *Sustainability* **2024**, *16*, 1539. https://doi.org/10.3390/su16041539

Academic Editors: Marijana Hadzima-Nyarko, Grigorios L. Kyriakopoulos and Dorin Radu

Received: 15 December 2023
Revised: 6 February 2024
Accepted: 8 February 2024
Published: 11 February 2024

1. Introduction

The impacts of global warming pose a significant threat to all life forms on Earth. As these effects become visible, the concept of sustainability has gained prominence as a crucial aspect, intending to improve future generations' well-being and minimize, to the greatest extent possible, the harmful consequences foreseen in the future.

Sustainability maintenance necessitates profound personalization, integrating the subject into one's daily existence [1]. The concept revolves around economic, social, and environmental equilibrium, which is crucial for embracing sustainable measures. Hence, there has been a notable surge in research on sustainability in recent years, driven by amplified awareness of global warming and its consequences across various industries. With increased awareness over the years, the notion of sustainable development has come to the fore, leading to the proliferation of studies on the topic.

One of the primary contributors to energy consumption is the construction industry. This sector utilizes mostly non-renewable resources and generates significant waste [2]. For instance, in the EU, this construction industry consumes 40% of total energy, accounting for 36% of CO_2 emissions [3]. In Turkey, it contributes to approximately 50% of total energy consumption [4]. Given its negative environmental impact, sustainability principles must be integrated into this field of activity.

When selecting construction materials, it is crucial to assess their long-term environmental impact throughout their life cycle, from extraction and manufacturing to disposal or recycling. The preference for sustainable materials should rely on their capacity to reduce greenhouse gas emissions, energy consumption, waste generation, and toxicity. Selecting sustainable materials aims to strike a harmonious equilibrium between environmental, economic, and social aspects [5–9].

There is a growing body of research on this topic, with numerous publications promoting sustainability principles. In this context, articles detailing sustainable criteria for construction materials from the available literature have been reviewed and briefly highlighted.

Petticrew and Roberts [10] described and implemented assessment standards to help architects and construction designers to choose eco-friendly materials for building projects. They identified 24 criteria based on sustainable triple-bottom-line principles considering the input of various stakeholders and six essential criteria for ensuring sustained advancement in the selection of construction materials.

Snyder [11] highlights evaluation criteria, computational techniques, and analytical models for selecting sustainable materials. He scrutinized the best options for eco-friendly materials, considering numerous factors that affect the selection process and assessing the relationships between these factors and qualitative aspects. The Fuzzy Extended Analytical Hierarchical Process was employed to gather and assign numerical values (i.e., weights) to measure the importance of these criteria for a specific material choice. Additionally, an innovative approach was proposed by amalgamating Life Cycle Sustainability Assessment, Building Information Modeling, and Multi-Criteria Decision Analysis to identify the most sustainable material choices for construction [12]. Their case study established four lists of materials for the same building to determine which alternative was the most sustainable. The research emphasized differences in global warming potential, variations in energy costs for lighting, and discrepancies in energy costs for heating, ventilation, and air conditioning systems among the options under consideration.

Hasan et al. [13] developed a three-phase process grounded in the concept of sustainable development to pinpoint suitable materials for the building sector in the Indian context. Their research involved selecting three primary criteria and 23 sub-criteria, and they employed the Best-Worst Method (BWM) to calculate the weights and rankings. By evaluating materials using the BWM criteria weights and the Fuzzy TOPSIS approach, they determined that burnt clay fly ash was the top choice among the four types of bricks. A model was created to select sustainable materials used in the external enclosure of a Tehran residential building, relying on local experts' knowledge to consider internal factors and current energy consumption conditions [14].

A model for addressing the selection of sustainable construction materials in uncertain construction environments is presented by [15]. The authors used the Dempster–Shafer theory of evidence and the Additive Ratio Assessment (ARAS) to select five sustainable materials for building façades. By integrating these approaches, they overcome uncertain information to arrive at a feasible solution for selecting sustainable materials.

The authors of [16] established sustainable evaluation criteria for selecting the most environmentally friendly superstructure runway material for runway superstructures in the aviation industry using multi-criteria analysis, mathematical methodologies, and systematic analytical frameworks. The Fuzzy Analytic Hierarchy Process was incorporated into their evaluation approach to support the design team. Their research shows that technical factors significantly influence sustainability, followed by environmental and socio-economic factors.

Mathiyazhagan et al. [17] summarized the preliminary design's functions in identifying the challenges and integrating material selection with sustainability criteria. They developed a comprehensive conceptual framework for sustainability-based material selection, considering the three pillars of sustainability and using the BREEAM and LEED methodologies.

Hatefi et al. [18] proposed a novel technique for creating multi-material façade systems and objectively quantifying a sustainability index. Their model combines the Knapsack algorithm with a Multi-Attribute Value Function-Based Methodology for Sustainability Assessment (MIVES). The former generates multi-material façade sets while the latter quantifies the Sustainability Index, considering economic, environmental, and social factors, stakeholder preferences, and local regulations. A multi-objective MIVES-based technique for assessing the sustainability index of façade panels was presented in [19], focusing on new textile waste cement boards. The research included an experimental program to evaluate the material's thermal, acoustic, and fire resistance integrated into the sustainability assessment model.

A total of 5 fundamental and 26 subsidiary criteria encompassing the origins and effectiveness of eco-friendly building materials are established in [20]. They prove their value for selecting façade materials to meet certification requirements and adhering to sustainability standards in either newly constructed or renovated structures.

According to [21], sustainable material selection is essential for an environmentally friendly construction industry. The authors introduced a traditional Combinative Distance Assessment (CODAS) approach enhanced with Interval Valued Intuitionistic Fuzzy Sets (IVIFN) to facilitate comprehensive, rational, and intelligent decision-making, especially in uncertain material selection scenarios. Mayhoub et al. [22] aimed to detect the attributes of green materials to achieve the sustainability goals for buildings' façades. In the same idea, Siksnelyte-Butkiene et al. [23] reviewed decision-making techniques for selecting buildings' insulation material. The study emphasized a Renovation Wave Strategy, aiming to augment the buildings' energy performance and double renovation rates in the next ten years.

These investigations typically employed various multi-criteria decision-making techniques to identify the most suitable option for selecting sustainable building materials. Nevertheless, a review of existing literature reveals that the volume of research focused on selecting the most sustainable materials for building façades remains relatively small. Façades are important components of buildings as they play a dual role as a protective outer layer and the visual face of buildings, significantly affecting energy efficiency, durability, visual appearance, etc.

This paper embarks on a research journey focusing on identifying sustainable criteria for façade materials and assessing their significance for Turkey and European Union countries. To address the urgent demand for eco-friendly materials in this field, the article investigates the similarities between European countries and Turkey in terms of their criteria for choosing sustainable materials for façades. Specifically, the goals of the research are as follows:

1. To identify the criteria for selecting sustainable materials for façades;
2. To test hypothesis H0: 'No difference exists in the selection of sustainable materials for façades in Turkey and European countries' against H1: 'There is a difference in the selection of sustainable materials for façades in Turkey and European countries';
3. To confirm the findings by comparing the results with those of cases from other countries (USA and China).

The search performed in the first phase returned three criteria—Environmental, Social/Economic, and Technical (with six, eight, and eight sub-criteria, respectively)—affecting the preferences in selecting the material for façades. The importance given to these criteria in Turkey and European Union countries is assessed by statistical methods applied after an in-depth review of the scientific literature. It attempts to offer insights into the similarities and variability in sustainability criteria preferences from environmental, economic, and social perspectives by employing the chi-square test of independence. More sophisticated knowledge of intricate interactions between regions and sustainability issues in the building sector will result from the comparing these preferences with cases from the USA and China.

The novelty is that this article is the first to investigate the criteria for choosing façade materials in Turkey and Romania. Moreover, the statistical methods employed here were not used in other studies with similar goals. The scientific literature relies on multi-criteria approaches with disadvantages that will be presented in the Discussion section.

2. Materials and Methods

This section presents the research methodology employed to attain the study's objectives. It encompasses the research framework, the data collection, and analysis techniques. The choice of research methodology was guided by the research problem's inherent nature and the specific objectives outlined in this study. The steps of the research methodology are shown in Figure 1.

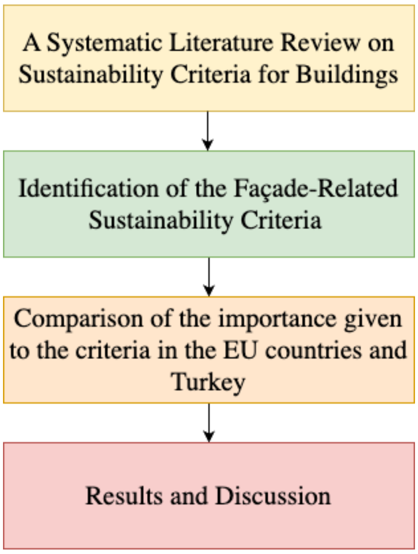

Figure 1. Research Methodology.

2.1. A systematic Literature Review on Sustainability Criteria for Buildings

A systematic approach is adopted to define sustainable criteria for building façades.

The first step includes a comprehensive review of previous research covering sustainable criteria for various building materials to compile a preliminary list of criteria for selecting the most sustainable building façades.

A systematic literature review represents a rigorous approach to research, aiming to identify, evaluate, and consolidate all relevant information related to a specific research question or topic [10]. This process considered the three pillars of sustainability: social, environmental, and economic impact. Compiling sustainability criteria derived from the existing literature plays a crucial role in discerning the factors significantly influencing material selection. The systematic literature review was performed following various steps [10]: (a) state the research aim; (b) identify the databases, keywords, and categories of pertinent studies; (c) conduct a thorough literature search; (d) sift through the search results using the selection and exclusion criteria; (e) critically evaluate the obtained results; (f) summarize the research; (g) conclude the research.

The procedure was performed to identify sustainability criteria for selecting building materials for façades. ScienceDirect, Scopus, and Web of Science databases were utilized to retrieve pertinent scientific articles. A set of research keywords aligned with the research objectives was defined. They included “Sustainable Material”, “Building Materials”, “Material Selection”, “Civil Engineering”, “Decision Making”, and “Construction Management”, and were applied in the “title/abstract/keywords” field of the search engines, utilizing Boolean operators such as “AND” and “OR”. Each article’s criteria and sub-criteria within the research scope were categorized under the primary headings of the sustainability pillars. Furthermore, the selected articles were evaluated to satisfy the technical criteria.

This study aims to evaluate the scientific works relevant to the subject published between 2012 and 2022 due to the increased interest in this field over the past decade. The search strategy is presented in Table 1.

Table 1. Search strategy.

Academic Databases Searched	Web of Science, Scopus, Science Direct
Other data sources	Google (non-academic sources)
Target items	Research papers, conference papers, journal articles
Search applied	Titles, abstracts, keywords
Language	English
Publication period	2012–2022

Given that sustainability has occupied a prominent position on the agenda in many industries, particularly in recent years, search queries in the construction management literature have been limited to presenting significant and well-focused results from previous studies. The keywords were applied to the databases that have been determined [24,25], with the "AND" and "OR" rules, as shown in Table 2.

Table 2. Applied "AND" and "OR" rules for each database.

Database	Keywords
Scopus Web of Science	((Sustainable Assessment Criteria OR Sustainable Assessment OR Sustainable Criteria) AND Construction Materials AND (Material Selection OR Decision Making) AND (Construction Industry OR Building Industry))
Science Direct	TITLE-ABS-KEY ((Sustainable Assessment Criteria OR Sustainable Assessment OR Sustainable Criteria) AND Construction Materials AND (Material Selection OR Decision Making) AND (Construction Industry OR Building Industry))

2.2. Identification of the Façade-Related Sustainability Criteria

This process aims to evaluate and compare the importance given to sustainability criteria pertinent to the chosen façade-related criteria within distinct regions. Observed values were retrieved from the Scopus and Web of Science databases through specialized keyword combinations tailored for each criterion and region. Notably, the ScienceDirect database was excluded from this research because it lacks filtering options for countries or regions. The primary keywords selected were "Construction Materials", "Construction Industry", or "Building Industry", in conjunction with the specific "criterion" under consideration. Moreover, 27 European Union countries were included in the keywords to ensure a precise count of papers related to each criterion. These countries include Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. All computations were conducted separately for the two databases. Although the number of articles indexed in the two databases may vary for each criterion, the results should align closely, providing insights into the reliability of the findings. Subsequently, they will be subject to a comparative analysis.

The meticulous formulation of these strategies is integral to the rigor and validity of the resulting literature. A notable deviation lies in the database-specific filtering mechanisms for countries. In Scopus, search engines are refined using the formulas TITLE-ABS-KEY, AND, OR, LIMIT-TO (AFFILCOUNTRY). In contrast, the formulas AB, TS, TI, KP, AND, OR, and CU were applied to obtain comparable filtering results in the Web of Science database. For a clear understanding, the search strategies applied to Scopus and Web of Science are presented in Tables A1–A4 in the Appendix A for the recycling and reuse, maintenance cost, and acoustic insulation.

2.3. Statistical Comparison of the Importance Given to the Criteria in the EU Countries and Turkey

With the help of the observed frequencies obtained using the formulations given above, an optimal comparison of the sustainability criteria between the specified regions was made. The following hypothesis was tested:

H_0: *There is no association between the region and environmental criteria when selecting façade materials (as reflected by the scientific literature),versus*

H_1: *There is an association between the region and environmental criteria when selecting façade materials (reflected by the scientific literature).*

A chi-square test [26] was utilized, with the following steps:

- Create the contingency table that contains the recorded frequencies (o_{ij}) for each criterion and each region;
- Compute the expected frequencies (e_{ik}):

$$e_{ik} = \frac{\left(\sum_{i=1}^{m} o_{ik}\right)\left(\sum_{k=1}^{n} o_{ik}\right)}{\sum_{i=1}^{m}\sum_{k=1}^{n} o_{ik}} = \frac{O_{i.}O_{.k}}{S}, \quad (1)$$

where m is the number of rows (criteria), and n is the number of columns (2, in this case, because two regions—EU and Turkey—are the main focus of the study), o_{ij} is the observed frequency of the i-th criterion in j-th region, $O_{i.}$ is the sum of frequencies on the row i, $O_{.k}$ is the sum of frequencies on the column k, and S is the total sum of frequencies (on rows and columns).

- Compute the values of the test statistics, χ_c^2, using

$$\chi_c^2 = \sum_{i=1}^{m}\sum_{k=1}^{n} \frac{(o_{ik} - e_{ik})^2}{e_{ik}}, \quad (2)$$

- Determine the degree of freedom, df, by

$$df = (m-1)(n-1). \quad (3)$$

In this study, df = $m - 1$ because n = 2.

For the fixed significance level (α = 0.05), determine the critical value of the test statistics (χ_0^2). The null hypothesis will be rejected when $\chi_c^2 > \chi_0^2$. If the null hypothesis is rejected for a certain criterion, the Kruskal–Wallis test [27] is utilized to determine if there are statistically significant differences between two groups of values formed by the number of papers reflecting the criteria specified in the EU and Turkey. The general procedure is as follows:

Assign a number i = 1,. . ., m, to the samples (1 and 2 in our case);

- Determine the sizes ($n_1, \ldots, n_m$) of the samples, the grand total $n = n_1 + \ldots + n_m$;
- Combine all values, placing them in ascending order, and rank them;
- Determine the sum of the ranks of the values from each sample separately, and denote them $T_1, \ldots, T_m$;
- Compute the Kruskal–Wallis H statistic:

$$H = \frac{12}{n(n+1)}\sum_{i=1}^{m}\frac{T_i^2}{n_i} - 3(n+1) \quad (4)$$

- Compare H with the critical value from the tables of the χ^2 probability distribution (right tail) with $m - 1$ degree of freedom at a significance level of 0.05;
- To conclude, if H is higher than the critical value, one can reject the null hypothesis that there is no statistically significant difference between the groups of values.

This article aims to compare the similarities in the use of sustainability criteria for selecting façade materials in two regions, Turkey and EU countries. It does not have the aim of introducing or developing algorithms for selecting sustainable materials (which already exist); this would extend the research area in another direction and deserves an extended separate investigation. In our approach, the uncertainty is due only to the significance level at which the statistical test is performed (in this case, 5%). The search for analogous studies in the same field did not return results.

In a closely connected domain, algorithms developed for selecting sustainable materials (SMs) based on different material properties exist. They are multi-criteria decision-making (MCDM) techniques, like Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Complex Proportional Assessment (COPRAS), Rank Reversal Problem (RRP) [28–30], MIVES [18], CODAS-IVIFN [21], etc.

Mousavi-Nasab and Sotoudeh-Anvari identified some limitations of these algorithms, such as not presenting a solution for the RRP, limiting the assessment of rank reversal cases to the addition/removal of alternatives, and presenting new difficult-to-operationalize methods for practical applications. Moreover, all have a different degree of uncertainty that cannot be estimated because they rely on scores assigned by experts, which are subjective (based on their experience and knowledge)—see the last [31,32]. Unfortunately, none of the above algorithms are more reliable than the statistical approach proposed here, given that the experts have their opinions that cannot be objectively measured.

3. Results and Discussion

3.1. Results of the Systematic Review of Sustainability Criteria for Building Façades

The outcomes of the systematic literature review are summarized in Table 3.

Table 3. Number of publications for each database between 2012 and 2022.

Database	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Science Direct	0	1	2	3	4	5	6	5	10	13	7	56
Scopus	1	0	1	1	4	2	4	6	5	11	5	40
Web of Science	3	5	6	8	11	9	11	20	25	29	19	146
Total	4	6	9	12	19	16	21	31	40	53	31	242

This phase aims to identify the most relevant articles from the online academic library. Only articles written in English and fully available for download, excluding those containing non-technical information, were retained. Filtering was performed in three steps: (1) identification, (2) screening, and (3) eligibility. In the initial screening phase, fifty-eight papers were identified as duplicates across the databases and removed. In the next phase, each article's title and abstract were examined to exclude irrelevant papers. Consequently, 124 research papers were discarded. Subsequently, a review of the abstracts of the remaining 60 articles found that 24 articles were irrelevant, and these were eliminated.

In the last stage, the complete articles' texts on the shortlist were examined to determine their eligibility for further analysis. Thirty-four papers were excluded because their objectives did not align with the research scope. Figure 2 indicates the filtering results after each step.

The primary rationale for excluding these papers is their departure from critical aspects of material selection and incomplete consideration of sustainability criteria. They do not focus on the rigorous material selection process, a crucial element in various contexts such as manufacturing, construction, and design. Furthermore, a comprehensive sustainability assessment requires a multifaceted analysis considering environmental, social, and economic factors. The excluded papers did not explore these dimensions in depth, neglecting to provide a holistic understanding of the sustainability outcomes associated with the selected materials. Additionally, through the snowballing method, 23 new records were uncovered from the references of the selected articles. Consequently, only 25 studies were retained for in-depth analysis.

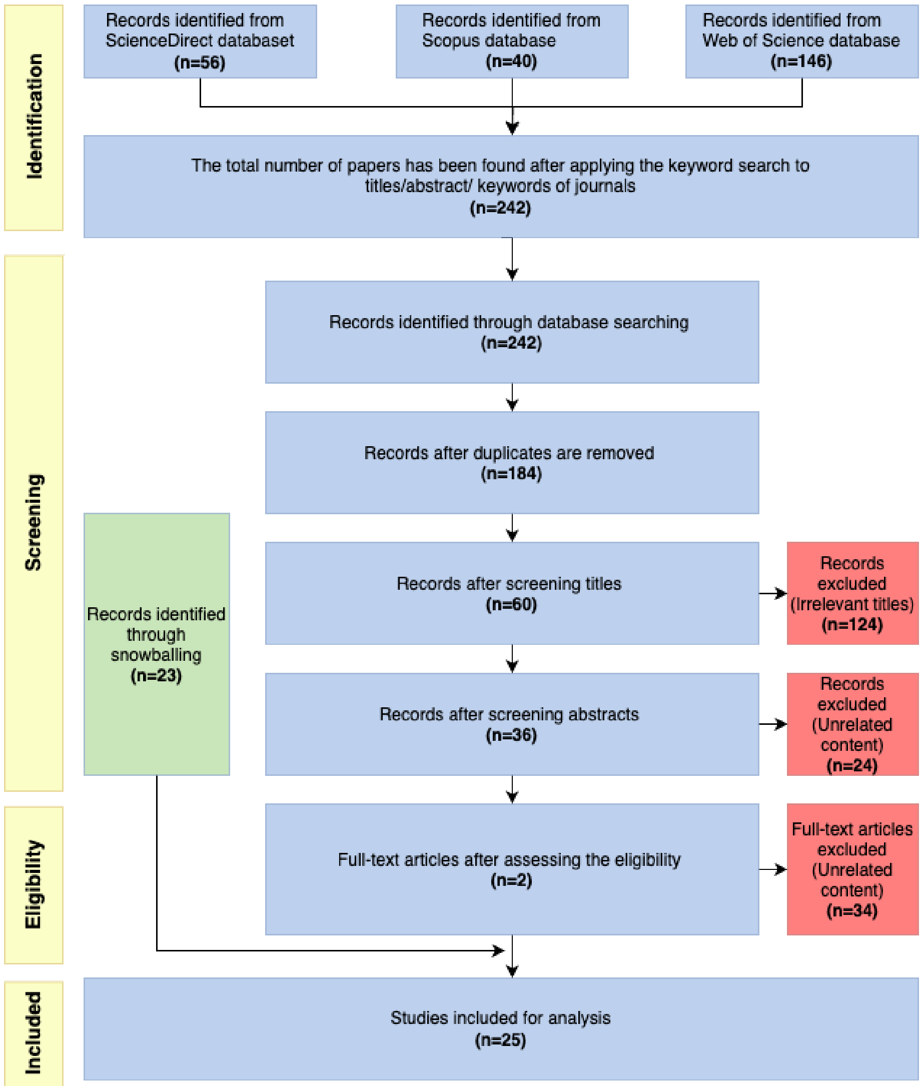

Figure 2. PRISMA flowchart of the systematic review process.

3.2. *Identification of the Façade-Related Sustainability Criteria*

After evaluating 25 studies, the analysis reveals considerable variation in the sub-criteria used, primarily due to each study's different research objectives and motivations. Some academic studies have added supplementary technical criteria driven by the specific research contexts. These criteria, intertwined with the operational and methodological subtleties of the studies, have further enriched the evaluation framework used. A logical selection process was conducted to distill the primary criteria for the current research endeavor. In this context, the main ones reflect environmental conservation, social and economic factors (given their intrinsic interdependence and common research objectives), and the inclusion of technical criteria (to cover a comprehensive range of assessment parameters).

An exhaustive examination of pertinent articles from the literature was conducted to choose the most acceptable criteria based on proven research and professional insights. Table 4 shows the selected most suitable criteria for façade materials and the articles including these criteria. Some agreed definitions and characterizations of the sustainability criteria are presented in Table 4.

Table 4. List of sustainable material selection criteria for façades.

	Criteria	Publications
Environmental criteria	E1: Potential for recycling	[14–18,22,23,33–38]
	E2: CO_2 emissions	[12,20–23,33,35–37,39–41]
	E3: Energy consumption	[15,16,20–23,34,36–39,42–45]
	E4: Zero or low toxicity	[14–16,19,22,33,38]
	E5: Reduction in carbon footprint	[44,45]
	E6: Waste management and reuse	[17,18,20,22,33,34,36,44,45]
Social/economic criteria	EC1: Maintenance cost	[10–23,33–38,40,42,44–46]
	EC2: Transportation cost	[12,14–23,33–46]
	EC3: Design cost	[40]
	EC4: Labor cost	[33,40]
	EC5: Material cost	[40]
	S1: Aesthetics	[14–17,22,34,36–38,40,42,44]
	S2: Health and safety	[14–19,27,34,36,37,42]
	S3: Duration	[18,23,37]
Technical criteria	T1: Acoustic insulation	[20–23,34,37,38,40]
	T2: Thermal insulation	[14,15,20–23,34,37,38,40,41]
	T3: Fire resistance	[14–16,18,20–23,33,34,36–38,42]
	T4: Resistance to decay	[14–16,33,40]
	T5: Life expectancy of material (Durability)	[14–16,18,23,33,37,38,42,44,45]
	T6: Water resistance	[17–19,23,34–37,41,42]

Environmental criteria consider the following aspects:

a. The impact on natural resources, with a focus on the use of renewable energies and reducing the consumption of finite resources;
b. The emission of greenhouse gases or the evaluation of the carbon footprint of materials, having a preference for materials with low CO_2 emissions;
c. Air and water quality, meaning the reduction of polluting emissions in air and water during the production and use of materials, at the same time avoiding chemicals hazardous to water and air quality;
d. The ability to recycle materials while reducing waste and promoting the circular economy;
e. rotecting and promoting biodiversity in areas of natural resource exploitation.

E1 refers to the ability to recycle and reuse the material [36].
E2 addresses the CO_2 material's emissions during its lifetime and is closely connected to the carbon footprint [36,47].
E3 concerns the total energy consumption of the material during its lifetime.
E4 indicates the necessity of using materials with toxicity as close as possible to zero and satisfying WHO regulations related to health risk assessment [48]. These materials are less hazardous to workers and buildings' occupants [49,50].
E5 Carbon footprint is an index that compares the total amount of greenhouse gases (GHG) released in the atmosphere by a specific entity, activity, or product from production to final consumption and disposal. For other definitions see [47].
E6 refers to the ease of waste management after the end of a product's life [36,51,52]. This criterion is more relevant than ever in the context of urban regeneration.

Social factors are based on the following:

a. The impact on local communities, through the assessment of how the production of materials affects local communities and the promotion of ethical practices in relation to local populations;
b. Labor rights, ensuring fair working conditions in the materials manufacturing industry in compliance with employee rights and international labor standards;

c. The health and safety of employees during production processes, which involves avoiding hazardous substances for workers' health;
d. The involvement of the local community in the decision-making process regarding construction projects;
e. Accessibility and equity, which are achieved by promoting access to sustainable housing and building materials for all social strata.

Economic factors include the following:

a. Initial and maintenance costs, looking to reduce dependence on high-cost materials and promote the local economy by purchasing materials from local suppliers. This can reduce the transportation costs and can also lead to an increase in local employment;
b. The use of materials with high energy performance to reduce the energy costs.
c. Reducing replacement and repair costs using sustainable materials, which can increase the durability and strength of the building elements.

EC1 Maintenance cost is to be spent for the maintenance in its effective lifetime.
EC2 According to [53,54], transportation cost is the linkage process in logistics, including fuel taxation, infrastructure and environmental costs, overhead costs, etc.
EC3 The design cost for construction projects depends on the project complexity, size, location, the design services' scope, regulatory requirements, project phase and schedule [55].
EC4 Direct labor refers to people directly involved in the project and is determined by the costs per day for each employee multiplied by the number of days needed for completing a job. Sustainability in this field means good labor availability for manufacturing the material use of the final product and a sustainable involved cost (minimizing the environmental impact and ensuring long-term profitability) [56,57].
EC5 Material cost includes all the tangible items that go into the finished product, like the type and grade of materials used in the project, overhead and margin, freight costs (shipping, customs, and import/export fees, and air freight), etc. [56].

Aesthetics (S1) refers to the look and appearance of the material [36].

The health and safety criterion (S2) requires that the material should withstand all types of disruption and provide health and safety to users during its lifetime [49].

The technical criteria considered are as follows:

a. The structural performance of buildings and building elements, achieved by ensuring that materials meet structural and safety requirements. This implies testing and certification according to relevant technical standards;
b. Thermal and acoustic insulation can provide a comfortable and healthy living or working environment, reducing energy consumption, carbon emissions, costs, and health problems for the inhabitants (like stress, exhaustion, hearing loss, or cardiovascular difficulties);
c. Fire and water resistance, which can prolong the lifespan of a building, reducing injuries or even fatalities during the occurrence of a fire, lowering the development of mold and the deterioration of building components;
d. Installation and handling should be easy;
e. The durability and wear resistance of materials under normal use conditions, which can increase the financial feasibility of the structure by making an initial investment in robust materials that will last longer and preserve functionality and appearance for a considerable amount of time;
f. Compatibility with other materials, which ensures good performance over time and under specific loads and natural phenomena;
g. Encouraging the use of innovative materials and research to improve sustainability.

Acoustic insulation represents the ability to reduce the transfer of noise inside and outside a building [58]. Sound insulation expresses how well an element (specimen or system) hinders sound from traveling through it. It is defined as the ratio of sound power incident on the element to the amount of sound [59].

Thermal insulation is the reduction in thermal energy transfer between objects of different temperatures in thermal contact with or in the range of radiative influence [58].

Fire resistance is the property of materials or their assemblies that prevents or retards the passage of excessive heat, hot gasses, or flames under the use conditions [60,61].

The decay describes the material and temporal boundary between states of matter. It is the capability to withstand corrosion, erosion, etc. [62].

The life expectancy of a material (Durability) is the total operational life of the material until disposal in a particular environment or under specified circumstances [63].

Water resistance is the property of having a long resistance to different types of water action (from work, ground, atmosphere, condensation, accidents provoking moistures, etc.) [64,65].

3.3. Results from the Scopus Database

Tables 5–7 list the results obtained from the Scopus database after the previous research phase, as follows:

- The first column contains the sub-criteria for each main category. Six sub-criteria were determined under Environmental (Table 5) and Technical (Table 8) criteria, and eight under Social/Economic (Table 7).
- The second and third columns, rows 2–7, contain the number of references to each sub-criteria in the EU and Turkey, respectively.
- The numbers in the last column, rows 2–7, are obtained by summing up the corresponding values from rows 2 and 3.
- The last rows contain the total records for the EU, Turkey and the general total.

Table 5. Observed frequencies of Environmental criteria obtained from the Scopus database.

Environmental Criteria	EU	Turkey	Total
E1: Potential for recycling and reuse	1336	96	1432
E2: CO_2 emissions	390	28	418
E3: Energy consumption	536	47	583
E4: Zero or low toxicity	24	2	26
E5: Reduction in carbon footprint	188	13	201
E6: Waste management	655	57	712
Total	3129	243	3372

Table 6. Observed frequencies of Social/Economic criteria obtained from the Scopus database.

Social/Economic Criteria	EU	Turkey	Total
EC1: Maintenance cost	188	13	201
EC2: Transportation cost	85	10	95
EC3: Design cost	524	29	553
EC4: Labor cost	43	9	52
EC5: Material cost	1510	132	1642
S1: Aesthetics	101	5	106
S2: Health and safety	591	26	617
S3: Duration	96	8	104
Total	3138	232	3370

Table 7. Observed frequencies of Technical criteria obtained from the Scopus database.

Technical Criteria	EU	Turkey	Total
T1: Acoustic insulation	76	14	90
T2: Thermal insulation	370	27	397
T3: Fire resistance	123	11	134
T4: Resistance to decay	41	2	43
T5: Life expectancy of material (Durability)	128	9	137
T6: Water Resistance	222	26	248
Total	960	89	1049

Table 8. Expected frequencies of Environmental criteria obtained from the Scopus database.

Environmental Criteria	EU	Turkey	Total
E1: Potential for recycling and reuse	1328.80	103.20	1432.00
E2: CO_2 emissions	387.88	30.12	418.00
E3: Energy consumption	540.99	42.01	583.00
E4: Zero or low toxicity	24.13	1.87	26.00
E5: Reduction in carbon footprint	186.52	14.48	201.00
E6: Waste management	660.69	51.31	712.00
Total	3129	243	3372

The expected frequencies for each criterion were derived from the observed frequencies using the formula (1). For example, 1328.80 in the second row and column in Table 8 is computed by multiplying 1432 (the total records for E1) by 3129 (the total records for EU) and dividing the result by 3372 (the general total).

The other values in Tables 8–10 were computed similarly, except those from the last row, which represent the sums of the values in the corresponding columns. Notice that the total is the same in the tables containing the recorded frequencies and the (corresponding) expected ones. This procedural step is crucial for conducting a thorough test and acquiring the requisite results. According to the Methodology, the degrees of freedom in the chi-square test are df = 5 (for environmental and technical criteria) and df = 7 (for social/economic criteria); the corresponding critical values, χ_0^2, are 11.0705 and 14.0671, respectively.

Table 9. Expected frequencies of Social/Economic criteria obtained from the Scopus database.

Social/Economic Criteria	EU	Turkey	Total
EC1: Maintenance cost	187.16	13.84	201.00
EC2: Transportation cost	88.46	6.54	95.00
EC3: Design cost	514.93	38.07	553.00
EC4: Labor cost	48.42	3.58	52.00
EC5: Material Cost	1528.96	113.04	1642.00
S1: Aesthetics	98.70	7.30	106.00
S2: Health and safety	574.52	42.48	617.00
S3: Duration	96.84	7.16	104.00
Total	3138	232	3370

Table 10. Expected frequencies of Technical criteria obtained from the Scopus database.

Technical Criteria	EU	Turkey	Total
T1: Acoustic insulation	82.36	7.64	90.00
T2: Thermal insulation	363.32	33.68	397.00
T3: Fire resistance	122.63	11.37	134.00
T4: Resistance to decay	39.35	3.65	43.00
T5: Life expectancy of material (Durability)	125.38	11.62	137.00
T6: Water resistance	226.96	21.04	248.00
Total	960	89	1049

Given that $\chi_c^2 = 2.1931 < 11.0705$, for the Environmental criteria, and $\chi_c^2 = 9.9956 < 11.0705$ for the Technical criteria, the null hypothesis cannot be rejected. There is not enough evidence to support the idea that there is a significant association between the region and the Environmental criteria for the selection of materials for façades, as reflected in the studied scientific articles.

When the test was applied for the social/economics criteria, $\chi_c^2 = 24.3156 > 14.0671$, so there is enough evidence to reject the hypothesis that there is no association between the region and the social/economic criteria for façade material selection, reflected in the investigated scientific literature.

To conclude, the analysis of the articles indexed in Scopus emphasized that the criteria that make difference between the two studied regions from the viewpoint of selecting sustainable materials for façades are social/economics.

3.4. Results from the Web of Science Database

The same procedure as presented in the previous section was applied to the records from the Web of Science database. The observed frequencies for the three groups of criteria are presented in Tables 11–13.

Table 11. Observed frequencies of environmental criteria obtained from Web of Science.

Environmental Criteria	EU	Turkey	Total
E1: Potential for recycling and reuse	854	70	924
E2: CO_2 emissions	261	17	278
E3: Energy consumption	312	31	343
E4: Zero or low toxicity	88	7	95
E5: Reduction in carbon footprint	104	7	111
E6: Waste management	317	30	347
Total	1936	162	2098

Table 12. Observed frequencies of Social/Economic criteria obtained from Web of Science.

Social/Economic Criteria	EU	Turkey	Total
EC1: Maintenance cost	53	7	60
EC2: Transportation cost	18	5	23
EC3: Design cost	281	31	312
EC4: Labor cost	33	5	38
EC5: Material cost	54	6	60
S1: Aesthetics	706	86	792
S2: Health and safety	423	43	466
S3: Duration	41	8	48
Total	1609	191	1800

Table 13. Observed frequencies of technical criteria obtained from Web of Science.

Technical Criteria	EU	Turkey	Total
T1: Acoustic insulation	43	5	48
T2: Thermal insulation	211	15	226
T3: Fire resistance	90	7	97
T4: Resistance to decay	19	1	20
T5: Life expectancy of material (Durability)	440	65	505
T6: Water Resistance	120	17	137
Total	923	110	1033

After a similar computation as in Tables 8–10 (not presented here for the sake of conciseness), the following values of the statistics, χ_c^2, were obtained for the three groups of criteria: 2.6129, 6.1859, and 8.7647, respectively. Since each is less than the corresponding critical values—11.0705, 14.067, and 11.0705, respectively—the null hypothesis cannot be rejected in any case.

To conclude, the hypothesis that no association exists between the region and the environmental (Social/Economic and Technical, respectively) criteria for selecting façade materials cannot be rejected.

These outcomes emphasize the necessity of extending the investigation on the significance attributed to these criteria within the EU countries and Turkey, which is undertaken in the next section.

3.5. Discussion

As mentioned in the previous sections, the Web of Science and Scopus databases were employed in this examination. However, definitive conclusions regarding the results provided by examining the Web of Science database cannot be reached due to the impossibility of rejecting the hypothesis H_0. Consequently, only the results from the Scopus database are included in this section and subjected to interpretation. The hypothesis H_1 is substantiated based on the test outcomes derived from the Scopus database concerning social/economic criteria. Hence, the commentary on this test's result can be articulated as follows. There is enough evidence that, to a certain extent, the publications referring to the analyzed regions reflect the differences attributed to social/economic criteria.

Performing the Kruskal–Wallis on the data series from the rows 2–9 and columns 2 and 3 from Table 6 (Social/Economic criteria from the Scopus database (so $m = 2$, df = 1), we found that $H = 8.647$, with a p-value = 0.0033 < 0.05, leading to the rejection of the hypothesis that there is no difference between the two data series. Performing the Kruskal–Wallis on the data series from the rows 2–9 and columns 2 and 3 from Table 12 (so $m = 2$, df = 1), we found that $H = 5.243$, p-value = 0.0156, leading to the rejection of the hypothesis that there is no difference between the two data series at a significance level of 0.05 (but not at 0.01, because 0.0156 > 0.01). These results confirm the findings from the previous section and open up discussion about the most important criteria for selecting sustainable materials for façades in both EU countries and Turkey.

Figure 3 illustrates the observed frequencies of the social/economic criteria in Scopus-indexed publications, normalized by the highest record in columns 2 and 3 from Table 6; in Figure 4, normalizing was carried out using the highest record in column 2 (3) for the values in column 2 (3) for a better evaluation of the criteria inside each region.

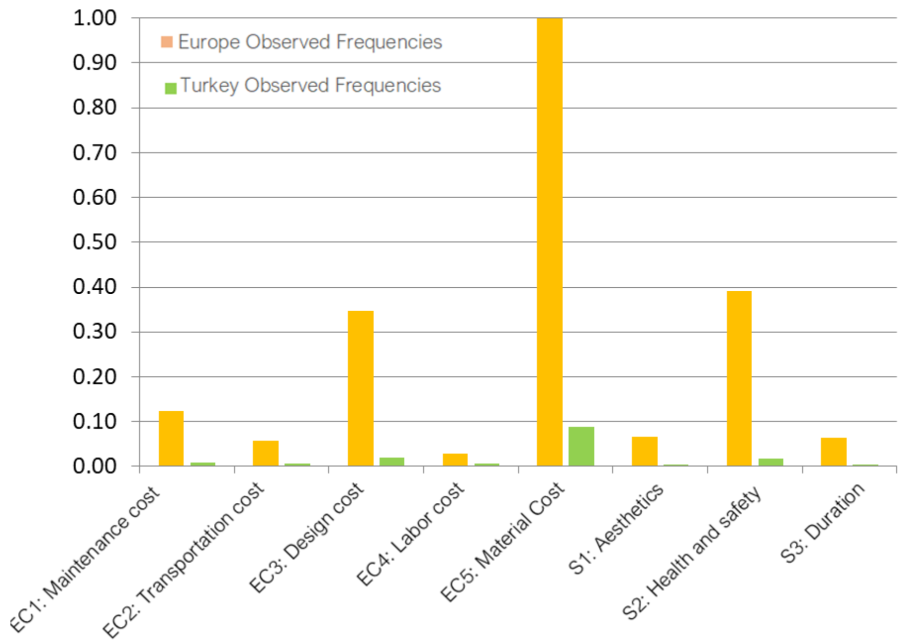

Figure 3. Observed frequencies of social/economic criteria (after normalizing by the highest record in both regions).

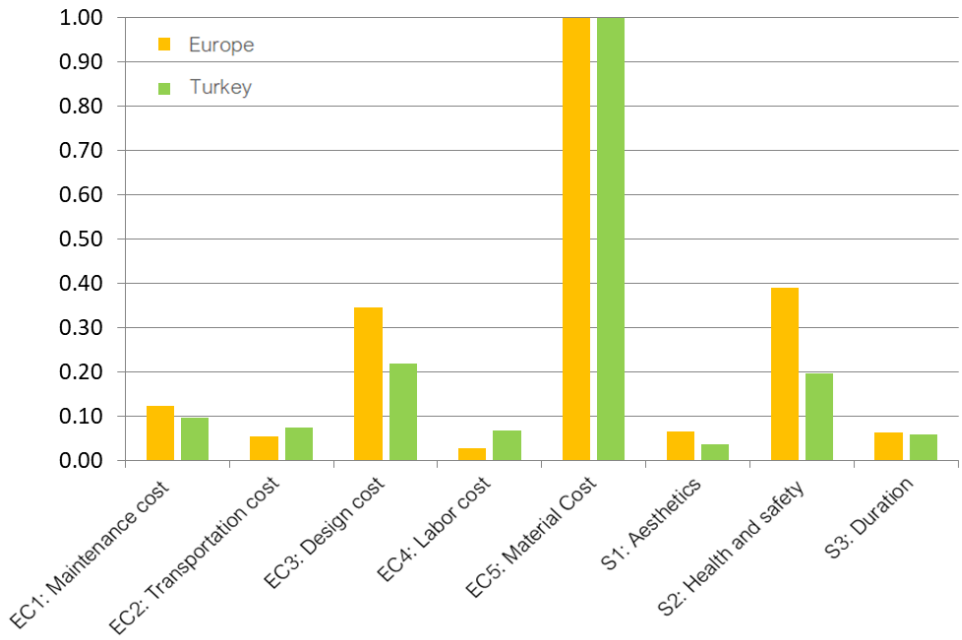

Figure 4. Observed frequencies of social/economic criteria (after normalizing by the highest record in each region).

Based on Figure 3, the primary significant sustainability criterion for Social/Economic for both the European Union countries and Turkey is material cost. In the context of the European Union, the second most significant criterion is health and safety (S2), followed by the design cost (EC3), while in Turkey, it is design cost (EC3). The situation seems to be reversed when considering these regions' third most important criterion. Still, the difference between the number of articles concerning the S2 and EC3 criteria is only 3. Given that we cannot pretend that the search was exhaustive, the ranking of EC3 and S2 for Turkey could not be considered absolute. Therefore, considering possible errors, we could assert that at this point, a similar importance appears to be given to these criteria in Turkey. A deeper investigation on this topic should be conducted in a separate study.

Considering this perspective, the significance of the material cost criterion is self-evident. Cost considerations are paramount in keeping a construction project within its allocated budget. Cost overruns can lead to financial challenges, project delays, and even project abandonment. Construction professionals can mitigate financial risks by monitoring and managing costs, ensuring the project's financial viability, and contributing to its uninterrupted progress.

Moreover, cost management is pivotal for profitability, enabling professionals to optimize earnings by accurately estimating project costs, competitive bidding, and effective expense control throughout construction. In this context, material cost emerges as an essential element directly influencing the project's outcome. Consequently, it is entirely understandable why this criterion holds the utmost importance in both regions.

Maintenance occupies the fourth place in the ranking of criteria, given that maintaining is better than reconstructing when possible, as it incurs lower costs. Differences in wage structures and living conditions mean that labor costs are generally higher in the European Union than in Turkey. It seems that the importance given to this criterion is more evident in EU countries. So, further research must be conducted on this topic in the Turkish context.

Additionally, to accurately compare transportation costs between EU countries and Turkey, a comprehensive study considering specific locations and types of construction materials is required. Key issues to consider in this assessment might include factors such as the type of building materials used and the scale of construction projects. The results of the study revealed that publications on this topic are more prevalent in EU member states and highlighted the importance of Turkey focusing more on this area to improve the efficiency of transport costs.

In the realm of sustainability in construction, the criterion of aesthetics may be less emphasized in Turkey. Nevertheless, it is essential to acknowledge that aesthetic considerations can substantially enhance the overall sustainability of buildings. While energy efficiency, material selection, and environmental impact take precedence, aesthetic criteria should not be underestimated, particularly regarding user experience and cultural sustainability. Given the considerable time spent by people in and around buildings, creating a positive environment through aesthetically pleasing façades is imperative. Incorporating visually appealing elements can enhance users' overall experience, contributing to their well-being and satisfaction. Furthermore, Turkey's rich architectural heritage and cultural context emphasize the importance of preserving or complementing the region's architectural traditions. In this light, including aesthetic criteria in material selection can positively impact cultural sustainability. By respecting and integrating culturally sustainable elements, buildings can maintain a harmonious relationship with their surroundings and contribute to preserving Turkey's architectural legacy.

Although aesthetics may hold a lower priority than energy efficiency, material selection, and environmental impact in the Turkish construction context, it is crucial to recognize the value of aesthetics in creating sustainable and culturally sensitive built environments. Integrating aesthetic considerations into the construction process can strike a balance between functional sustainability and the preservation of cultural identity.

Conversely, when considering European Union countries, the criterion of labor cost emerges as the least important. Labor cost plays a substantial role in the overall cost of a construction project. In the context of sustainable initiatives, the meticulous management of labor costs is pivotal for financial sustainability. Skillful estimation, budgeting, and regulation of labor costs are instrumental in ensuring that construction projects remain within their allocated budget limits, averting the risk of overspending and potential financial strains. Consequently, the aspect of labor cost warrants heightened attention within the context of European Union countries.

An alternative perspective for this research is to include the United States and China in the analysis. The inclusion of these regions leads to an observable increase in the number of instances where hypothesis H_1 is met, indicating a significant change in the observed frequency values. Consequently, this adjustment leads to more interpretable findings. Since an extended study on this topic is relevant, and it will be published as a separate article; here, we present only the results concerning the Social/Economic criteria from the records from the Scopus database. Table 14 shows the number of records for each criterion, for Europe, Turkey, China, and the USA. Applying the chi-square test led to the following computed value of the chi-square test statistic: χ_c^2 = 123.145 > 32.6705 (the critical value). Thus, there is enough evidence to reject the hypothesis that there is no association between the region and the social/economic criteria for the selection of materials for façades, as reflected in the investigated scientific literature.

Table 14. Observed frequencies of Social/Economic criteria obtained from the Scopus database for Europe, Turkey, China, and the US.

Social/Economic Criteria	Europe	Turkey	China	US	Total
EC1: Maintenance cost	188	13	29	160	390
EC2: Transportation cost	85	10	63	145	303
EC3: Design cost	524	29	211	617	1381
EC4: Labor cost	43	9	46	176	274
EC5: Material cost	1510	132	1483	1483	4608
S1: Aesthetics	101	5	18	69	193
S2: Health and safety	591	26	372	658	1647
S3: Duration	96	8	29	91	224
Total	3138	232	2251	3399	9020

For an easier comparison, the results are summarized in the chart in Figure 5, where data series are transformed dividing all values by the maximum (1510).

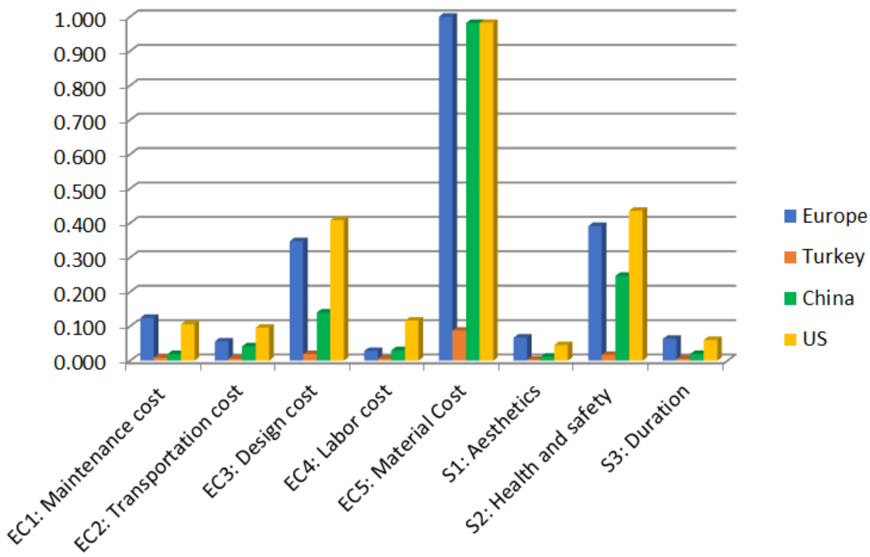

Figure 5. Observed frequencies of Social/Economic criteria obtained from the Scopus database for Europe, Turkey, China, and the US.

From the present study, the material cost criterion consistently emerges as the most critical factor in all four regions. The second most important criterion for the United States and China remains health and safety, followed by the design cost.

It is worth noting that the least important criteria show regional differences. Aesthetics is the least important criterion for Turkey, the United States, and China. In contrast, labor costs occupy this position for the European Union countries. These findings underline the importance of tailoring emphasized criteria to regional contexts.

It is also worth emphasizing the proportions of articles referring to each region's first three ranking criteria. For Europe (Turkey, China, and the US), EC5/S2 = 2.5550 (4.5517, 3.9866, and 2.2540), S2/EC3 = 1.1279 (1.1154, 1.7630, and 1.066). Significant values are noted for the first ratio in Turkey and China, emphasizing that the most crucial criterion is the material cost, followed to a lesser extent by health and safety.

For the EU and US, a higher importance is given to the second criterion with respect to the first, emphasized by similar ratios in EC5/S2. The highest ratio between the second and third criteria corresponds to China, underscoring significantly higher attention given to health and safety compared to design cost with respect to the other countries. A more in-depth analysis should be conducted within a larger economic and cultural context.

4. Conclusions

In summary, the increasing effects of global warming have highlighted how crucial sustainability is in today's globalized environment. A comprehensive analysis of the environmental, economic, and social criteria will be crucial for successfully integrating sustainability concepts into building methods since it enables the development of practical and ethical solutions. The urgent need for environmentally responsible building methods inspired this study, which set out to determine sustainable standards for façade materials.

The chi-square independence test allowed for the examination of data covering Turkey and other European nations, and the results produced a wealth of insightful information. These results shed light on complex approaches to sustainability in construction by illuminating both the similarities and differences in sustainable criteria choices from various perspectives. Understanding these differences is essential for promoting international cooperation and coordinating efforts toward a more resilient and sustainable built environment as global issues continue to change. This study is an important first step in this joint effort, laying the groundwork for more investigation and well-informed choices in the hunt for sustainable building methods.

An inherent constraint within this study concerns the challenge of interpreting test results that align with the established null hypothesis when employing the chi-square independence test. The study may not effectively clarify these outcomes. As a solution, an approach combining linguistic and statistical data has been chosen to optimize the comparison process, acknowledging the possibility of unfavorable results. One such restriction is the presence of irrelevant articles in the study findings, which were not eliminated when keyword formulations were applied to the databases in order to produce the test results. As such, although it might be too soon to consider these results final conclusions, they are nonetheless considered valid within the parameters of the research. It is crucial to proceed delicately and approach these results knowing that more improvement and confirmation may be required.

To conclude, this study has added to texpanding contributions to the literature by completing the selection of sustainable façade materials through the use of a chi-square test of independence within a comparison analysis. The findings emphasized the necessity of comprehensive sustainability evaluations while shedding light on the contextual differences in the selection of criteria between Turkey and the member states of the European Union. By integrating environmental, social, and economic factors, decision makers may effectively support sustainable construction practices and progress toward an ecologically sound and resilient future.

Author Contributions: Conceptualization, R.M. and E.C.A.; methodology, H.B.D., A.B. and R.M.; software, A.B.; validation, H.B.D. and A.B.; formal analysis, R.M. and E.C.A.; investigation, H.B.D. and A.B.; resources, H.B.D., A.B. and R.M.; data curation, H.B.D.; writing—original draft preparation, H.B.D.; writing—review and editing, A.B; visualization, H.B.D. and A.B.; supervision, A.B., R.M. and E.C.A.; project administration, A.B.; funding acquisition, A.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available in the cited manuscripts.

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

Appendix A

Table A1. Formulation applied to the Scopus database for European Union countries.

Environmental criteria	TITLE-ABS-KEY (((recycling OR reuse) AND construction AND materials AND (construction AND industry OR building AND industry))) AND (LIMIT-TO (AFFILCOUNTRY, "Italy") OR LIMIT-TO (AFFILCOUNTRY, "Spain") OR LIMIT-TO (AFFILCOUNTRY, "Portugal") OR LIMIT-TO (AFFILCOUNTRY, "Germany") OR LIMIT-TO (AFFILCOUNTRY, "Czech Republic") OR LIMIT-TO (AFFILCOUNTRY, "Belgium") OR LIMIT-TO (AFFILCOUNTRY, "France") OR LIMIT-TO (AFFILCOUNTRY, "Greece") OR LIMIT-TO (AFFILCOUNTRY, "Romania") OR LIMIT-TO (AFFILCOUNTRY, "Austria") OR LIMIT-TO (AFFILCOUNTRY, "Denmark") OR LIMIT-TO (AFFILCOUNTRY, "Finland") OR LIMIT-TO (AFFILCOUNTRY, "Poland") OR LIMIT-TO (AFFILCOUNTRY, "Sweden") OR LIMIT-TO (AFFILCOUNTRY, "Lithuania") OR LIMIT-TO (AFFILCOUNTRY, "Cyprus") OR LIMIT-TO (AFFILCOUNTRY, "Ireland") OR LIMIT-TO (AFFILCOUNTRY, "Latvia") OR LIMIT-TO (AFFILCOUNTRY, "Slovakia") OR LIMIT-TO (AFFILCOUNTRY, "Croatia") OR LIMIT-TO (AFFILCOUNTRY, "Luxembourg") OR LIMIT-TO (AFFILCOUNTRY, "Estonia") OR LIMIT-TO (AFFILCOUNTRY, "Malta") OR LIMIT-TO (AFFILCOUNTRY, "Slovenia") OR LIMIT-TO (AFFILCOUNTRY, "Netherlands") OR LIMIT-TO (AFFILCOUNTRY, "Hungary") OR LIMIT-TO (AFFILCOUNTRY, "Bulgaria"))
Social/ Economic criteria	TITLE-ABS-KEY (((maintenance AND cost) AND construction AND materials AND (construction AND industry OR building AND industry))) AND (LIMIT-TO (AFFILCOUNTRY, "Italy") OR LIMIT-TO (AFFILCOUNTRY, "Spain") OR LIMIT-TO (AFFILCOUNTRY, "Portugal") OR LIMIT-TO (AFFILCOUNTRY, "Germany") OR LIMIT-TO (AFFILCOUNTRY, "Czech Republic") OR LIMIT-TO (AFFILCOUNTRY, "Belgium") OR LIMIT-TO (AFFILCOUNTRY, "France") OR LIMIT-TO (AFFILCOUNTRY, "Greece") OR LIMIT-TO (AFFILCOUNTRY, "Romania") OR LIMIT-TO (AFFILCOUNTRY, "Austria") OR LIMIT-TO (AFFILCOUNTRY, "Denmark") OR LIMIT-TO (AFFILCOUNTRY, "Finland") OR LIMIT-TO (AFFILCOUNTRY, "Poland") OR LIMIT-TO (AFFILCOUNTRY, "Sweden") OR LIMIT-TO (AFFILCOUNTRY, "Lithuania") OR LIMIT-TO (AFFILCOUNTRY, "Cyprus") OR LIMIT-TO (AFFILCOUNTRY, "Ireland") OR LIMIT-TO (AFFILCOUNTRY, "Latvia") OR LIMIT-TO (AFFILCOUNTRY, "Slovakia") OR LIMIT-TO (AFFILCOUNTRY, "Croatia") OR LIMIT-TO (AFFILCOUNTRY, "Luxembourg") OR LIMIT-TO (AFFILCOUNTRY, "Estonia") OR LIMIT-TO (AFFILCOUNTRY,"Malta") OR LIMIT-TO (AFFILCOUNTRY, "Slovenia") OR LIMIT-TO (AFFILCOUNTRY, "Netherlands") OR LIMIT-TO (AFFILCOUNTRY, "Hungary") OR LIMIT-TO (AFFILCOUNTRY, "Bulgaria"))
Technical criteria	TITLE-ABS-KEY (((acoustic AND insulation) AND construction AND materials AND (construction AND industry OR building AND industry))) AND (LIMIT-TO (AFFILCOUNTRY, "Italy") OR LIMIT-TO (AFFILCOUNTRY, "Spain") OR LIMIT-TO (AFFILCOUNTRY, "Portugal") OR LIMIT-TO (AFFILCOUNTRY, "Germany") OR LIMIT-TO (AFFILCOUNTRY, "Czech Republic") OR LIMIT-TO (AFFILCOUNTRY, "Belgium") OR LIMIT-TO (AFFILCOUNTRY, "France") OR LIMIT-TO (AFFILCOUNTRY, "Greece") OR LIMIT-TO (AFFILCOUNTRY, "Romania") OR LIMIT-TO (AFFILCOUNTRY, "Austria") OR LIMIT-TO (AFFILCOUNTRY, "Denmark") OR LIMIT-TO (AFFILCOUNTRY, "Finland") OR LIMIT-TO (AFFILCOUNTRY, "Poland") OR LIMIT-TO (AFFILCOUNTRY, "Sweden") OR LIMIT-TO (AFFILCOUNTRY, "Lithuania") OR LIMIT-TO (AFFILCOUNTRY, "Cyprus") OR LIMIT-TO (AFFILCOUNTRY, "Ireland") OR LIMIT-TO (AFFILCOUNTRY, "Latvia") OR LIMIT-TO (AFFILCOUNTRY, "Slovakia") OR LIMIT-TO (AFFILCOUNTRY, "Croatia") OR LIMIT-TO (AFFILCOUNTRY, "Luxembourg") OR LIMIT-TO (AFFILCOUNTRY, "Estonia") OR LIMIT-TO (AFFILCOUNTRY, "Malta") OR LIMIT-TO (AFFILCOUNTRY, "Slovenia") OR LIMIT-TO (AFFILCOUNTRY, "Netherlands") OR LIMIT-TO (AFFILCOUNTRY, "Hungary") OR LIMIT-TO (AFFILCOUNTRY, "Bulgaria"))

Table A2. Search strategies used in the Web of Science database for European Union countries.

Environmental criteria	(AB = (((recycling OR reuse) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TI = (((recycling OR reuse) AND Construction Materials AND (Sustainability) AND (Construction Industry OR Building Industry))) OR TS = (((recycling OR reuse) AND Construction Materials AND (Construction Industry OR Building Industry))) OR KP = (((recycling OR reuse) AND Construction Materials AND (Construction Industry OR Building Industry)))) AND (CU == ("Slovenia" OR "Portugal" OR "Bulgaria" OR "Spain" OR "Italy" OR "Germany" OR "Romania" OR "Belgium" OR "Czech Republic" OR "Poland" OR "Greece" OR "Netherlands" OR "Lithuania" OR "Malta" OR "Croatia" OR "Denmark" OR "France" OR "Sweden" OR "Austria" OR "Cyprus" OR "Luxembourg" OR "Latvia" OR "Finland" OR "Ireland" OR "Hungary" OR "Estonia" OR "Slovakia"))
Social/ economic criteria	(AB = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TI = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TS = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry))) OR KP = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry)))) AND (CU == ("Slovenia" OR "Portugal" OR "Bulgaria" OR "Spain" OR "Italy" OR "Germany" OR "Romania" OR "Belgium" OR "Czech Republic" OR "Poland" OR "Greece" OR "Netherlands" OR "Lithuania" OR "Malta" OR "Croatia" OR "Denmark" OR "France" OR "Sweden" OR "Austria" OR "Cyprus" OR "Luxembourg" OR "Latvia" OR "Finland" OR "Ireland" OR "Hungary" OR "Estonia" OR "Slovakia"))
Technical criteria	(AB = (((acoustic insulation OR acoustic ability) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TI = (((acoustic insulation OR acoustic ability) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TS = (((acoustic insulation OR acoustic ability) AND Construction Materials AND (Construction Industry OR Building Industry))) OR KP = (((acoustic insulation OR acoustic ability) AND Construction Materials AND (Construction Industry OR Building Industry)))) AND (CU == ("Slovenia" OR "Portugal" OR "Bulgaria" OR "Spain" OR "Italy" OR "Germany" OR "Romania" OR "Belgium" OR "Czech Republic" OR "Poland" OR "Greece" OR "Netherlands" OR "Lithuania" OR "Malta" OR "Croatia" OR "Denmark" OR "France" OR "Sweden" OR "Austria" OR "Cyprus" OR "Luxembourg" OR "Latvia" OR "Finland" OR "Ireland" OR "Hungary" OR "Estonia" OR "Slovakia"))

Table A3. Search strategies used in the Scopus database for Turkey.

Environmental criteria	TiTLE-ABS-KEY(((recycling OR reuse) AND construction AND materials AND (construction AND industry OR building AND industry))) AND (LIMIT-TO (AFFILCOUNTRY, "Turkey"))
Social/Economic criteria	TITLE-ABS-KEY((maintenance AND cost) AND construction AND materials AND (construction AND industry OR building AND industry)) AND (LIMIT-TO (AFFILCOUNTRY, "Turkey")
Technical criteria	TITLE-ABS-KEY((acoustic AND insulation OR acoustic) AND construction AND materials AND (construction AND industry OR building AND industry)) AND (LIMIT-TO (AFFILCOUNTRY, "Turkey"))

Table A4. Search strategies used in the Web of Science database for Turkey.

Environmental criteria	(AB = (((recycling OR reuse) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TI = (((recycling OR reuse) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TS = (((recycling OR reuse) AND Construction Materials AND (Construction Industry OR Building Industry))) OR KP = (((recycling OR reuse) AND Construction Materials AND (Construction Industry OR Building Industry)))) AND (CU == ("Turkey" OR "Turkiye"))
Social/Economic criteria	(AB = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TI = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TS = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry))) OR KP = (((maintenance cost) AND Construction Materials AND (Construction Industry OR Building Industry)))) AND (CU == ("Turkey" OR "Turkiye"))

Table A4. *Cont.*

Technical criteria	(AB = (((acoustic insulation OR acoustic property) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TI = (((acoustic insulation OR acoustic property) AND Construction Materials AND (Construction Industry OR Building Industry))) OR TS = (((acoustic insulation OR acoustic property) AND Construction Materials AND (Construction Industry OR Building Industry))) OR KP = (((acoustic insulation OR acoustic property) AND Construction Materials AND (Construction Industry OR Building Industry)))) AND (CU == ("Turkey" OR "Turkiye"))

References

1. Kuhlman, T.; Farrington, J. What is Sustainability? *Sustainability* **2010**, *2*, 3436–3448. [CrossRef]
2. Mata-Lima, H.; Silva, D.W.; Nardi, D.C.; Klering, S.A.; de Oliveira, T.C.F.; Morgado-Dias, F. Waste-to-Energy: An Opportunity to Increase Renewable Energy Share and Reduce Ecological Footprint in Small Island Developing States (SIDS). *Energies* **2021**, *14*, 7586. [CrossRef]
3. Blauert, J.; Zadek, S. *Mediating Sustainability: Growing Policy from the Grassroots*; Kumarian Press: West Hartford, CT, USA, 1998.
4. Retzlaff, R.C. Green Building Assessment Systems: A Framework and Comparison for Planners. *J. Am. Plann. Assoc.* **2008**, *74*, 505–519. [CrossRef]
5. Oprea, S.-V.; Bâra, A.; Ciurea, C.-E.; Stoica, L.F. Smart Cities and Awareness of Sustainable Communities Related to Demand Response Programs: Data Processing with First-Order and Hierarchical Confirmatory Factor Analyses. *Electronics* **2022**, *11*, 1157. [CrossRef]
6. Bucurica, I.-A.; Dulama, I.-D.; Radulescu, C.; Banica, A.L. Surface Water Quality Assessment Using Electroanalytical Methods and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). *Rom. J. Phys.* **2022**, *67*, 802.
7. Chilian, A.; Tanase, N.-M.; Popescu, I.V.; Radulescu, C.; Bancuta, O.-R.; Bancuta, I. Long-Term Monitoring of the Heavy Metals Content (Cu, Ni, Zn, Cd, Pb) in Wastewater Before and after the Treatment Process by Spectrometric Methods of Atomic Absorption (FAAS and ETAAS). *Rom. J. Phys.* **2022**, *67*, 804.
8. Chiritescu, R.-V.; Luca, E.; Iorga, G. Observational study of major air pollutants over urban Romania in 2020 in comparison with 2019. *Rom. Rep. Phys.* **2024**, *76*, 702.
9. Stihi, C.; Bute, O.C. Indoor air quality monitoring in educational environments: A case study. *Rom. Rep. Phys* **2023**, *75*, 706. [CrossRef]
10. Petticrew, M.; Roberts, H. *Systematic Reviews in the Social Sciences: A Practical Guide*; Blackwell: Malden MA, USA, 2006.
11. Snyder, H. Literature review as a research methodology: An overview and guidelines. *J. Bus. Res.* **2019**, *104*, 333–339. [CrossRef]
12. Figueiredo, K.; Pierott, R.; Hammad, A.W.; 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]
13. Hasan, A.; Baroudi, B.; Rameezdeen, R.; Elmualim, A. Factors affecting construction productivity: A 30 year systematic review. *Eng. Constr. Arch. Manag.* **2017**, *25*, 916–937. [CrossRef]
14. Akadiri, P.O.; Olomolaiye, P.O. Development of sustainable assessment criteria for building materials selection. *Eng. Constr. Arch. Manag.* **2021**, *19*, 666–687. [CrossRef]
15. Ahadiri, P.O.; Olomolaiye, P.O.; Chinyio, E.A. Multi-criteria evaluation model for the selection of sustainable materials for building projects. *Autom. Construct.* **2013**, *30*, 113–125. [CrossRef]
16. AlKheder, S.; AlKandari, D.; AlYatama, S. Sustainable assessment criteria for airport runway material selection: A fuzzy analytical hierarchy approach. *Eng. Constr. Arch. Manag.* **2022**, *29*, 3091–3113. [CrossRef]
17. Mathiyazhagan, K.; Gnanavelbabu, A.; Prabhuraj, B.L. A sustainable assessment model for material selection in construction industries perspective using hybrid MCDM approaches. *J. Adv. Manag. Res.* **2018**, *16*, 234–259. [CrossRef]
18. Hatefi, S.M.; Asadi, H.; Shams, G.; Tamošaitiene, J.; Turskis, Z. Model for the Sustainable Material Selection by Applying Integrated Dempster-Shafer Evidence Theory and Additive Ratio Assessment (ARAS) Method. *Sustainability* **2021**, *13*, 10438. [CrossRef]
19. Dinh, T.H.; Dinh, T.H. Building a Comprehensive Conceptual Framework for Material Selection in Terms of Sustainability in The Construction Preliminary Design Phase. *Int. J. Sustain. Constr. Eng. Technol.* **2021**, *12*, 73–84. [CrossRef]
20. Gilani, G.; Hosseini, S.A.; Pons-Valladares, O.; de la Fuente, A. An enhanced multi-criteria decision-making approach oriented to sustainability analysis of building façades: A case study of Barcelona. *J. Build. Eng.* **2022**, *54*, 104630. [CrossRef]
21. Sadrolodabaee, P.; Hosseini, S.A.; Claramunt, J.; Ardanuy, M.; Haurie, L.; Lacasta, A.M.; de la Fuente, A. Experimental characterization of comfort performance parameters and multi-criteria sustainability assessment of recycled textile-reinforced cement façade cladding. *J. Clean. Prod.* **2022**, *356*, 131900. [CrossRef]
22. Mayhoub, M.M.G.; El Sayad, Z.M.T.; Ali, A.A.M.; Ibrahim, M.G. Assessment of Green Building Materials' Attributes to Achieve Sustainable Building Façades Using AHP. *Buildings* **2021**, *11*, 474. [CrossRef]
23. Siksnelyte-Butkiene, I.; Streimikiene, D.; Balezentis, T.; Skulskis, V.A. Systematic Literature Review of Multi-Criteria Decision-Making Methods for Sustainable Selection of Insulation Materials in Buildings. *Sustainability* **2021**, *13*, 737. [CrossRef]

24. Stoica, L.F.; Stoica, F. ATLDesigner: ATL Model Checking Using An Attribute Grammar. *Int. J. Softw. Eng. Knowl. Eng. (IJSEKE)* **2022**, *32*, 1125–1154. [CrossRef]
25. Stoica, F.; Stoica, L.F. Integrated Tool for Assisted Predictive Analytics. In Proceedings of the 7th International Conference on Modelling and Development of Intelligent Systems (MDIS 2020), Sibiu, Romania, 22–24 October 2020; pp. 149–166.
26. Pearson, K.X. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. *Lond. Edinb. Dublin Philos. Mag. J. Sci.* **1900**, *50*, 157–175. [CrossRef]
27. Kruskal, W.H.; Wallis, W.A. Use of ranks in one-criterion variance analysis. *J. Am. Stat. Assoc.* **1952**, *47*, 583–621. [CrossRef]
28. Zhang, H.; Peng, Y.; Tian, G.; Wang, D.; Xie, P. Green material selection for sustainability: A hybrid MCDM approach. *PLoS ONE* **2017**, *12*, e0177578. [CrossRef]
29. Mousavi-Nasab, S.H.; Sotoudeh-Anvari, A. A new multi-criteria decision-making approach for sustainable material selection problem: A critical study on rank reversal problem. *J. Clean. Prod.* **2018**, *182*, 466–484. [CrossRef]
30. Mousavi-Nasab, S.H.; Sotoudeh-Anvari, A. A comprehensive MCDM based approach using TOPSIS, COPRAS and DEA as an auxiliary tool for material selection problems. *Mater. Des.* **2017**, *121*, 237–253. [CrossRef]
31. Aires, R.F.F.; Ferreira, L. The Rank Reversal Problem in Multi-Criteria Decision Making: A Literature Review. *Pesqui. Oper.* **2018**, *38*, 331–362. [CrossRef]
32. Aires, R.F.d.F.; Ferreira, L.A. New Multi-Criteria Approach for Sustainable Material Selection Problem. *Sustainability* **2022**, *14*, 11191. [CrossRef]
33. Yang, J.; Ogunkah, I.C.B. A Multi-Criteria Decision Support System for the Selection of Low-Cost Green Building Materials and Components. *J. Build. Constr. Plann. Res.* **2013**, *1*, 89–130. [CrossRef]
34. Al-Atesh, E.A.A.; Rahmawatib, Y.; Zawawi, N.A.B.W.; Elmansoury, A. Developing the Green Building Materials Selection Criteria for Sustainable Building Projects. *Int. J. Adv. Sci. Eng. Inform. Technol.* **2021**, *11*, 2012–2020. [CrossRef]
35. Zhong, Y.; Wu, P. Economic sustainability, environmental sustainability and constructability indicators related to concrete- and steel-projects. *J. Clean. Prod.* **2015**, *108A*, 748–756. [CrossRef]
36. Govindan, K.; Shankar, K.M.; Kannan, D. Sustainable material selection for construction industry—A hybrid multi-criteria decision making approach. *Renew. Sustain. Energy Rev.* **2016**, *55*, 1274–1288. [CrossRef]
37. Streimikiene, D.; Skulskis, V.; Balezentis, T.; Agnusdei, G.P. Uncertain multi-criteria sustainability assessment of green building insulation materials. *Energy Build.* **2020**, *219*, 110021. [CrossRef]
38. Balali, A.; Valipour, A. Identification and selection of building façade's smart materials according to sustainable development goals. *Sustain. Mater. Technol.* **2020**, *26*, e00213. [CrossRef]
39. de la Fuente, A.; Fernández-Ordóñez, D. A multi-criteria decision-making based approach to assess the sustainability of concrete structures. *IOP Conf. Ser. Mat. Sci. Eng.* **2018**, *442*, 012008. [CrossRef]
40. Nadoushani, Z.S.M.; Akbarnezhad, A.; Jornet, J.F.; Xiao, J. Multi-criteria selection of façade systems based on sustainability criteria. *Build. Environ.* **2017**, *121*, 67–78. [CrossRef]
41. Civic, A.; Vucijak, B. Multi-criteria Optimization of Insulation Options for Warmth of Buildings to Increase Energy Efficiency. *Procedia Eng.* **2014**, *69*, 911–920. [CrossRef]
42. Mahmoudkelaye, S.; Katayoon, A.T.; Pourvaziri, M.; Asadian, E. Sustainable material selection for building enclosure through ANP method. *Case Stud. Constr. Mater.* **2018**, *9*, e00200. [CrossRef]
43. Vilutiene, T.; Kumetaitis, G.; Kiaulakis, A.; Kalibatas, D. Assessing the Sustainability of Alternative Structural Solutions of a Building: A Case Study. *Buildings* **2020**, *10*, 36. [CrossRef]
44. Ahmed, M.; Qureshi, M.N.; Mallick, J.; Kahla, N.B. Selection of Sustainable Supplementary Concrete Materials Using OSM-AHP-TOPSIS Approach. *Adv. Mat. Sci. Eng.* **2019**, *2019*, 2850480. [CrossRef]
45. Falqi, I.I.; Ahmed, M.; Mallick, J. Siliceous Concrete Materials Management for Sustainability Using Fuzzy-TOPSIS Approach. *Appl. Sci.* **2019**, *9*, 3457. [CrossRef]
46. Roy, J.; Das, S.; Kar, S.; Pamučar, D. An Extension of the CODAS Approach Using Interval-Valued Intuitionistic Fuzzy Set for Sustainable Material Selection in Construction Projects with Incomplete Weight Information. *Symmetry* **2019**, *11*, 393. [CrossRef]
47. Wright, L.A.; Kemp, S.; Williams, I. Carbon footprinting': Towards a universally accepted definition. *Carbon Manag.* **2011**, *2*, 61–67. [CrossRef]
48. WHO Human Health Risk Assessment Toolkit. Chemical Hazards. Available online: https://www.inchem.org/documents/harmproj/harmproj/harmproj8.pdf (accessed on 22 January 2024).
49. Akadiri, P.O.; Chinyio, E.A.; Olomolaiye, P.O. Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector. *Buildings* **2012**, *2*, 126–152. [CrossRef]
50. Kim, J.; Rigdon, B. *Qualities, Use, and Examples of Sustainable Building Materials*; National Pollution Prevention Center for Higher Education: Ann Arbor, MI, USA, 2008; pp. 48109–48115. Available online: http://www.umich.edu/~nppcpub/resources/compendia/architecture.html (accessed on 10 November 2008).
51. Zutshi, A.; Creed, A. An international review of environmental initiatives in the construction sector. *J. Clean. Prod.* **2015**, *98*, 92–106. [CrossRef]
52. Ofori, G.; Gang, G.; Briffett, C. Implementing environmental management systems in construction: Lessons from quality systems. *Build. Environ.* **2002**, *37*, 1397–1407. [CrossRef]

53. Gattorna, J.L.; Walters, D.W. *Managing the Supply Chain: A Strategic Perspective*; Red Globe Press: London, UK, 1996.
54. Shakantu, W.; Tookey, J.E.; Bowen, P.A. The hidden cost of transportation of construction materials: An overview. *J. Eng. Des. Technol.* **2003**, *1*, 103–118. [CrossRef]
55. What Is the Typical Design Cost for Construction Projects? Available online: https://www.quora.com/What-is-the-typical-design-cost-for-construction-projects (accessed on 28 January 2024).
56. Flex. Calculating Labor and Material Costs in Construction. Available online: https://www.flex.one/construction-resources/labor-and-material#what-does-labor-and-materials-mean (accessed on 22 January 2024).
57. Gong, R.; Wu, Y.-Q.; Chen, F.-W.; Yan, T.-H. Labor Costs, Market Environment and Green Technological Innovation: Evidence from High-Pollution Firms. *Int. J. Environ. Res. Public Health* **2020**, *17*, 522. [CrossRef] [PubMed]
58. Zhang, H. 12—Heat-insulating Materials and Sound-absorbing Materials. In *Building Materials in Civil Engineering*; Woodhead Publishing Series in Civil and Structural Engineering; Woodhead Publishing: Cambridge, UK, 2011; pp. 304–423.
59. Zeitler, B. Chapter 2.3. In*fluence of internal thermal insulation on the sound insulation of walls. In Energy-Efficient Retrofit of Buildings by Interior Insulation: Materials, Methods and Tools*; Wakili, K.G., Stahl, T., Eds.; Butterworth-Heinemann: Oxford, UK, 2022; pp. 193–218.
60. Panias, D.; Balomenos, E.; Sakkas, K. 16—The fire resistance of alkali-activated cement-basedconcrete binders. In *Handbook of Alkali-Activated Cements, Mortars and Concretes*; Pacheco-Torgal, F., Labrincha, J.A., Leonelli, C., Palomo, A., Chindaprasirt, P., Eds.; Woodhead Publishing: Cambridge, UK; Science Press: Beijing, China, 2015; pp. 423–461.
61. 2008 Construction Code. Available online: https://www.nyc.gov/site/buildings/codes/2008-construction-codes.page (accessed on 20 December 2023).
62. What Is Decay? Available online: https://designwithdecay.com/introduction.html#:~:text=%20To%20consider%20decay%20in%20architecture,%20inevitable%20degradation%20of%20physical%20matter%20 (accessed on 20 December 2023).
63. Merriam-Webster Dictionary. Available online: https://www.merriam-webster.com/dictionary/dictionary (accessed on 1 January 2020).
64. Vidales-Barriguete, A.; Atanes-Sánchez, E.; del Río-Merino, M.; Piña-Ramírez, C. Analysis of the Improved Water-Resistant Properties of Plaster Compounds with the Addition of Plastic Waste. Available online: https://oa.upm.es/56575/1/INVE_MEM_2019_305412.pdf (accessed on 20 December 2023).
65. Sustainable Refurbishment of Building Facades and External Walls. Available online: https://cordis.europa.eu/project/id/226858/reporting/fr (accessed on 20 December 2023).