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Multi-Criteria Ranking of Green Materials According to the Goals of Sustainable Development

Amirhossein Balali [1], Alireza Valipour [1,*], Edmundas Kazimieras Zavadskas [2,*] and Zenonas Turskis [2]

[1] Department of Civil Engineering, Shiraz Branch, Islamic Azad University, Shiraz 5-71993, Iran; a.balali@iaushiraz.ac.ir

[2] Institute of Sustainable Construction, Vilnius Gediminas Technical University, LT–10223 Vilnius, Lithuania; zenonas.turskis@vgtu.lt

* Correspondence: vali@iaushiraz.ac.ir (A.V.); edmundas.zavadskas@vgtu.lt (E.K.Z.)

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Abstract: Modern, well-educated and experienced policy-makers support and promote the use of environmentally friendly materials and resources. The use of green resources is an exceptional and inevitable strategy to meet the needs of a rapidly growing Earth population. The growing population raises the need for new housing construction and urban infrastructure development. Such substances in construction refer to green building materials (GBMs). The environmental impact is lower if GBMs replace non-GBMs. Here, ranking among GBMs can facilitate and support the selection process. This study aimed to contribute to the body of knowledge to introduce a method for identifying and prioritizing GBMs in the construction industry to use in green building. The required data were collected using existing literature, interviews and questionnaires. Relevant Sustainable Development Goals (SDGs) are the first criteria for assessing GBM selection criteria. Critical weighted GBM selection criteria are the second criteria for prioritizing GBMs. The results show that "Natural, Plentiful and Renewable", "Affordability from cradle to gate" and "Affordability during operation" are the top three GBM selection criteria. The real case study helped select "Stramit Strawboard", "Aluminium Composite Panels (ACPs)" and "Solar Roof Tiles" as the most suitable GBMs for use in the context of the study. The model and results presented in this study will help actors of the construction industry to select and use GBMs more quickly and thus achieve a better level of construction sustainability, as well as environmental friendliness, than before.

Keywords: green building materials (GBMs); building industry; Sustainable Development Goals (SDGs); construction industry; MCDM; SWARA method; COPRAS method; real case study

1. Introduction

The vast majority of human activities in the modern world affect the environment. In most cases, this is a negative factor. It is essential to find the best solutions that cause the least possible conflict between people's wellbeing, their activities and the environment instead of looking for answers to such disputes [1]. Buildings are an integral part of all societies as they provide housing for people. Unfortunately, the building sector is known as one of the biggest energy-consuming sectors, and exploiting energy contributes to global climatic change and other environmental issues [2,3]. Previous studies illustrated that the building sector is responsible for consuming over 40% of the total final energy, using approximately 30% of the total resources, producing 45–65% of the waste disposed to landfills and emitting more than 30% of the greenhouse gases in developed countries [4–9].

Although constructing buildings results in environmental issues, there are some ways to decrease its negative impacts. One of the ways to achieve this goal is to consider sustainability in various parts of a building project. According to the definition of the United Nations' World Commission on Environment and Development (WCED) in 1987, sustainability is "development that meets the needs of the present without comprising the ability of the future generation to meet their own needs". The given definition can be thus linked to the low cost of operation and maintenance (O & M), long service life and high energy efficiency as pillars of a sustainable and green building [10].

The consideration of sustainability in the construction industry has delivered some valuable benefits by reducing the extensive impact on the environment through the use of renewable energy, analysing the consequences of design choices over the entire building life cycle, revised energy codes and low environmental impact materials [11]. Low environmental impact materials, also known as green building materials (GBMs), are widely used in the construction industry in order to alleviate the negative impacts of constructing buildings [12].

These materials are usually considered environmentally friendly and environmentally responsible [13,14]. GBMs not only promote health but also help in meeting sustainability goals [15]. Generally, various definitions of greenness in building materials can be summarised into possessing two main concepts, including "being sustainable during whole life-cycle" and "not being hazardous for human health". The former concept can be quantified by the life-cycle assessment (LCA) methodology, in a "cradle to grave" perspective [16]. With regards to the latter concept, GBMs must not lead to indoor types of pollutions constituting radon emissions, biological pollutions, uncomfortable indoor climate conditions and hazardous fibre dispersion [17,18]. Exploiting GBMs in the construction industry results in achieving Sustainable Development Goals (SDGs) in both direct and indirect ways. SDGs are discussed in the next paragraphs.

Sustainable Development Goals (SDGs) consist of 17 primary goals and 169 targets in various parts of sustainability. The mentioned goals are illustrated in Figure 1 [19–22].

Figure 1. Sustainable Development Goals (SDGs) [21].

Some of the SDGs are directly or indirectly related to the construction industry. For instance, Goal 11 is about sustainable cities and communities. Figure 2 illustrates the targets of this goal, which show a sensible relationship [21,23]. The construction industry consumes a large amount of natural resources, water, energy and materials; it can have a dramatic impact on achieving SDGs and some of the global challenges such as climate change, health and wellbeing [24,25]. The World Green Building Council (WGBC) illustrated how using GBMs can help the construction industry to attain SDGs. The mentioned contribution is illustrated in Figure 3 [26].

11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums

11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons

11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries

11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage

11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations

11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities

11.A Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning

11.B By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels

11.C Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials

Figure 2. Targets of SDG 11 [21].

SGDs are less considered in all the fields and especially in the construction industry of Iran. An extensive study was conducted through the existing literature in order to find papers that are relevant to SDGs, but only a few were found, and no relevant studies on GBMs within Iran could be identified.

To be able to select the optimum GBM for use in the construction industry, GBM selection criteria are required. Various studies have been conducted to introduce such criteria since 2009 [14,27]. Khoshnava et al. identified GBM's selection criteria using three pillars of sustainability in 2018. According to their findings, the mentioned criteria can be divided into five critical categorisations by considering their characteristics. These categorisations were AF (Affordability), WC (Water Efficiency), EE (Energy Efficiency), IAQ (Indoor Air Quality) and RE (Resource Efficiency), which stand for Affordability, Water Conservation, Energy Efficiency, Indoor Air Quality and Resource Efficiency, respectively [12]. Figure 4 illustrates this categorisation.

Mokal et al. studied the advantages, disadvantages, durability and economic impacts of various GBMs consisting of lime, sand-lime bricks, eco-friendly tiles, coloured lime plaster and reflectasol glass, concluding that GBMs reduce the adverse effects on construction projects [28]. Chauhan and Kamboj (2016) identified different means and needs to go green in the world's construction industry and found that exploiting green materials in the mentioned industry plays an important role in bringing benefits to both humans and the environment [29]. Another study was conducted in order to assess the relative fungal resistance of four pairs of GBMs. It was illustrated that the presence of organic matter in GBMs plays a significant role in their environmental impacts [30].

The general lack of related studies in the context of Iran and the absence of available GBMs makes it hard for regional comparison conceptually and the local industry practices to embrace sustainable practices in the material selection. Therefore, this paper aims to identify GBMs as well as rank them in the construction industry of Shiraz, Iran. The novelty of this study is that two groups of selection criteria were being used together to conduct this ranking. The first group of selection criteria was SDGs. Both relevant SDGs and the existing GBM selection criteria, which exist in the literature, were used to weight selection criteria. Then, these weighted criteria were exploited to rank GBMs. The SWARA and the COPRAS methods were used as the data analysing tools due to their success in solving complex decision-making problems. The findings of this study can be widely used by designers, engineers, managers and contractors in the construction industry in both existing and new buildings.

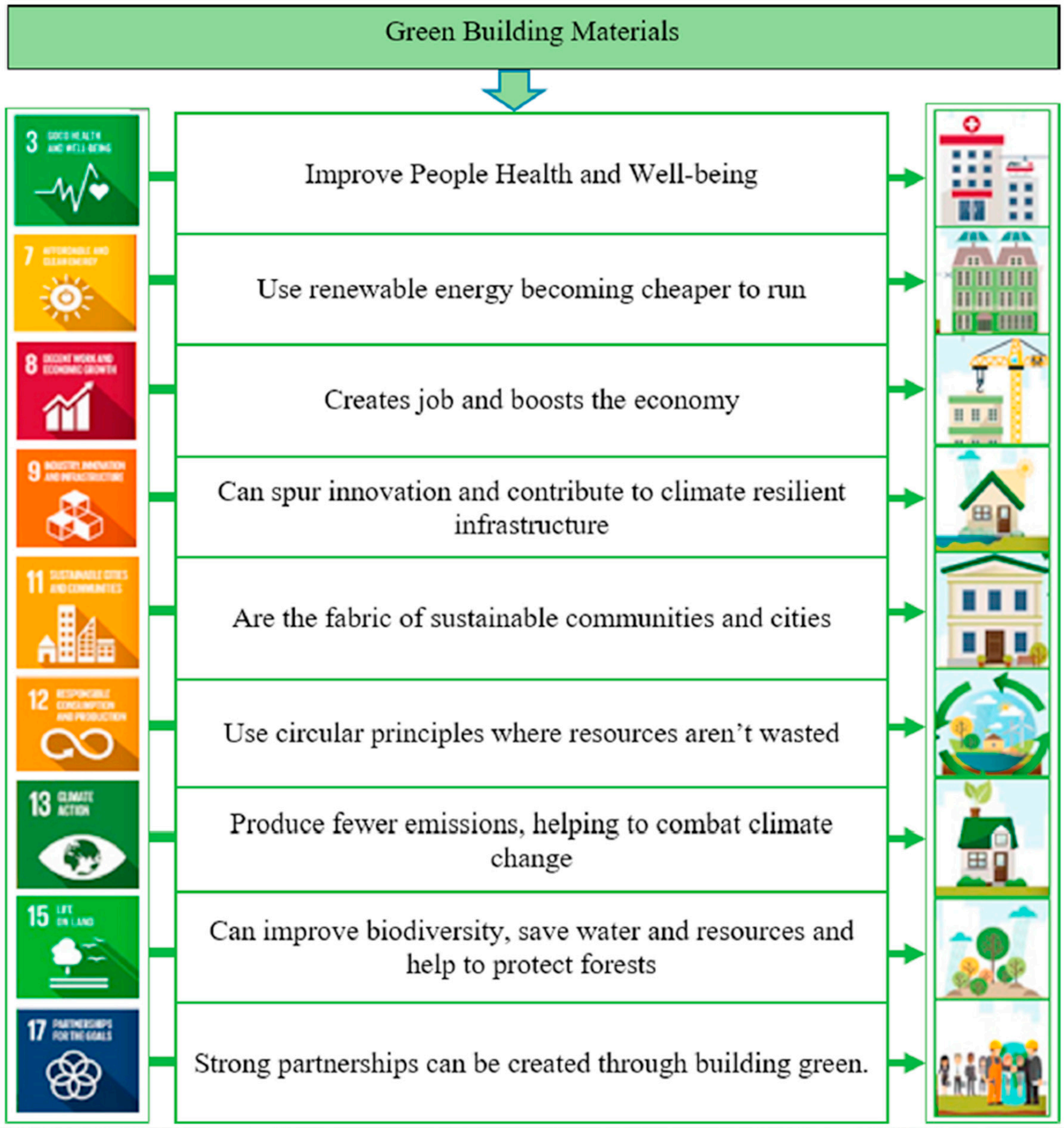

Figure 3. Relationship between green building materials (GBMs) and SDGs [26].

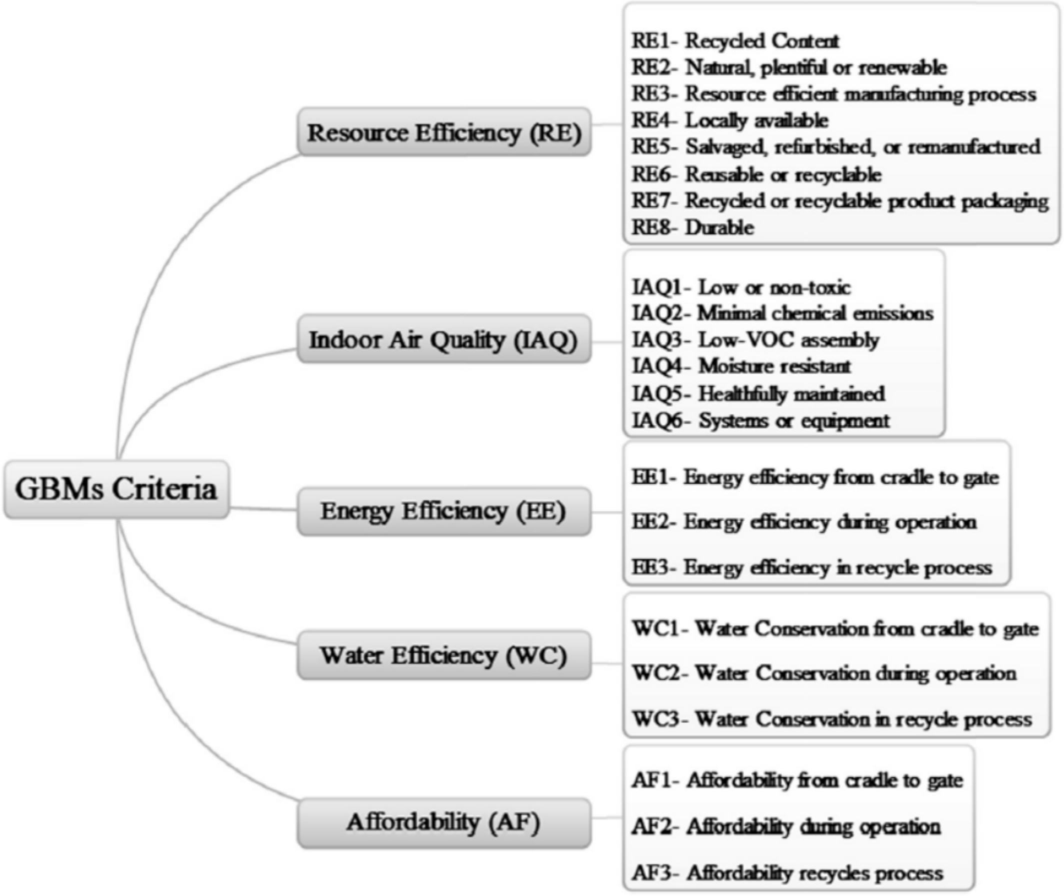

Figure 4. Categorization of GBM's selection criteria [12].

2. Research Methodology

The current paper's research methodology can be divided into four main steps. Firstly, green building materials were identified through conducting an extensive study on the existing literature, including journal papers, books, interviews with experts and online resources [14,16,28]. Then, in the second step, Sustainable Development Goals (SDGs) were studied precisely to identify relevant goals for the construction industry. To do so, several experts were interviewed. Then, using a questionnaire distributed among experts, the relevant goals were weighted using the SWARA method. Data of the questionnaires were gathered, analysed and put in the SWARA process for weighting. The third step focused on identifying and weighting the identified GBM selection criteria according to the specified SDGs using the previous studies and considering experts' opinions. The second questionnaire was used, and the COPRAS method was exploited as the analysis method. Concerning the usage of the COPRAS method, the weighted SDGs and GBM selection criteria were considered simultaneously and put in the process of the COPRAS method. In the final step, the weighted GBM selection criteria were exploited to prioritize GBMs through the second questionnaire using the COPRAS method. The COPRAS method assumes direct and proportional dependence of the significance and utility degree of considered versions based on a system of criteria proportionally explaining the alternatives and on weights and values of the criteria; this is the superiority of the COPRAS method compared to the other MCDM methods. Figure 5 illustrates the research methodology of this study.

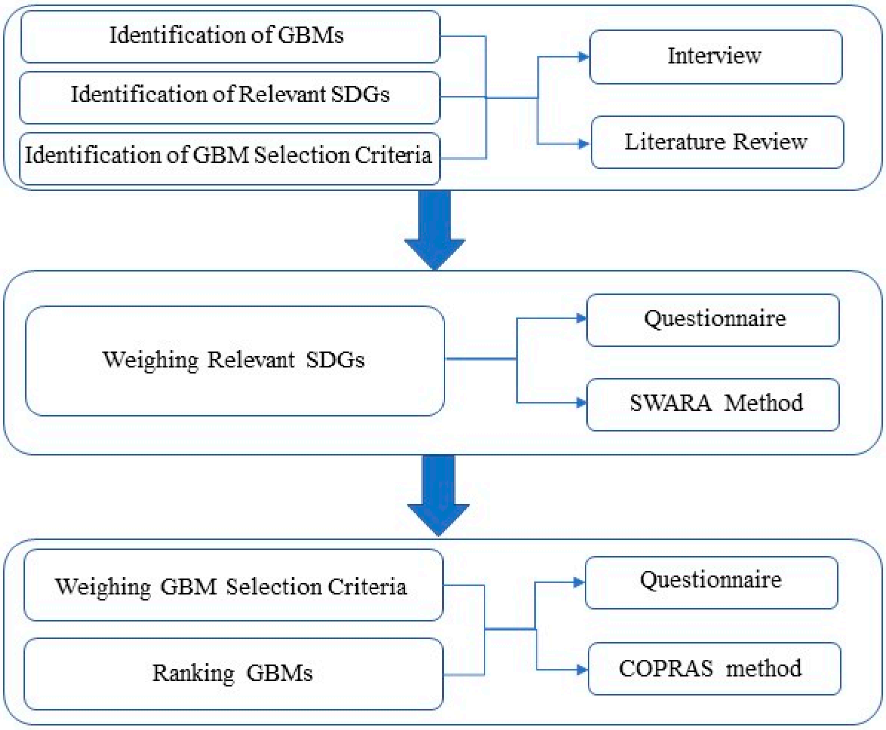

Figure 5. Research methodology.

2.1. Questionnaire

Questionnaires are widely used in different research as information collecting tools. In fact, questionnaires provide raw data, which will be analysed later. In this study, three types of questionnaires were exploited. Respondents' general information, including sex, years of experience, educational level and working background, can be seen in Section 3.2. Questionnaire A was used to weight the identified relevant SDGs. In Questionnaire B, the aim was to weight GBM selection criteria according to the weighted SDGs. Finally, questionnaire C was exploited to prioritise GBMs. In all the designed questionnaires, experts were supposed to give scores from 1 to 5, in which 1 and 5 stand for "very inappropriate" and "very appropriate", respectively.

Questionnaires must be reliable. Otherwise, the results are not viable. One of the ways to attain this goal is to compute Cronbach's alpha. Questionnaires that are more reliable possess a higher value of Cronbach's alpha. The value of 0.7 is regarded as an acceptable value [31–33]. In this study, the mentioned coefficient was calculated by SPSS software. Table 1 shows the computed values.

Table 1. Cronbach's alpha values of questionnaires.

Questionnaire	Purpose	Value
A	Obtaining weight of relevant SDGs	0.912
B	Obtaining weight of GBM selection criteria	0.871
C	Ranking GBMs	0.934

2.2. SWARA (Step-Wise Weight Assessment Ratio Analysis) Method

Keršuliene et al. introduced the SWARA method in 2010. The technique is exploited to weight criteria. This method has been exploited by numerous researchers [34,35]. Balali et al. used the SWARA method as part of their study to weight passive energy consumption strategies in Iran [36]. Akhanova et al. assessed the building's sustainability by SWARA in Kazakhstan [37]. Prajapati et al. prioritised the solutions of reverse logistics implementation to mitigate its barriers in India using the SWARA method [35]. Valipour et al. assessed risks of deep foundation excavation projects in Malaysia by using this method [38]. Maghsoodi et al. used SWARA to select dam materials in Iran [39]. Jaber assessed construction projects' risks in Iraq by using the SWARA method [40]. Readers are referred to the following papers [41–47] to observe more usages of the SWARA method.

In this study, the identified Sustainable Development Goals were weighted using SWARA. These goals were first ranked by experts from 1 to 5, where 1 and 5 stand for the most and least important goals, respectively. Average values of the returned questionnaires were used for analysis. The procedure of the SWARA method is illustrated below [35,48–53]:

1. Selection criteria are identified.
2. Identified criteria are sorted in terms of relative importance in descending order according to the respondents' points of view.
3. Comparative average value (s_j) is calculated. To do so, the second important ($j-1$) criterion is compared to the first criterion (j), and its relative importance is expressed. The same trend is continued for all the criteria.
4. Coefficient k_j, which stands for comparative importance, is computed according to the following formula:

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{1}$$

5. Recalculated weights (q_j) are determined:

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{2}$$

6. Relative weights of the selection criteria (w_j) are computed as follows:

$$w_j = \frac{q_j}{\sum_{m=1}^{n} q_m} \tag{3}$$

where n stands for the number of selection criteria.

2.3. The COPRAS Method

Zavadskas and Kaklauskas introduced the complex proportional assessment (COPRAS) in 1994, which is a powerful and useful multi-criteria decision-making (MCDM) tool [54]. This method is usually used as the second tool due to its need for weighted selection criteria. Criteria are supposed to be weighted by other methods like the analytic hierarchy process (AHP), the analytic network process (ANP), the step-wise weight assessment ratio analysis (SWARA) or any other method [55,56] and software [57]. The COPRAS method has been used by many researchers. For instance, Ghose and Pradhan analysed renewable energy sources in India using the fuzzy COPRAS [58]. Tolga and Durak used the fuzzy COPRAS to evaluate innovation projects [59]. Amoozad Mahdiraji et al. exploited the COPRAS to identify and prioritise sustainable architecture factors in Iran [60]. Kundakcı and Işık used the COPRAS as part of their study for selecting a textile company's air compressor [61].

In this study, the COPRAS method was exploited to weight GBM selection criteria, as well as ranking GBMs. The procedure of using the method is presented as follows [54,62–64]:

1. Weighted selection criteria (q_i) were calculated before. Here, alternatives are determined.

2. Matrix X is constructed as below:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}; i = \overline{1, n} \text{ and } j = \overline{1, m}$$

where i, j, m and n stand for an alternative, its corresponding criteria, number of alternatives and number of criteria, respectively.

3. Decision matrix $\overline{X}$ is normalised as follows:

$$\overline{X}_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}};\ i = \overline{1, n} \tag{4}$$

4. Weighted-normalised decision matrix $(\hat{X})$ is calculated in which the values are computed according to the formula below:

$$\hat{x}_{ij} = \overline{x}_{ij}.q_j; i = \overline{1, n} \text{ and } j = \overline{1, m} \tag{5}$$

where the importance of the ith criterion is shown with q_i.

5. Beneficial and non-beneficial (positive and negative) attributes are calculated using the following formulas:

$$P_{i\,+} = \sum_{j=1}^{k} \hat{x}_{ij} \tag{6}$$

$$P_{i-} = \sum_{j=k\,+\,1}^{m} x_{ij} \tag{7}$$

6. Minimum value of P_{i-} is calculated as follows:

$$P_{min-} = \min P_{i-};\ i = \overline{1, n} \tag{8}$$

7. The importance degree of each alternative is calculated and illustrated by Q_i:

$$P_{min-} = \min P_{i-};\ i = \overline{1, n} \tag{9}$$

8. Optimality criterion (K) is determined as below:

$$K = maxQ_i;\ i = \overline{1, n} \tag{10}$$

9. Alternatives' order ranking is determined according to Q_i.
10. Finally, the utility degree of each alternative is computed:

$$N_i = \frac{Q_i}{Q_{max}} \times 100\% \tag{11}$$

3. Application of the Model

The current study's purpose was identifying and ranking various green building materials for Shiraz, Iran. The generated results of this paper can be used in the buildings that are located in Shiraz and other cities that possess similar conditions. Two hundred building specialists were identified and contributed to the survey to attain this goal. By using the SWARA and the COPRAS methods, relevant SDGs to this topic, GBM selection criteria and GBMs themselves were weighted and ranked.

3.1. Case Study

Shiraz is one of the most populous cities in southwestern Iran [65]. The Shiraz climate is moderate [66,67]. Humidity and temperature difference between days and nights in Shiraz are vital factors influencing building materials and construction projects [68]. The municipality of Shiraz has reported that, according to the latest statistics, more than 1,500,000 people live in Shiraz [38]. Due to the growing demand for housing, many buildings are growing. It seems necessary to try to use GBMs in such projects. In this way, less damage would be done to the environment, leading to greater sustainability than before.

3.2. Sample Size

Building specialists who take part in building construction projects of Shiraz, Iran, were considered as the sample size of this study. The formula used for achieving the number of required specialists is shown as follows [69]:

$$SS = \frac{z^2 p(1-p)}{c^2} \tag{12}$$

where SS stands for the calculated sample size, z stands for the confidence level value, p stands for percentage picking a choice, and c stands for a confidence interval. Then, the corrected sample size was computed as follows:

$$Corrected\ SS = \frac{SS}{1 + \left(\frac{SS-1}{pop}\right)} \tag{13}$$

where rr stands for response rate.

Two hundred professional building experts were considered as the sample size. In this study, to get an acceptable result, the values of the variables were as follows. Percentage picking a choice (p) was considered as 0.5. The confidence level value (z) was taken as 95%. The confidence interval was also considered 10%. According to the conducted calculations, this survey required at least 116 questionnaires to be filled out by experts, which was considered. Table 2 describes general information about specialists.

Table 2. Cronbach's alpha values of questionnaires.

Category	Classification	Number
Occupation	Academia	33
	Manager	48
	Contractor	21
	Technician	22
Sex	Male	74
	Female	50
Experience (years)	<5	22
	5–10	14
	10–15	30
	>15	58

4. Results and Discussion

4.1. Identification and Allocation of Weights to the Relevant Sustainable Development Goals (SDGs)

Sustainable Development Goals include 17 primary goals, as well as 169 corresponding targets in vast areas [21]. Some of these goals and targets are related to the construction industry. Due to the profound impact of the construction industry on the environment and society, it is important to find relevant SDGs and consider them in decision-making problems. Various studies have taken place that showed the impact of the construction industry on achieving SDGs [24,25].

Thus, identifying relevant SDGs was the first stage of this research. A large number of building specialists, constituting both academic and building industry experts, were identified and interviewed. Finally, five relevant SDGs were identified according to three pillars of sustainability goals such as economy, environment and society. In the interviews' questions, the mentioned pillars were considered. The identified SDGs were G7, G9, G11, G12 and G17. These goals are illustrated in Table 3.

Table 3. Relevant Identified SDGs.

Sign	SDG	Nature
G7	Affordable and Clean Energy	Benefit
G9	Industry, Innovation and Infrastructure	Benefit
G11	Sustainable Cities and Communities	Benefit
G12	Responsible Consumption and Production	Benefit
G17	Partnerships for the Goals	Benefit

These goals were then analysed by the SWARA method to obtain their weights [34]. To do that, Questionnaire A was distributed among specialists to prioritise the goals. Table 4 shows the outcome of this part of the study.

Table 4. Weight of each selection criterion.

Criteria	S_j	$K_j = s_j$+1	q_j	w_j	Rank
G9	—	1	1	0.43	1
G7	0.63	1.63	0.61	0.26	2
G11	0.63	1.63	0.38	0.16	3
G12	0.78	1.78	0.21	0.09	4
G17	0.74	1.73	0.12	0.05	5

The results show that "Industry, Innovation and Infrastructure" (G9), "Affordable and Clean Energy" (G7), "Sustainable Cities and Communities" (G11), "Responsible Consumption and Production" (G12) and "Partnerships for the Goals" (G17) were ranked first to fifth important SDGs, respectively. Weights of the SDGs are shown in Table 4.

4.2. Identification and Weighting GBM Selection Criteria

GBM selection criteria must be identified in decision-making problems regarding GBMs. Various studies have been conducted to do so [14,27]. For instance, in one study in 2018, GBM selection criteria were identified and categorised into five main groups including affordability (AF), water conservation (WC), energy efficiency (EE), indoor air quality (IAQ) and resource efficiency (RE) [12].

In the current study, after obtaining the weights of the identified relevant SDGs, the next stage was to identify and weight GBM selection criteria. To identify GBM selection criteria, relevant identified SDGs from the last step were considered. GBM selection criteria were put into five categorisations using the findings of a study on the existing literature and conducting interviews with specialists, as well as considering the aims of the relevant SDGs. The descriptions of the relevant SDGs are illustrated in Figure 6 [21]. Finally, 19 criteria were identified [12]. These criteria and their categorisation are illustrated in Table 5.

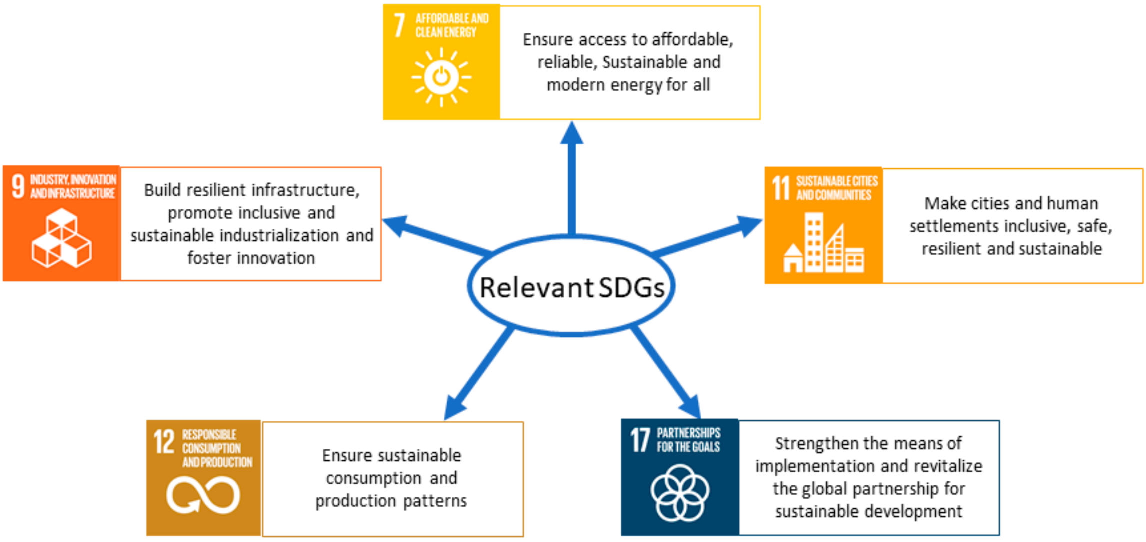

Figure 6. Descriptions of the relevant SDGs [21].

Table 5. Identified GBM selection criteria.

Main GBM Selection Criteria	Sign	GBM Selection Criteria
Resource Efficiency (RE)	RE1	Recycled content
	RE2	Natural, plentiful or renewable
	RE3	Resource-efficient manufacturing process
	RE4	Locally available
	RE5	Salvaged, refurbished or remanufactured
	RE6	Reusable or recyclable
	RE7	Recycled or recyclable product packaging
	RE8	Durable
Indoor Air Quality (IAQ)	IAQ1	Low or non-toxic
	IAQ2	Minimal chemical emissions
	IAQ3	Moisture resistant
	IAQ4	Healthfully maintained
	IAQ5	Systems or equipment
Energy Efficiency (EE)	EE1	Energy efficiency from cradle to gate
	EE2	Energy efficiency during operation
	EE3	Energy efficiency in the recycling process
Affordability (AF)	AF1	Affordability from cradle to gate
	AF2	Affordability during operation
	AF3	Affordability recycles process

Questionnaire B was given to specialists to weight GBM selection criteria, and the analysis took place through the COPRAS method. By considering the calculated criteria weights, the mentioned criteria were ranked. As it was mentioned before, due to the beneficial nature of SDGs, sums of normalised values for non-beneficial criteria do not exist in this study. Therefore, the sums of the weighted normalised values for beneficial criteria (pi +) are calculated and presented in Table 6. Priority values, as well as the quantitative utility of GBM selection criteria, are also calculated and presented in Table 7.

Table 6. The COPRAS results for GBM selection criteria.

GBM Selection Criteria	$P_{i+} = \sum_{j=1}^{k} x_{ij}$
RE1	0.055
RE2	0.070
RE3	0.053
RE4	0.036
RE5	0.043
RE6	0.054
RE7	0.044
RE8	0.041
IAQ1	0.056
IAQ2	0.051
IAQ3	0.060
IAQ4	0.039
IAQ5	0.047
EE1	0.062
EE2	0.045
EE3	0.055
AF1	0.067
AF2	0.064
AF3	0.056

Table 7. GBM selection criteria weights and ranking.

GBM Selection Criteria	$Q_i = P_i + \frac{\sum_{i=1}^{n} M_i}{R_i \sum_{i=1}^{n} \frac{1}{R_i}}$	$N_i = \frac{Q_i}{Q_{max}} 100\%$	Rank
RE1	0.055	78.07	9
RE2	0.070	100	1
RE3	0.053	75.27	11
RE4	0.036	51.69	19
RE5	0.043	61.85	16
RE6	0.054	76.96	10
RE7	0.044	62.69	15
RE8	0.041	58.58	17
IAQ1	0.056	79.92	7
IAQ2	0.051	71.98	12
IAQ3	0.060	85.65	5
IAQ4	0.039	55.12	18
IAQ5	0.047	67.06	13
EE1	0.062	88.46	4
EE2	0.045	63.66	14
EE3	0.055	78.41	8
AF1	0.069	95.05	2
AF2	0.064	91.81	3
AF3	0.056	80.34	6

According to the results, it is illustrated that the top three GBM selection criteria were "Natural, plentiful and renewable" (RE2), "Affordability from cradle to gate" (AF1) and "Affordability during operation" (AF2), respectively.

4.3. Identification and Prioritisation of GBMs

The final stage of this study was identifying and ranking GBMs. Many researchers have identified and investigated GBMs [14]. For instance, according to a survey conducted in India, five GBMs were investigated in terms of economic effects, durability, pros and cons. The mentioned GBMs were reflecting sol glass, coloured lime plaster, eco-friendly tiles, sand-lime bricks and lime [28]. However, it is worth noting that any new building material can be regarded as a green material if it possesses the required properties. Thus, no study can claim that it has identified and investigated all the GBMs. In this study, by considering previous research, as well as specialists' opinions, nine green building materials were finally identified for Shiraz and are shown in Table 8.

Table 8. Identified GBMs.

Sign	GBM Selection Criteria
M1	Cement Plast Artificial Stone
M2	Sand-Lime Bricks
M3	Fibre-Reinforced Concrete
M4	Solar Roof Tiles
M5	Thermochromic Windows
M6	Grasscrete
M7	Stramit Strawboard
M8	Aluminium Composite Panels (ACPs)
M9	Fly Ash Concrete

The purpose of the last questionnaire, questionnaire C, was ranking GBMs. Like in the previous part of the study, experts were asked to use their knowledge, expertise and experience to complete the questionnaire. Ranking of GBMs was conducted using GBM selection criteria weights and exploiting the COPRAS method. Weighted normalised values for beneficial criteria (pi +) were computed and are shown in Table 7.

To weight GBM selection criteria, Questionnaire B was exploited. Each specialist was asked to complete the questionnaire according to their own knowledge and experience, and the scores were analysed by the COPRAS method. As mentioned before, due to the beneficial nature of SDGs, sums of normalised values for non-beneficial criteria did not exist in this study. Therefore, the sums of the weighted normalised values for beneficial criteria (pi +) were computed and are illustrated in Table 9. Priority values, as well as the quantitative utility of GBMs, were also calculated and are presented in Table 10.

Table 9. The COPRAS results for GBM ranking.

GBMs	$P_{i+}=\sum_{j=1}^{k} x_{ij}$
M1	0.107
M2	0.113
M3	0.104
M4	0.122
M5	0.086
M6	0.104
M7	0.130
M8	0.124
M9	0.111

According to the results, it is shown that the top three GBMs were "Stramit Strawboard" (M7), "Aluminium Composite Panels (ACPs)" (M8) and "Solar Roof Tiles" (M4), respectively. As it was mentioned in the previous parts of the study, there has not been a ranking for selecting GBMs. Although GBMs have been discussed separately in other papers, and their benefits and advantages illustrate that the ranking of this study seems sensible and accurate. This ranking can be used by members of the construction industry to assess GBMs in other regions.

Table 10. The COPRAS results for GBM ranking.

GBMs	$Q_i = P_i + \frac{\sum_{i=1}^{n} M_i}{R_i \sum_{i=1}^{n} \frac{1}{R_i}}$	$N_i = \frac{Q_i}{Q_{max}} 100\%$	Rank
M1	0.107	82.87	6
M2	0.113	87.68	4
M3	0.104	80.92	8
M4	0.122	94.97	3
M5	0.086	66.49	9
M6	0.104	81.26	7
M7	0.129	100	1
M8	0.124	96.53	2
M9	0.111	86.36	5

5. Conclusions

Due to a growing number of people and therefore constructing a large number of buildings, it is necessary to attain sustainability using green building materials, which are environmentally friendly. To do so, the existence of a ranking of green building materials can help decision-makers to select suitable GBMs for their projects more manageable. This paper identified several GBMs and prioritised those using the SWARA and the COPRAS methods as tools to analyse options. To move through sustainability, relevant Sustainable Development Goals (SGDs) to the research topic were identified and used as the first selection criteria. These goals were "Affordable and Clean Energy" (G7), "Industry, Innovation and Infrastructure" (G9), "Sustainable Cities and Communities" (G11), "Responsible Consumption and Production" (G12), and "Partnerships for the Goals" (G14). These goals were weighted using the SWARA method, and it was shown that G9, G7 and G11 were the top three goals with weights of 0.431, 0.264 and 0.162, respectively. The next part of the research was associated with identifying and weighting GBM selection criteria according to the weights of the identified SDGs using the COPRAS method. Results show that "Natural, plentiful and renewable" (RE2), "Affordability from cradle to gate" (AF1) and "Affordability during operation" were the top three GBM selection criteria with weights of 0.070, 0.067 and 0.064, respectively. The last part of the study focused on the identification and prioritisation of GBMs. "Stramit Strawboard" (M7), "Aluminium Composite Panels (ACPs)" (M8) and "Solar Roof Tiles" (M4) were the top three GBMs, respectively.

The method used in this study is an appropriate one that can be exploited in other construction industry problems. Members of the construction industry in Shiraz, as well as all the cities possessing similar climatic and economic situations, can use this paper's results. The GBMs identified by this study are highly suggested to be used to move towards sustainability more than before. One of the limitations of this study was considering residential buildings. Therefore, it is suggested that prospective researchers conduct similar studies about other types of buildings such as commercial and industrial buildings. The authors also suggest using other MCDM tools and comparing their obtained results with this study.

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