Article

Application of analytic hierarchy process in the green building criteria comparison

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Received 29 May 2022; Accepted 8 July 2022; Published online 29 July 2022; Published 1 September 2022

Abstract
Construction activities consume natural resources and produce pollution. It is important to decrease construction's negative impact on natural resources and the environment. Green building is an environmentally sustainable building to decrease the environmental impacts and increase environmental conservation. The present study aimed to compare green building criteria. The study was conducted by adopting 3 dimensions with 9 indicators and 79 parameters relevant to the green building criteria. For comparison of the green building criteria, a three-level hierarchical structure was constructed in which Level 1 was the green building criteria, Levels 2 and 3 as the 9 indicators, and 79 parameters, respectively. Analytic Hierarchy Process (AHP) was used for criteria comparison. The data were collected from the field experts via questionnaires and pairwise. The parameters' weights calculate using Expert Choice Software and the most important parameters are presented according to their weights. The results indicated priorities of the green building parameters from the environmental, economical, and social perspectives denoted as dimensions. The results can be useful to green building engineers.

Keywords green building technology; construction industry; analytical hierarchy process; criteria weightings.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

Today, three of the biggest challenges to the world are energy conservation, carbon reduction , and pollutant emissions reduction (Lu et al., 2015; Shad et al., 2017). The construction industry generates the greatest environmental impacts among all the other industries (Samer, 2013). The construction sector constitutes a major challenge to the environment (Vyas et al., 2019). Buildings consume a great ratio of resources and energy in different steps of construction and the period of buildings used, in the present decade (KarimiZarchi et al., 2012). Buildings are responsible for more than one-third of the total world energy use and greenhouse gas emissions (Shad et al., 2017). An estimated, at least 40% of energy use, 42% of the global water consumption, and 50% of the global consumption of raw materials are utilized by building activities in different phases. In addition, building activities contribute an estimated 42% of greenhouse gases, 48% of all solid wastes, 50% of all water pollution, 50% of the world’s air pollution, and 50% of all chlorofluorocarbons to the environment (GRIHA, 2007; Bhatt and Macwan, 2012; Vyas and Jha, 2016; Vyas et al., 2019). Several statistics in worldwide show that approximately 17% of fresh water, 25% of wood stock, and about 40% of material and energy produced are consumed in building construction. Therefore, natural resources and energy use can have a harmful impact on the society and environment (KarimiZarchi et al., 2012; Kansal and Kadambari, 2010).

Buildings reflect resources and waste impacts during the life cycle, as this industry outputs. Construction activities are known as resource intensive and the impacts are reflected in the consumption of natural resources and pollution (Lam et al., 2010; Nilashi et al., 2015). Accordingly, the environmental performance of buildings, energy management, and waste minimization are heavily debated topics in the construction process (Calderón et al., 2015; Shad et al., 2017).

Currently, researchers can understand how human activities are impacting the environment. This can save on expenses and have environmental benefits (Doczy and AbdelRazig, 2017). Academic and professional fields are trying to find new technologies, renewable resources, and useful strategies for environmental impacts (Wang et al., 2009; Shad et al., 2017). The importance and awareness of maintaining sustainable developments within the engineering and planning sector have led to looking for innovative and new ways to incorporate sustainability into designs. The term ‘green’ building defines environmentally friendly technologies and techniques used in the design and construction of the built environment (Love et al., 2012; Nilashi et al., 2015). On the other hand, a green building is an environmentally sustainable building, designed, constructed, and operated to minimize the total environmental impacts (Rana and Bhatt, 2016). Green building design aims to minimize the demand for nonrenewable resources, maximize the utilization efficiency of these resources, and maximize the recycling, reuse, and utilization of renewable resources (Vyas et al., 2019). It can play a key role in the construction industry's sustainability (Chatterjee, 2009; Samer, 2013). Therefore, the construction industry has made efforts to develop green building practices (Gluch, 2005; Samer, 2013). It is a set of human activities that can increase the efficiency with which the buildings use materials, water, and energy. Therefore, it can reduce the building’s impacts on human health, conditions, and the environment, through a better design, construction, operation, maintenance, and building life cycle. In addition, it can reduce the undesirable human impacts on the natural surroundings, and enhances human health and the natural environment (Okhovat et al., 2009; Bahaudin et al., 2014).

The comparison of green building’s criteria is a challenging and complex task because it involves a high number of attributes, numerous technical experts are required from varied fields, and the process varies with different geographical conditions. These processes can be overcome with the application of multi-attribute decision-making methods (Chang, 2014; Vyas et al., 2019), such as the analytical hierarchy process (AHP), which was used in this study to determine the weights of green building’s criteria (Vyas et al., 2019). The proposed approach incorporates the experience and knowledge of green building experts involved in the framework identification and determination the green building’s criteria (Vyas et al., 2019).

2 Green Building

The green building is a new concept of a building that appears in the recent decade. The term green building can include environmental benefits in various aspects such as economic, social, etc, and involved in different aspects of buildings such as sustainable design and construction techniques. It can involve the construction techniques and sustainable design in every aspect of the building and designing buildings that reduce the impact of the built environment on human health and the natural environment (Kelly et al., 2010; KarimiZarchi et al., 2012).

The green building concept starts with the understanding that the built environment can have positive and negative effects on the natural environment, as well as the people who inhabit buildings. It is a practice to increase the positive and decrease the negative of these effects throughout the entire life cycle of a building (Doczy and AbdelRazig, 2017). Green building design and construction practices address sustainable site planning, conservation of materials and resources, safeguarding water and water efficiency, energy efficiency, and indoor environmental quality (Bahaudin et al., 2014).

Chatterjee (2009) defined the “green building practice” as a process to create buildings and infrastructure in such a way that minimizes the use of resources, reduces harmful effects on the ecology, and creates better environments for occupants. Green buildings exhibit a high level of economic, environmental, and engineering performance. These include resource and material efficiency, improved indoor air quality, energy efficiency and conservation, and occupant's health and productivity (Chatterjee, 2009; Samer, 2013). Green building design focuses on increasing resource use efficiency (including materials, water, and energy) and reducing building impacts on the environment and human health during the building’s lifecycle, through better location, design, construction, operation, maintenance, and removal. Table 1 presents a comparison between “green buildings” and “non-green buildings” or “traditional buildings” (Samer, 2013).

The green building concept has been adopted by many countries as the best way in sustaining the environment and preserving resources (Al-Kaabi et al., 2009; Samer, 2013) that is how to minimize environmental degradation caused by building practices (Samer, 2013).

Table 1 Comparison of “green building” and “non-green building”.

Building Type	Green buildings	Non- green buildings
Feasibility	> 5% than threshold	Threshold
Project practices	Sophisticated	Normal
Building materials	Environmentally friendly	Not environmentally friendly
Indoor environment quality	Very good	Good
Emissions	Low	High
Energy consumption	Low	High
Waste management	Highly efficient	Efficient

3 Study Area and Methodology

Analytic Hierarchy Process (AHP) has been applied to compare green building criteria in this research. The Analytic Hierarchy Process (AHP) is for analyzing complex decision-making that can assist to understand the problem better and find the required objective (KarimiZarchi et al., 2012; Zhang, 2019).

3.1 Analytic Hierarchy Process (AHP)

The AHP is a decision-making tool that requires a decision maker to break a problem’s attributes down to a hierarchal structure (Doczy and AbdelRazig, 2017; Zhang, 2019). It is a systematic procedure to deal decision-making problems with many alternatives (Nilashi et al., 2015). This method forms a hierarchy that consists of the project goal, criteria, subcriteria, and alternatives (Doczy and AbdelRazig, 2017; Zhang, 2019) that is based on a hierarchical structuring of decision-making elements using pairwise comparisons. At each level of the hierarchy in AHP, a scale of 1-9 (1: equally preferred; 5: strongly preferred; 9: extremely preferred) is recommended to assign judgment in comparing the pairs of alternatives (Table 2) (Nilashi et al., 2015). This method is practical and simple that its procedure is presented in Fig. 1. As stated in Fig. 1, if the consistency ratio is less than 0.10, the pairwise comparisons are considered consistent; otherwise pairwise comparisons should be reanalyzed by decision-makers to ensure that they are logical (Doczy and AbdelRazig, 2017).

Table 2 Preference scale for pairwise comparison.

Linguistic term	Numerical value
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strong preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

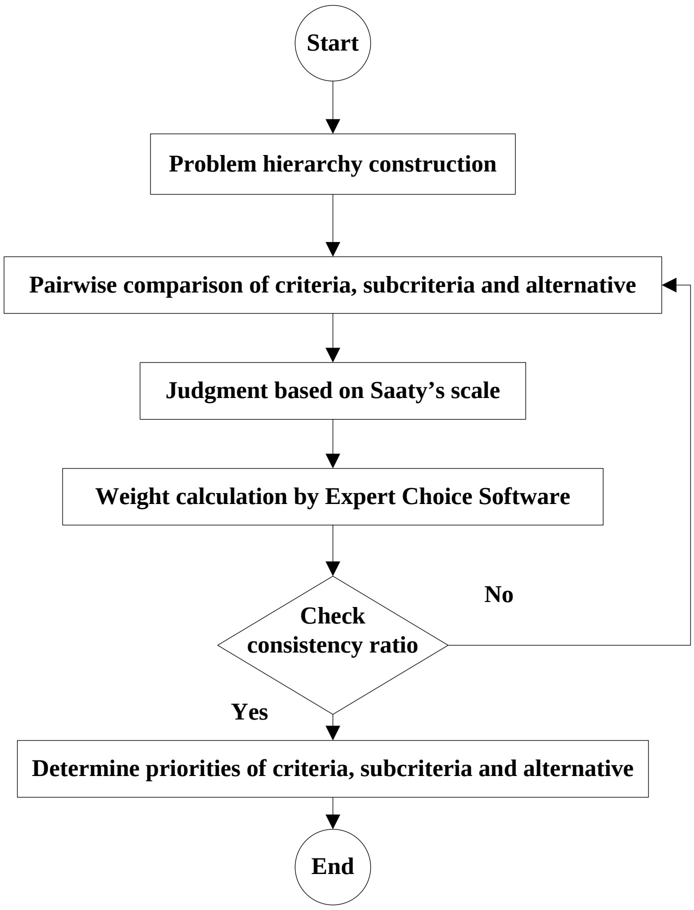

Fig. 1 AHP technique steps.

3.2 Empirical study

3.2.1 Questionnaire design for the computation of weights by the AHP

AHP as a multi-criteria decision-making technique can be used for evaluating and weighting the components of a model that include criteria, subcriteria, and alternatives. In the first step, according to the goal, criteria, subcriteria, and alternatives have been identified based on the literature review (Nilashi et al., 2015). Fig. 2 indicates the hierarchical structure as the green building approach should consider three main criteria social, environmental, and economic (Chandratilake and Dias, 2013; Nilashi et al., 2015). As the study's aim was to compare the green building's criteria, interviews with the building and environmental experts were necessary to collect data. A questionnaire was designed to elicit responses from green building experts for the computation of relative weights for different components. All 12 experts that participated in the survey (Nilashi et al., 2015) included field experts having an average experience of 11 years in green building hence their opinions are important (Vyas et al., 2019). The surveyed experts made their judgments based on their professional experience and the information provided about the green building's characteristics (Nilashi et al., 2015). The pairwise comparison matrices are developed by the experts by using the scale given in Table 2 which is the preference scale for pairwise comparisons recommended by Saaty (Saaty, 2008; Nilashi et al., 2015).

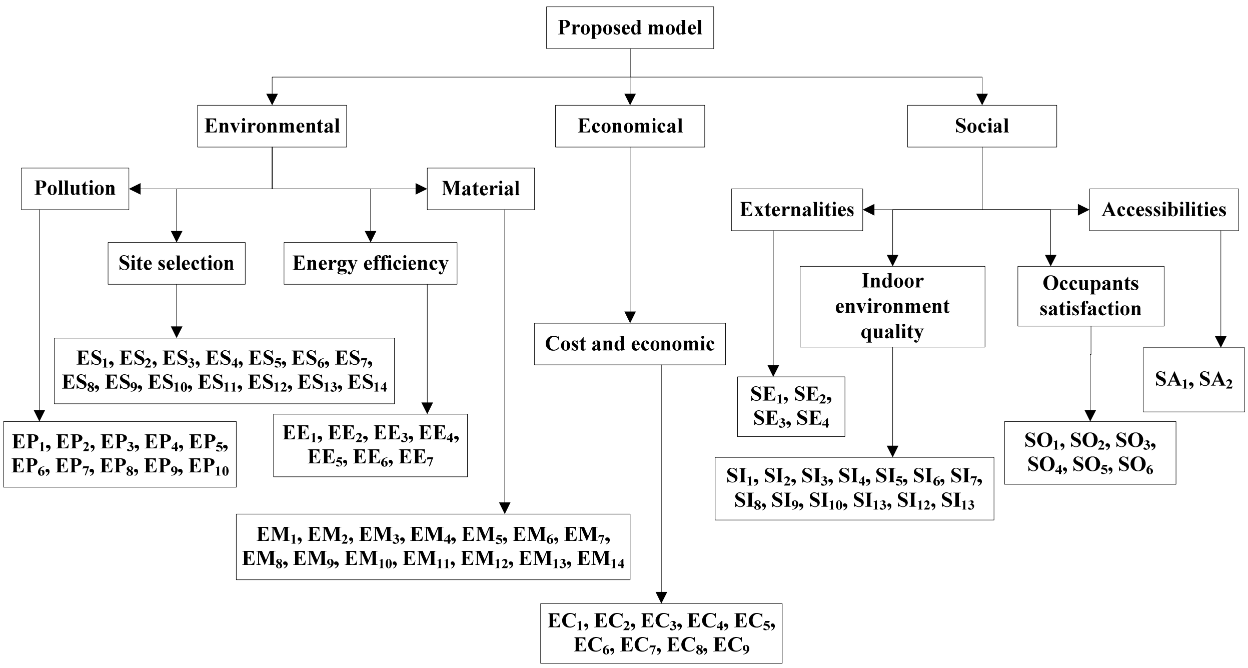

Fig. 2 Assessment dimensions, indicators, and parameters for the proposed model

3.2.2 Computing the weights of the components by the AHP

As can be seen, the list of criteria and subcriteria are presented in Fig. 2. After collecting the pair comparison questionnaires, Expert Choice software was used to calculate parameters rank in the AHP technique (Fig. 3). The most important parameters in each dimension based on threshold decided by experts were selected. The geometric mean method was used to aggregate individual judgment by the Excel Software for obtaining a collective judgment. The geometric mean method for *n* element of $x_1, x_2, \ldots, x_n$ is presented in Eq. (1) (Nilashi et al., 2015).

$$GM = \sqrt[n]{\prod_{i=1}^{n} x_i} \tag{1}$$

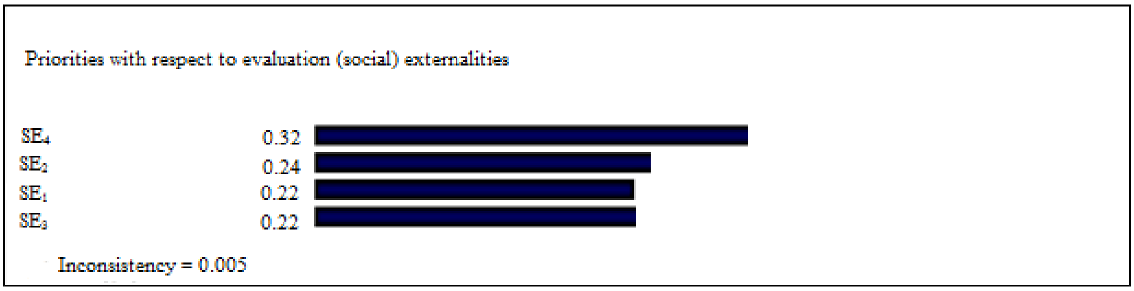

Fig. 3 Priority of criteria and subcriteria.

4 Results and Discussion

Table 3 summarizes the weights of the parameters in the three dimensions. From Table 3, the top environmental, economical and social prominent attributes are (1) accessibility to public transportation, and (2) accessibility to urban amenities with weights of 0.52, and 0.48 respectively. From the weights in Table 3, the most important parameters are selected with a threshold value of 0.1. Hence, site design, landscape design, transportation, loss of habitat, and low-impact construction site techniques with weights 0.11, 0.11, 0.1, 0.1, and 0.1 are selected for the site selection indicator. For the pollution, air pollution, water pollution, waste management strategies, recyclable waste storage, waste treatment and recycling facilities, and waste water management with weights 0.12, 0.12, 0.12, 0.12, 0.1, and 0.1 are selected. For energy efficiency, all parameters are selected as their weights are greater than the threshold value. Resource reuse, water recycle, rainwater harvesting, innovative water reduction technologies, and environmental impact of materials with weights 0.1, 0.1, 0.1, 0.11, and 0.11 are selected for the material indicator. For the cost and economic, except material and construction, water efficiency, waste management, and affordability of rental with weights of 0.04, 0.06, 0.08, and 0.06 other parameters are selected. For the indicators of accessibilities and externalities, all parameters are selected as their weights are greater than the threshold value. In the indoor environment quality indicator, daylight and occupant's health, safety, and comfort were important with weights of 0.12 and 0.14. For the occupant's satisfaction, all parameters are selected as their weights are greater than the threshold value. In Table 4, the important parameters selected by the AHP method are presented.

5 Conclusions

In this research, an effort has been made to compare the green building criteria using the AHP technique. The assessment criteria have been selected from the literature based on the three main dimensions of assessment, environmental, economic, and social. For this research, the data has been collected from experts in the field via pair-wise questionnaires. AHP was applied to select the most important factors in each dimension. Table 5 indicates the ranks of green building attributes based on environmental, social, and economical parameters as the three dimensions. To compare the green building criteria based on the environmental dimensions, the top parameters to be considered are (1) site design, (2) landscape design, (3) transportation, (4) loss of habitat, (5) low-impact construction site techniques, (6) air pollution, (7) water pollution, (8) waste management strategies, (9) recyclable waste storage, (10) waste treatment and recycling facilities, (11) wastewater management, (12) building envelope performance, (13) energy resources, (14) renewable energy technology, (15) natural lighting/lighting, (16) energy-efficient heating/cooling system, (17) lighting efficiency, (18) greenhouse gases emission, (19) resource reuse, (20) water recycle, (21) rainwater harvesting, (22) innovative water reduction technologies, and (23) environmental impact of materials. Based on the economical dimensions, parameters including (24) site, (25) energy efficiency, (26) operation and maintenance cost, (27) cost of investment, and (28) investment risk are the top parameters under consideration. The top parameters to be considered under the social dimensions are (29) accessibility to urban amenities, (30) accessibility to public transportation, (31) available services, (32) occupant productivity, (33) social cost-benefit analysis, (34) local employment opportunities, (35) daylight, and (36) occupant's health, safety, and comfort.

Table 3 Indicators, their parameters, and weights using AHP.

Dimension	Indicators	Parameters	Collective judgment (Weight)	Parameters	Collective judgment (Weight)
Environmental	Site selection	Site design (ES_1)	0.11	Transportation (ES_8)	0.1
		Land use (ES_2)	0.02	Microclimate and atmosphere (ES_9)	0.06
		Landform (ES_3)	0.05	Ecological environment (ES_{10})	0.08
		Onsite processes (ES_4)	0.06	Loss of habitat (ES_{11})	0.1
		Sustainable site selection (ES_5)	0.05	The heat island effect (ES_{12})	0.08
		Appropriate site development (ES_6)	0.06	Low-impact construction site techniques (ES_{13})	0.1
		Landscape design (ES_7)	0.11	Housing density (ES_{14})	0.02
	Pollution	Air pollution (EP_1)	0.12	Waste reduction (EP_6)	0.08
		Water pollution (EP_2)	0.12	Waste management strategies (EP_7)	0.12
		Noise pollution (EP_3)	0.09	Recyclable waste storage (EP_8)	0.12
		Soil pollution (EP_4)	0.08	Waste treatment and recycling facilities (EP_9)	0.1
		Light pollution (EP_5)	0.07	Waste water management (EP_{10})	0.1
	Energy efficiency	Building envelope performance (EE_1)	0.16	Energy-efficient heating/cooling system (EE_5)	0.13
		Energy resources (EE_2)	0.15	Lighting efficiency (EE_6)	0.12
		Renewable energy technology (EE_3)	0.18	Greenhouse gases emission (EE_7)	0.1
		Natural lighting/lighting (EE_4)	0.16		
	Material	Local/regional materials (EM_1)	0.03	Innovative water reduction technologies (EM_8)	0.11
		Renewable material (EM_2)	0.04	Durability (EM_9)	0.06
		Recycle material (EM_3)	0.04	Insulation (EM_{10})	0.04
		Resource reuse (EM_4)	0.1	Fire risk (EM_{11})	0.03
		Water conservation (EM_5)	0.06	Carbon content (EM_{12})	0.09
		Water recycle (EM_6)	0.1	Material efficiency over its lifecycle (EM_{13})	0.09
		Rain water harvesting (EM_7)	0.1	Environmental impact of materials (EM_{14})	0.11
Economical	Cost and economic	Site (EC_1)	0.18	Affordability of rental (EC_6)	0.06
		Material and construction (EC_2)	0.04	Operation and maintenance cost (EC_7)	0.13
		Water efficiency (EC_3)	0.06	Cost of investment (EC_8)	0.19
		Energy efficiency (EC_4)	0.13	Investment risk (EC_9)	0.13
		Waste management (EC_5)	0.08		
Social	Accessibilities	Accessibility to urban amenities (SA_1)	0.48	Accessibility to public transportation (SA_2)	0.52
	Externalities	Available services (SE_1)	0.22	Social cost benefit analysis (SE_3)	0.22
		Occupant's productivity (SE_2)	0.24	Local employment opportunities (SE_4)	0.32
	Indoor environment quality	Climatic conditions (SI_1)	0.05	Visual quality (SI_8)	0.08
		Acoustic comfort (SI_2)	0.04	Indoor air quality performance (SI_9)	0.07
		Lighting comfort (SI_3)	0.06	Acoustic and noise control (SI_{10})	0.07
		Thermal comfort (SI_4)	0.04	Natural ventilation efficiency (SI_{13})	0.09
		Daylight (SI_5)	0.12	Plantation of adoptive plants (SI_{12})	0.09
		Occupants health, safety, and comfort (SI_6)	0.14	Green Features and Innovation (SI_{13})	0.07
		Quality of life (SI_7)	0.08		

	Occupant's satisfaction	Car parking capacity (SO_1)	0.16	Privacy (SO_4)	0.26
		Pedestrian and cyclist safety (SO_2)	0.16	Human interactions (SO_5)	0.1
		Access to view (SO_3)	0.18	Interior qualities (SO_6)	0.14

Table 4 Important parameters selected by the AHP method.

Dimension	Indicators	Parameters	Collective judgment (Weight)
Environmental	Site selection	Site design (ES_1)	0.11
		Landscape design (ES_7)	0.11
		Transportation (ES_8)	0.1
		Loss of habitat (ES_{11})	0.1
		Low-impact construction site techniques (ES_{13})	0.1
	Pollution	Air pollution (EP_1)	0.12
		Water pollution (EP_2)	0.12
		Waste management strategies (EP_7)	0.12
		Recyclable waste storage (EP_8)	0.12
		Waste treatment and recycling facilities (EP_9)	0.1
		Waste water management (EP_{10})	0.1
	Energy efficiency	Building envelope performance (EE_1)	0.16
		Energy resources (EE_2)	0.15
		Renewable energy technology (EE_3)	0.18
		Natural lighting/lighting (EE_4)	0.16
		Energy-efficient heating/cooling system (EE_5)	0.13
		Lighting efficiency (EE_6)	0.12
		Greenhouse gases emission (EE_7)	0.1
	Material	Resource reuse (EM_4)	0.1
		Water recycle (EM_6)	0.1
		Rain water harvesting (EM_7)	0.1
		Innovative water reduction technologies (EM_8)	0.11
		Environmental impact of materials (EM_{14})	0.11
Economical	Cost and economic	Site (EC_1)	0.18
		Energy efficiency (EC_4)	0.13
		Operation and maintenance cost (EC_7)	0.13
		Cost of investment (EC_8)	0.19
		Investment risk (EC_9)	0.13
Social	Accessibilities	Accessibility to urban amenities (SA_1)	0.48
		Accessibility to public transportation (SA_2)	0.52
	Externalities	Available services (S_{E1})	0.22
		Occupant's productivity (SE_2)	0.24
		Social cost benefit analysis (SE_3)	0.22
		Local employment opportunities (SE_4)	0.32
	Indoor environment quality	Daylight (SI_5)	0.12
		Occupants health, safety, and comfort (SI_6)	0.14
	Occupant's satisfaction	Car parking capacity (SO_1)	0.16
		Pedestrian and cyclist safety (SO_2)	0.16
		Access to view (SO_3)	0.18
		Privacy (SO_4)	0.26
		Human interactions (SO_5)	0.1
		Interior qualities (SO_6)	0.14

Table 5 Ranking of parameters for the environment, social, and economic dimensions to compare green building criteria.

Rank	Prominent parameters based on environmental dimension	Rank	Prominent parameters based on Economical dimension	Rank	Prominent parameters based on social dimension
1	Renewable energy technology	1	Cost of investment	1	Accessibility to public transportation
2	Building envelope performance	2	Site	2	Accessibility to urban amenities
2	Natural lighting/lighting	3	Energy efficiency	3	Local employment opportunities
3	Energy resources	3	Investment risk	4	Occupant's productivity
4	Energy-efficient heating/cooling system	3	Operation and	4	Privacy
5	Air pollution	4	Water and waste management	5	Available services
5	Water pollution	5	Water efficiency	5	Social cost benefit analysis
5	Waste management strategies	5	Affordability of rental	6	Access to view
5	Recyclable waste storage	6	Material and construction	7	Car parking capacity
5	Lighting efficiency			7	Pedestrian and cyclist safety
6	Site design			8	Occupant's health, safety, and comfort
6	Environmental impact of materials			8	Interior qualities
6	Landscape design			9	Daylight
6	Innovative water reduction technologies			10	Human interactions
7	Transportation			11	Natural ventilation efficiency
7	Loss of habitat			11	Plantation of adoptive plants
7	Low-impact construction site techniques			12	Quality of life
7	Waste treatment and recycling facilities			12	Visual quality
7	Waste water management			13	Indoor air quality performance
7	Greenhouse gases emission			13	Acoustic and noise control
7	Resource reuse			13	Green features and innovation
7	Water recycle			14	Lighting comfort
7	Rain water harvesting			15	Climatic conditions
8	Noise pollution			16	Acoustic comfort
8	Carbon content			16	Thermal comfort
8	Material efficiency over its lifecycle				
9	Soil pollution				
9	Ecological environment				
9	The heat island effect				
9	Waste reduction				
9	Waste reduction				
10	Light pollution				
11	Onsite processes				
11	Appropriate site development				
11	Water conservation				
11	Microclimate and atmosphere				
11	Durability				
12	Landform				
12	Sustainable site selection				
13	Renewable material				
13	Recycle material				
13	Insulation				
14	Local/regional materials				
14	Fire risk				
15	Land use				
15	Housing density				

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