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Integration of Sustainability Criteria and Life Cycle Sustainability Assessment Method into Construction Material Selection in Developing Countries: The Case of Vietnam

Trong Hung Dinh[1*], Trung Hieu Dinh[2], Uwe Götze[1]

[1] Department of Management Accounting and Control, Faculty of Economics and Business Administration, Chemnitz University of Technology, Chemnitz 09126, Germany
[2] Department of Economic Basis and Management, Faculty of Transport Economics, University of Transport and Communications, Hanoi 100000, Vietnam

Corresponding Author Email: dthung@utc.edu.vn

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ABSTRACT

A sustainable development concerning economic, environmental, and social aspects is a global need as well as challenge in general and especially regarding the selection of construction materials. However, it is assumed that the importance of sustainability criteria is different in developed and developing countries. This is relevant for the application of Life Cycle Sustainability Assessment, a method that integrates the established methods for economic, ecological, and social evaluation (Life Cycle Costing, Life Cycle Assessment, and Social Life Cycle Assessment) without explicitly including importance weightings. This paper aims to review the reality of sustainable development in construction material selection in Vietnam, a developing country. A list of 18 sustainability criteria was set up by reviewing previous studies and using a questionnaire. These criteria were ranked and used to calculate the importance of weightings based on the Analytic Hierarchy Process method and a Likert scale. The results showed that the "price of material" was ranked as the first among the sustainability criteria. It is also pointed out that 42.06, 29.96, and 27.98 are the weightings of Life Cycle Costing, Life Cycle Assessment, and Social Life Cycle Assessment results, respectively. Besides, 11 obstacles for integrating sustainability criteria into material selection were identified in the questionnaire, and 4 out of them were marked as showing "high" importance.

1. INTRODUCTION

Countries around the world are increasingly interested in sustainability in the construction industry. Kauskale [1] surveyed Latvian participants and concluded that construction projects' sustainability performance influences sustainable development. Shi and Liu [2] reviewed the literature on green building and sustainability construction from 2002 to 2018 and found out that the number of relevant documents increased year by year. Construction materials are the main elements of buildings and infrastructures. A construction product may require more than 2 tons of 100 different kinds of construction material. These required materials may be familiar (such as stone, steel, and iron), rare, or specific [3]. Bhutta [4] concluded that the construction industry is the primary energy consumer and environmental pollution source. Therefore, material selection impacts significantly on sustainability. Several authors pointed out that the selected materials will most likely affect the whole project life cycle; therefore, material selection is one of the easiest ways of integrating sustainability into the construction industry [5, 6]. Kylili and Fokaides [7] concluded that increased use of recycled materials, either natural or modern, makes it easy to achieve sustainability.

There are some studies on integrating sustainability into construction material selection. Ahmadian [8] outlines a method of evaluating the trade-offs between economic, environmental, and social impacts by applying building information models and historical databases. Several authors have come up with a list of criteria for choosing materials concerning sustainability—this will be discussed in section two. Each material has its characteristics, making it necessary for designers and architects to compare the materials' specifications and criteria, so several authors have concluded that material selection is likely to be a multi-criteria decision problem [9-11].

A comprehensive method for evaluating and selecting objects with respect to sustainability is Life Cycle Sustainability Assessment (LCSA). According to Klöpffer [12], LCSA is a tool based on the triple bottom line assessing the sustainability of production systems by summing up the results of Life Cycle Costing (LCC), Life Cycle Assessment (LCA), and Social Life Cycle Assessment (SLCA). Klöpffer [12] proposed that in the "LCSA equation," the overall evaluation result is the sum of LCC, LCA, and SLCA results (Eq. (1)).

$$LCSA = LCC + LCA + SLCA \quad (1)$$

However, each country has different contexts and scenarios. As a result, countries and the people that are responsible for material selection (architects, designers) have different priorities in the three pillars of sustainability; for instance, in developing countries, economic sustainability is typically prioritized, while environmental aspects and social aspects are overshadowed [13, 14]. Therefore, it is necessary to consider the importance of LCC, LCA, and SLCA when calculating the overall LCSA result. This motivates a modified LCSA equation considering the level of importance of LCC, LCA, and SLCA results (Eq. (2)).

$$LCSA = \alpha * LCC + \beta * LCA + \gamma * SLCA \qquad (2)$$

where, α, β, and γ are the weightings of LCC, LCA, and SLCA results, respectively. A method based on such an LCSA approach, including importance weightings, would be helpful to help architects and designers make a well-informed choice of construction materials. The crucial issues of weighting calculation for LCSA parameters still exist in the current literature. Toosi et al. [15] concluded that considering equal weights for LCC, LCA, and SLCA values is a limitation, and it should be more studied in the future. Several authors have tried to estimate the importance weightings. Azizi et al. [16] compared the sustainability level of powder compost system and granular compost system by evaluating the LCSA value with Levels of Importance factors, which were identified by investigating previous models. The Integrated Value Model for Sustainable Assessment (MIVES) also served as a method to calculate the weightings, as suggested by Reddy et al. [17]. However, the problems of including and determining importance weightings in LCSA is still not solved.

Besides, institutions in developing countries may encounter many obstacles when integrating sustainability in construction material selection. These obstacles vary depending on religion, policy, or current status and should be known in order to enable systematic countermeasures.

This article aims to build a comprehensive list of sustainability criteria in material selection in developing countries based on Vietnam's case study. Based on a survey and applying the Analytic Hierarchy Process (AHP), importance weightings of each criterion and the overall LCC, LCA, and SLCA results will be determined. (for Eq. (2). This will provide insights concerning the importance of the single criteria as well as the overall weights of the economic, ecological, and social dimensions; and answer the question of whether the hypothesis that Eq. (2) should replace Eq. (1) is justified. After that, the obstacles that affect integrating the identified sustainability criteria into material selection will be identified and ranked.

2. LITERATURE REVIEW

Several authors have researched sustainability criteria using the triple bottom line approach, which focuses on social, environmental, and economic concerns. Zhou [18] identified mechanical properties, economic properties, and environmental properties as the most critical properties in selecting materials. However, the social aspects were mainly not considered in this research. Akadiri and Olomolaiye [19] developed a set of 24 sustainability criteria for building material selection. These criteria are categorized into three groups of socio-economic factors, environmental factors, and technical factors. Ogunka and Yang [20] defined a set of sustainability criteria by using questionnaires. Their survey pointed out that Environmental and Health factors and Technical factors are the most relevant considered variables when integrating sustainability into material selection. These articles are useful references, but their criteria were built based on the viewpoint of developed countries. Developing countries face many specific challenges, such as the shortage of capital and low capacity or devastating natural resources.

A material selection approach based on experience is bound to make more mistakes than employing numerical methods because architects' experience is limited, and available alternatives cannot be compared clearly without specific values or numbers. Kloepffer [12] proposed a numerical method called LCSA based on the summed up results of three life cycle approaches (see section 1). The LCSA equation is transparent and seems to be a logical approach. It also extends the scope of a standard LCA by integrating LCC and Social LCA to have more sustainable products [21]. However, this method has its weaknesses. Because the LCC, LCA, and SLCA methods can be applied independently, it is necessary to investigate their mechanisms and relationships [22]. The classifications between economic, social, and environmental aspects are not clear, so double-counting and overlapping may happen. In the basic form, weightings are not explicitly included. However, as suggested by Bachmann [23], the weightings can be included to interpret the results in specific decision-making situations. Therefore, this article considers the relevance of criteria and sustainability dimensions that may raise the necessity to involve weightings in the LCSA equation for construction material selection.

One promising method for determining importance weightings being suggested in the LCSA context as well is the AHP method [24-27]. The AHP is a structured technique used by decision-makers and researchers to analyze and organize complex decisions. This technique was developed by Thomas L. Saaty in the early 1970s [28], and it has been applied in many different fields such as planning, alternative selection, resource allocation, and logistics [29]. The AHP method employs an Eigenvalue approach with pair-wise comparisons. In these comparisons, a nine-point scale ranging from 1 (equal importance) to 9 (absolutely dominating) is utilized [30]. The comparisons' results are further processed for measuring the significance or performance of objects [29, 31]. In the case of criteria for the decision-making, the weightings represent the relative importance of each criterion.

Applying sustainability in the construction industry has many obstacles and barriers. Suliman and Omran [32] discussed the difficulties experienced in the implementation of sustainable construction. They pointed out that the lack of awareness, training and education, ineffective procurement systems, existing public policies, and regulatory frameworks are the key obstacles in sustainable construction. In addition, Othman [33] came up with four key challenges that institutions in developing countries face when selecting sustainable construction products. These challenges contain technical problems, human development, management, and policies. Therefore, selecting sustainable materials in developing countries needs many efforts. Akadiri [19] conducted a questionnaire survey to identify the main barriers encountered in selecting sustainable building materials in Nigeria. The results indicate that the "perception of the extra cost being incurred" is the top critical obstacle because there were limits on construction projects' budgets, and architects tended to assume that sustainable materials were expensive.

This literature review reveals that sustainability criteria were suggested according to developed countries' contexts and scenarios. Therefore, no comprehensive and complete lists of sustainability criteria have been created to facilitate construction material selection in developing countries. This article contributes to closing this gap by deriving a list of sustainability criteria based on the triple bottom line approach by utilizing a questionnaire survey with participants in Vietnam to rank the importance of these criteria. Therefore, their importance weightings were calculated based on the AHP method. Finally, the most critical obstacles were identified and ranked.

3. RESEARCH METHODOLOGY

The research methodology in this article includes a questionnaire, survey, and data analysis.

3.1 Questionnaire design

After reviewing the previous sources, an initial questionnaire was designed. The questionnaire included four main parts, each focusing on investigating the reality for applying sustainability criteria in construction material selection in developing countries. The first part of the questionnaire investigated the respondents' profession and experience. The second one requested the respondents to rank the frequency and reality of applying sustainability criteria in construction material selection in Vietnam. The last two sections asked the respondents to evaluate the importance of sustainability criteria (Table 1) in construction material selection and identify the obstacles (Table 2) impacting construction material selection. The criteria and questions were described as clearly as possible, and the most important parts were part three and part four. Besides, the respondents were free to add more criteria where necessary.

3.2 Questionnaire

The lists in Tables 1 and 2 were arranged in a questionnaire before being sent to the respondents. Vietnam was selected as a case study because it has all the characteristics of a developing country. The questionnaires, together with a letter and a stamped addressed envelope, were sent to 102 selected practitioners in the construction industry in Vietnam via emails. The practitioners included 33 architects and 69 designers responsible for selecting suitable construction materials in the planning and design phase. The respondents' contact information was obtained from several sources, including the author's relationships, company phonebook databases, and information about construction projects. This group of practitioners covers different experiences and positions in material selection processes. Gathering information from these two respondent categories contributes to the reliability of the questionnaire results.

Table 1. The list of sustainability criteria

ID	Sustainability criteria	References	Interpretation
A	**Economic criteria**		
A1	Price of materials	[18, 34-37]	"Price of material" is the price when the contractors or sponsors order from the suppliers. This study assumes that the material price covers the costs of the material extraction and manufacturing phases.
A2	Cost in the material transport	[18, 35, 38]	"Cost of the material transport" includes the costs of vehicles, trains, or ships in the material transportation process.
A3	Cost in the construction phase	[18, 35-37]	"Cost in the construction phase" contains the costs of labor, energy, water, or equipment in the construction area.
A4	Cost in operation and maintenance phase	[34-38]	"Cost in operation and maintenance phase" includes the costs of fixing or replacing materials.
A5	Cost in the demolition phase	[18, 34-37]	"Cost in the demolition phase" covers the costs of deconstruction or dismantling.
B	**Environmental criteria**		
B1	Energy consumption	[18, 34-36, 38, 39]	"Energy consumption" represents electricity or fuel consumed by construction equipment. The construction equipment needs gas or electricity in operation.
B2	Water consumption	[35, 36, 39, 40]	"Water consumption" criterion represents the amount of water consumed by laborers or construction equipment.
B3	Global warming	[35, 36, 41, 42]	"Global warming" causes the earth's temperature increase, which causes climate change. This criterion is represented by greenhouse gases emission (e.g., CO_2)
B4	Waste production management	[18, 36, 38, 39]	"Waste production management" is the management of waste production. The number of recycling scraps represents this criterion.
B5	Toxic emission	[18, 34, 35, 39, 42]	"Toxic emission" is the emission of poisons to the environment when using the construction material. Construction materials have many volatile organic compounds and poison chemicals.
B6	Natural resources depletion	[18, 35]	Construction materials are natural resources such as steel, wood, or oil. It makes the number of natural resources decrease.
B7	Acidification of land and water	[35, 41]	Construction material may emit chemical poison (e.g., SO_2, NO_x, H_2S,..) into land or water.
B8	Potential in recycling and reuse materials	[34-36, 42]	"Potential in recycling and reuse materials" refers to the recyclability of the construction material.
C	**Social criteria**		
C1	Safety in construction and operation	[34-36, 42]	In the construction site, safety is the priority, and it must be ensured for workers, residents, and clients.
C2	The health of laborers and residents	[34-36, 38, 42]	Some materials emit chemical poisons, which may harm the health of laborers and residents.
C3	Labor availability	[34, 36, 37]	The construction works may use many local laborers.
C4	Aesthetics	[20, 35-37]	The materials meet not only technical requirements but also aesthetic attributes. These attributes are intangible qualities of materials.
C5	Traffic congestion	[43]	The construction works may result in traffic congestion.

Table 2. The list of obstacles

ID	Obstacles	References
O1	Lack of environmental and social database for material selection	[14, 19]
O2	Restricted availability of sustainable materials for the construction industry	[44, 45]
O3	Lack of education, awareness, and knowledge about sustainable materials	[14, 19, 32, 45]
O4	Lack of affordable software or toolkits in material selection	[14, 19, 45]
O5	The sponsors only focus on economic criteria	[14, 45]
O6	Lack of government policy supports	[14, 32]
O7	Lack of client's demand and awareness	[14, 45]
O8	No culture for sustainable construction	[32, 44]
O9	Refuse to change the conventional criteria in material selection and construction methods	[19, 32]
O10	The evaluation is too complex	[14, 45]
O11	Risks in higher initial cost, total cost, and extra time	[14, 44]

After gathering results from the questionnaires and conducting data analysis, three experts were selected to review the results. These experts were chosen because of their rich experience in material selection and project management to achieve a high significance of the criteria list and their rankings. They were asked to reassess all the selected criteria as well as obstacles and the reliability of the questionnaire. They also checked the results for plausibility.

3.3 Data analysis

The results received from parts one and two of the questionnaire were analyzed based on descriptive statistics. Those from parts three and four were analyzed using SPSS software and ranked by Relative Index (RI) analysis. After that, the AHP method was used to evaluate the weightings of the criteria.

Cronbach's alpha was evaluated by SPSS software to test the reliability of the generated scale. The alpha (α) coefficient ranges typically between 0 and 1. The closer the alpha is to 1, the greater the significance of the results. The generally accepted lowest limit of Cronbach's alpha coefficient is 0.70 [46].

RI analysis was selected in this study to rank the criteria and obstacles according to their relative importance. The relative importance index analysis (RI) was computed using the formula below:

$$RI = \frac{\sum w}{A * N} \quad (3)$$

where, w is the weighting as assigned by each respondent on a scale of 1 to 5, with one implying the lowest and five the highest; A is the highest weight (it is 5 in this case); and N is the sample's total number. According Chen [47] and Akadiri [34], five important levels are transformed and assessed from RI values: high (H) ($0.8 \leq RI \leq 1$), Higher average (H–A) ($0.6 \leq RI < 0.8$), Average (A) ($0.4 \leq RI < 0.6$), lower average (L–A) ($0.2 \leq RI < 0.4$), and low (L) ($0 \leq RI < 0.2$).

The AHP method was applied to calculate the weightings. *First*, the results were transformed from a 5-point scale to a 9-point scale by IBM's equation below [48]:

$$Y = \frac{(B-A)(x-a)}{(b-a)} + A \quad (4)$$

where, Y represents the new value; x represents the current value; A and B represent the new minimum and maximum points, respectively; and a and b are the current minimum and maximum points, respectively. *Second*, the relative index was recalculated to define the relative importance, and *finally*, the results were applied in the AHP method to calculate the importance weightings. Many authors combined the Likert Scale and the AHP method to calculate weightings [49-52]. In this research, the AHP method included four main steps: First, hierarchy formation, which involved the criteria, needed segmentation, and hierarchical structuring. The LCSA target can be divided into LCC, LCA, and social LCA targets. Then, the LCC target (economic aspects) can also be divided into economic criteria. Similarly, the LCA goal (environmental aspects) can be categorized into environmental criteria, and the SLCA target (social aspects) can be specified by different categories including social criteria. Second, pair-wise comparison, which involved estimating and quantifying the relative importance of every criterion. Third, calculating, which involved the calculation of local priority vectors (weighting vector) for every pair-wise comparison matrix [53]. Fourth, consistency checking by examining the consistency of the priority assessment according to a value of consistency [30].

4. ANALYSIS RESULTS

Only 62 useful completed questionnaires were received from the respondents, resulting in a response rate of 60.78 percent. The results showed that 100 percent of respondents agree that the integration of sustainability criteria in Vietnam's material selection is crucial. Part two represented the differences in evaluating economic criteria, environmental criteria, and social criteria. The results in Figure 1 show that economic criteria were considered more regularly than environmental and social criteria. The average value for the frequency of evaluating economic criteria was 4.39, which is near the scale of "always." The frequencies of assessing social and environmental criteria were 3.58 and 3.6, respectively.

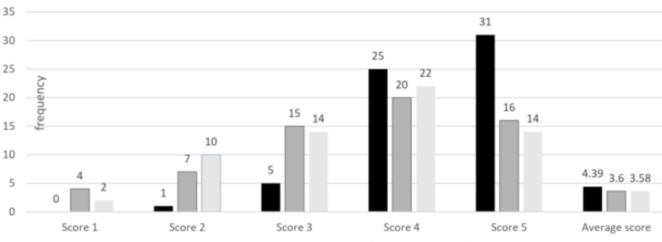

Figure 1. The results of evaluating the frequency of considering economic, environmental, and social criteria

The results of parts three and four were then fed into SPSS software, and Cronbach's alpha was calculated to test their reliability. In part three, Cronbach's alpha values for all criteria, economic criteria, environmental criteria, and social criteria, were 0.913, 0.814, 0.886, and 0.859. All alpha values were greater than 0.7, indicating that all the reliability coefficients were acceptable. Similarly, the Cronbach's alpha value for the obstacles was 0.839, which means that this reliability coefficient was acceptable. As a result, the internal consistency of the criteria included in the scale was suitable for the next analysis processes.

The relative index analysis in Eq. (3) was used to rank the criteria. Tables 3 and 6, and appendix 1-4 show the ranking results for each criterion and obstacle.

In part three, after ranking the criteria, the results showed that 2 out of the 18 criteria were marked as of "high" importance in the material selection, with RI values higher than 0.8. These two criteria were "price of material" and "aesthetics." Environmental criteria were not ranked as "high" because their RI values ranged between 0.6290 and 0.7387. This implies that architects and designers in Vietnam do not focus on environmental criteria in construction material selection. In general, all criteria were ranked higher than 0.6 and were marked as "higher average," meaning that they play or should play an essential role in integrating sustainability into construction material selection.

For economic criteria, the "price of material" was ranked as the most critical criterion. It was then followed by "cost of the material transport," with a value of 0.7806. For environmental criteria, "waste production management" criterion was ranked as the first with a RI value of 0.7387, and "potential in recycling and reuse materials" criterion was the second. When it came to social criteria, "aesthetic" was rated as the first compared to other social criteria, and "safety in construction and operation" was considered the second with a RI value of 0.7935. The RI values of the other criteria are presented in Table 3.

Table 3. Ranking and weightings of the sustainability criteria

ID	Sustainability criteria	Percentage of the score					Relative index	Ranking by category	Overall ranking	Importance level	Weightings
		1	2	3	4	5					
A	**Economic criteria**	**-**	**-**	**3.23**	**33.87**	**62.90**	**0.9193**				**42.06**
A1	Price of materials	0.00	1.61	12.90	46.77	38.71	0.8452	1	1	High	23.04
A2	Cost of material transport	3.23	3.23	14.52	58.06	20.97	0.7806	2	4	Higher average	21.04
A3	Cost in the construction phase	3.23	11.29	17.74	46.77	20.97	0.7419	3	7	Higher average	19.84
A4	Cost in operation and maintenance phase	6.45	16.13	19.35	38.71	19.35	0.6968	4	12	Higher average	18.44
A5	Cost in the demolition phase	3.23	20.97	29.03	30.65	16.13	0.6710	5	14	Higher average	17.64
B	**Environmental criteria**	**1.61**	**12.90**	**38.71**	**35.48**	**11.29**	**0.6838**				**29.96**
B1	Energy consumption	3.23	16.13	25.81	37.10	17.74	0.7000	3	10	Higher average	12.88
B2	Water consumption	6.45	17.74	30.65	30.65	14.52	0.6581	6	16	Higher average	11.98
B3	Global warming	14.5	22.58	16.13	27.42	19.35	0.6290	8	18	Higher average	11.34
B4	Waste production management	4.84	9.68	17.74	46.77	20.97	0.7387	1	8	Higher average	13.7
B5	Toxic emission	6.45	16.13	17.74	40.32	19.35	0.7000	3	10	Higher average	12.87
B6	Natural resources depletion	9.68	19.35	14.52	38.71	17.74	0.6710	5	14	Higher average	12.24
B7	Acidification of land and water	11.2	16.13	27.42	30.65	14.52	0.6419	7	17	Higher average	11.62
B8	Potential in recycling and reuse materials	8.06	8.06	19.35	43.55	20.97	0.7226	2	9	Higher average	13.37
C	**Social criteria**	**4.84**	**16.13**	**40.32**	**29.03**	**9.68**	**0.6451**				**27.98**
C1	Safety in construction and operation	3.23	3.23	17.74	45.16	30.65	0.7935	2	3	Higher average	18.67
C2	The health of laborers and residents	4.84	1.61	24.19	43.55	25.81	0.7677	3	5	Higher average	18.66
C3	Labor availability	8.06	1.61	25.81	35.48	29.03	0.7516	4	6	Higher average	19.33
C4	Aesthetics	0.00	4.84	20.97	33.87	40.32	0.8194	1	2	High	23.59
C5	Traffic congestion	14.5	8.06	25.81	29.03	22.58	0.6742	5	13	Higher average	19.75

After analyzing and ranking the criteria, the AHP method was applied to calculate the importance of weightings in the LCSA equation. First, the 5-point scale was transformed to a 9-point scale based on Eq. (4):

$$Y = (9 - 1) \times (X - 1)/(5 - 1) + 1 = 2X - 1 \qquad (5)$$

where, Y represents the new value, x represents the current one. Hence, the results of the questionnaire were converted to a 9-point scale, according to Eq. (5), and then their RI was recalculated. After that, the hierarchy of all criteria was built (see Figure 2), and the pair-wise comparison matrix was calculated according to their new indexes (see Table 4).

Table 4. Pair-wise comparison matrix of criteria, environmental, and social criteria

	Economic criteria (T1)	**Environmental criteria (T2)**	**Social criteria (T3)**
Economic criteria (T1)	1	1.4033	1.5029
Environmental criteria (T2)	0.7126	1	1.071
Social criteria (T3)	0.6654	0.9337	1

After that, the weightings of each criterion were calculated by normalization, and the results are illustrated in Table 5.

The VOC value of the weightings was 6.83x10^{-8} and lower than 0.1. Therefore, the equation of LCSA in the case of Vietnam is proposed as below:

$$LCSA=42.06*LCC+29.96*LCA+27.98*SLCA \quad (6)$$

Eq. (6) added the additional "average" weightings compared to the original LCSA equation (Eq. (1)). The original one estimated the LCSA value equally, while the weightings emphasize the importance of economic, environmental, and social performances based on specific conditions. Eq. (6) showed that the economic aspect's role is much higher than environmental and social's, and contributions of environmental and social's faces are nearly the same. Each LCA applicant can determine the weightings, but defining them based on a fundamental theory may increase the significance. Furthermore, construction projects need a huge budget, so the determination is also reviewed by a board of experts who require a theoretical basis in selection. In essence, if applying the importance weightings achieved by the survey, the LCC result accounts for 42.06% of the LCSA result when the LCA and SLCA values are responsible for 29.06% and 27.98% of the LCSA outcome, respectively. The results show that it is meaningful to replace Eq. (1) by Eq. (2) because of the different importance levels of LCC, LCA, and social LCA results in specific conditions.

Similarly, the importance weightings of the other sub-criteria were evaluated and illustrated in Table 3 and appendix 5-7. These weightings show the relevance of the single criteria (and can be used to calculate individual LCC, LCA, and SLCA values).

In *part four*, after ranking the obstacles, 4 out of 11 problems were marked as of "high" importance, with RI values higher than 0.8. They include "The sponsors only focus on economic criteria", "Lack of client's demand and awareness", "No culture for sustainable construction," and "Risks in higher initial cost, total cost, and extra time." The other seven problems were ranked as "high average" importance levels, with their RI values ranging between 0.7935 and 0.7258 (Table 6).

After getting the results, three experts were selected to review them. These are experienced experts with more than 15 years of working in construction projects in Vietnam. They concluded that the lists of criteria and barriers were acceptable, and the weightings were plausible.

The questionnaire results pointed out that Vietnamese designers and architects want to integrate sustainability criteria into construction material selection. However, they prioritize the economic aspect over the environmental and social ones. The list of sustainability criteria was created and evaluated by the respondents. In addition, the weightings of economic, environmental, and social criteria, together with their sub-criteria, were calculated. The weighting calculation method was proposed by integrating the Likert scale and the AHP method. Such weightings should complement the LCSA method. After that, the obstacles in integrating sustainability criteria into construction material selection were surveyed.

Table 5. Normalization and weighting calculation

	Normalized T1	**Normalized T2**	**Normalized T3**	**Average**	**Weightings**	**Consistency**
T1	0.420529801	0.420529801	0.420529801	0.4206	**42.06**	2.999431669
T2	0.299668874	0.299668874	0.299668874	0.2996	**29.96**	3.000622007
T3	0.279801325	0.279801325	0.279801325	0.2798	**27.98**	2.999946562
			CI= 0.00000004			RI=0.58000000
			C. Ratio=			**6.83E-08**

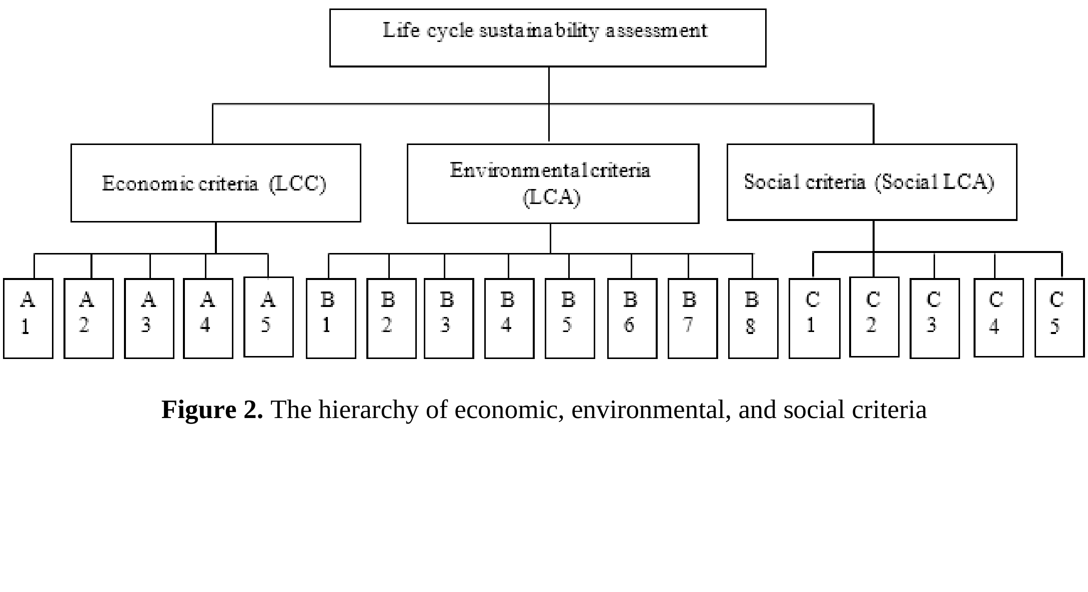

Figure 2. The hierarchy of economic, environmental, and social criteria

Table 6. Ranking the obstacles

Number	Obstacles	Percentage of the score 1	2	3	4	5	Relative index	Ranking	Importance level
O1	Lack of environmental and social database for material selection	4.84	3.23	27.42	40.32	24.19	0.7516	8	Higher average
O2	Restricted availability of sustainable materials for the construction industry	4.84	9.68	29.03	30.65	25.81	0.7258	11	Higher average
O3	Lack of affordable software or toolkits in material selection	3.23	4.84	24.19	40.32	27.42	0.7677	6	Higher average
O4	Lack of specific models, methods or toolkits in material selection	1.61	1.61	33.87	40.32	22.58	0.7613	7	Higher average
O5	The sponsors only focus on economic criteria	0.00	3.23	17.74	41.94	37.10	0.8258	1	High
O6	Lack of government policy supports	0.00	6.45	20.97	41.94	30.65	0.7935	5	Higher average
O7	Lack of client's demand and awareness	0.00	1.61	20.97	45.16	32.26	0.8161	2	High
O8	No culture for sustainable construction	0.00	0.00	22.58	53.23	24.19	0.8032	4	High
O9	Refuse to change the conventional criteria in material selection and construction methods	1.61	11.29	30.65	32.26	24.19	0.7323	10	Higher average
O10	The evaluation is too complex	4.84	1.61	37.10	33.87	22.58	0.7355	9	Higher average
O11	Risks in higher initial cost, total cost and extra time	4.84	1.61	11.29	45.16	37.10	0.8161	2	High

5. DISCUSSION

This study sought to build a comprehensive list of sustainability criteria in construction material selection adopted by developing countries. The results revealed a list of sustainability criteria and obstacles encountered in material selection. One result is that designers and architects want to integrate environmental and social aspects into material selection.

This study reviewed previous studies and researches in its quest to develop a list of sustainability criteria that reflect the specific situation of developing countries (assuming Vietnam to be a representative country). After that, the list was sent to 102 architects and designers, and then the results were analyzed. The importance weightings of Life Cycle Sustainability Assessment were also evaluated according to the questionnaires' results using the Likert scale and the AHP method. The weightings of LCC, LCA, and Social LCA methods were found to be 42.06, 29.96, and 27.98, respectively. It means that the consideration of importance weightings is crucial, and the paper offers a methodology for estimating these weightings. Further, the obstacles that impact the integration of sustainability criteria and material selection were considered. Eleven problems were surveyed, and all of them were ranked with RI values higher than 0.6, meaning that they are the main barriers.

6. CONCLUSION

This paper presented a review of the current reality of construction material selection in Vietnam as an example for developing countries. The results reveal that architects and designers often focus on the economic criteria, while environmental aspects and social aspects are underestimated. The LCSA method, which integrates economic, environmental, and social aspects into decision making, is instrumental in ascertaining the sustainability in construction material selection. The lists of sustainability criteria, their weightings, and possible obstacles were created from a survey questionnaire and the Likert scale.

This research has several limitations. First, the research subjects were only architects and designers. Other relevant stakeholders in the construction industry, such as sponsors, contractors, and clients, were not considered in this research. Second, this study only concentrated on one developing country. Third, the weightings were evaluated using the AHP method; therefore, problems associated with the AHP method were inevitable. Further research applying the Life Cycle Sustainability Assessment method for material selection in developing countries should focus on: First, broadening the analysis to include the opinions of sponsors, contractors, and clients on integrating sustainability criteria in material selection. Second, developing a comprehensive method of evaluating different material alternatives concerning economic, ecological, and social targets as well as their importance weightings with regard to sustainability.

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APPENDIX

Appendix 1. Frequency of economic, environmental, and social criteria

ID	Sustainable criteria	Percentage of the score									
		1		2		3		4		5	
		Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
A	**Economic criteria**										
A1	Price of materials	0	0.00	1	1.61	8	12.90	29	46.77	24	38.71
A2	Cost of the material transport	2	3.23	2	3.23	9	14.52	36	58.06	13	20.97
A3	Cost in the construction phase	2	3.23	7	11.29	11	17.74	29	46.77	13	20.97
A4	Cost in the operation and maintenance phase	4	6.45	10	16.13	12	19.35	24	38.71	12	19.35
A5	Cost in the demolition phase	2	3.23	13	20.97	18	29.03	19	30.65	10	16.13
B	**Environmental criteria**										
B1	Energy consumption	2	3.23	10	16.13	16	25.81	23	37.10	11	17.74
B2	Water consumption	4	6.45	11	17.74	19	30.65	19	30.65	9	14.52
B3	Global warming	9	14.52	14	22.58	10	16.13	17	27.42	12	19.35
B4	Waste production management	3	4.84	6	9.68	11	17.74	29	46.77	13	20.97
B5	Toxic emission	4	6.45	10	16.13	11	17.74	25	40.32	12	19.35
B6	Natural resources depletion	6	9.68	12	19.35	9	14.52	24	38.71	11	17.74
B7	Acidification of land and water	7	11.29	10	16.13	17	27.42	19	30.65	9	14.52
B8	Potential in recycling and reuse materials	5	8.06	5	8.06	12	19.35	27	43.55	13	20.97
C	**Social criteria**										
C1	Safety in construction and operation	2	3.23	2	3.23	11	17.74	28	45.16	19	30.65
C2	Health of labors and local residents	3	4.84	1	1.61	15	24.19	27	43.55	16	25.81
C3	Labor availability	5	8.06	1	1.61	16	25.81	22	35.48	18	29.03
C4	Aesthetics	0	0.00	3	4.84	13	20.97	21	33.87	25	40.32
C5	Traffic congestion	9	14.52	5	8.06	16	25.81	18	29.03	14	22.58

Appendix 2. The relative index of questions I1, I2, I3, I4, I5

ID	Job	exp	Do you want to integrate sustainability criteria in the material selection?	You evaluate economic criteria when you select the material	You evaluate environmental criteria when you select the material	You evaluate social criteria when you select the material	You use software or toolkits in evaluating economic criteria when you select the material	You use software or toolkits in evaluating environmental criteria when you select the material
ID	**job**	**exp**	**int**	**I1**	**I2**	**I3**	**I4**	**I5**
1	1	1	2	4	4	4	3	3
2	1	1	2	5	4	4	5	5
3	2	2	2	5	3	3	1	1
4	2	2	2	5	3	3	5	1
...	...	...	...	...	...	...	...	...
62	1	3	2	3	2	4	2	2
Relative Index	**0.87741935**	**0.719354839**	**0.71612903**	**0.567741935**	**0.448387097**			

Appendix 3. The relative index of sustainability criteria and obstacles

Number	Sustainability criteria	Relative index
A	**Economic criteria**	
A1	Price of materials	0.8452
A2	Cost of material transport	0.7806
A3	Cost in the construction phase	0.7419
A4	Cost in operation and maintenance phase	0.6968
A5	Cost in the demolition phase	0.6710
B	**Environmental criteria**	

Number	Sustainability criteria	Relative index
B1	Energy consumption	0.7000
B2	Water consumption	0.6581
B3	Global warming	0.6290
B4	Waste production management	0.7387
B5	Toxic emission	0.7000
B6	Natural resources depletion	0.6710
B7	Acidification of land and water	0.6419
B8	Potential in recycling and reuse materials	0.7226
C	**Social criteria**	
C1	Safety in construction and operation	0.7935
C2	The health of laborers and residents	0.7677
C3	Labor availability	0.7516
C4	Aesthetics	0.8194
C5	Traffic congestion	0.6742
O	**Obstacles**	
O1	Lack of environmental and social database in material selection	0.7516
O2	There are not many sustainable materials in the construction industry	0.7258
O3	Lack of education, awareness and knowledge about sustainable materials	0.7677
O4	Lack of specific models, methods or toolkits in material selection	0.7613
O5	The sponsors only focus on economic criteria	0.8258
O6	Lack of government policy supports	0.7935
O7	Lack of client demand and awareness	0.8161
O8	No culture for sustainable construction	0.8032
O9	Refuse to change the conventional method in material selection	0.7323
O10	The evaluation is too complex	0.7355
O11	Risks in the higher total cost and extra time	0.8161

Appendix 4. Frequency of obstacles

Number	Obstacles	Percentage of the score									
		1		2		3		4		5	
		Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
O1	Lack of environmental and social database in material selection	3	4.84	2	3.23	17	27.42	25	40.32	15	24.19
O2	There are not many sustainable materials in the construction industry	3	4.84	6	9.68	18	29.03	19	30.65	16	25.81
O3	Lack of education, awareness and knowledge about sustainable materials	2	3.23	3	4.84	15	24.19	25	40.32	17	27.42
O4	Lack of specific models, methods or toolkits in material selection	1	1.61	1	1.61	21	33.87	25	40.32	14	22.58
O5	The sponsors only focus on economic criteria	0	0.00	2	3.23	11	17.74	26	41.94	23	37.10
O6	Lack of government policy supports	0	0.00	4	6.45	13	20.97	26	41.94	19	30.65
O7	Lack of client demand and awareness	0	0.00	1	1.61	13	20.97	28	45.16	20	32.26
O8	No culture for sustainable construction	0	0.00	0	0.00	14	22.58	33	53.23	15	24.19
O9	Refuse to change the conventional method in material selection	1	1.61	7	11.29	19	30.65	20	32.26	15	24.19
O10	The evaluation is too complex	3	4.84	1	1.61	23	37.10	21	33.87	14	22.58
O11	Risks in higher total cost and extra time	3	4.84	1	1.61	7	11.29	28	45.16	23	37.10

Appendix 5. Weightings of economic sub-criteria

	Normalized A1	Normalized A2	Normalized A3	Normalized A4	Normalized A5	Average	Weighting
A1	0.2303	0.2303	0.2303	0.2303	0.2303	0.2304	**23.04**
A2	0.2104	0.2104	0.2104	0.2104	0.2104	0.2104	**21.04**
A3	0.1984	0.1984	0.1984	0.1984	0.1984	0.1984	**19.84**
A4	0.1844	0.1844	0.1844	0.1844	0.1844	0.1844	**18.44**
A5	0.1765	0.1765	0.1765	0.1765	0.1765	0.1764	**17.64**

Appendix 6. Weightings of economical sub-criteria

	Nor B1	Nor B2	Nor B3	Nor B4	Nor B5	Nor B6	Nor B7	Nor B8	Average	Weighting
B1	0.1287	0.1287	0.1287	0.1287	0.1287	0.1287	0.1287	0.1287	0.1288	**12.88**
B2	0.1197	0.1197	0.1197	0.1197	0.1197	0.1197	0.1197	0.1197	0.1198	**11.98**
B3	0.1135	0.1135	0.1135	0.1135	0.1135	0.1135	0.1135	0.1135	0.1134	**11.34**
B4	0.1370	0.1370	0.1370	0.1370	0.1370	0.1370	0.1370	0.1370	0.137	**13.7**
B5	0.1287	0.1287	0.1287	0.1287	0.1287	0.1287	0.1287	0.1287	0.1287	**12.87**
B6	0.1225	0.1225	0.1225	0.1225	0.1225	0.1225	0.1225	0.1225	0.1224	**12.24**
B7	0.1163	0.1163	0.1163	0.1163	0.1163	0.1163	0.1163	0.1163	0.1162	**11.62**
B8	0.1336	0.1336	0.1336	0.1336	0.1336	0.1336	0.1336	0.1336	0.1337	**13.37**

Appendix 7. Weightings of social sub-criteria

	Normalized C1	Normalized C2	Normalized C3	Normalized C4	Normalized C5	Average	Weighting
C1	0.1867	0.1669	0.1763	0.1965	0.2069	0.1867	**18.67**
C2	0.2078	0.1857	0.1640	0.1828	0.1924	0.1866	**18.66**
C3	0.2028	0.2169	0.1915	0.1733	0.1824	0.1933	**19.33**
C4	0.2239	0.2394	0.2604	0.2356	0.2202	0.2359	**23.59**
C5	0.1787	0.1911	0.2078	0.2118	0.1980	0.1975	**19.75**