

Interdependence and Rationality Between Sustainable Indicators and Criteria—A Fuzzy AHP Approach



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Abstract The rapid urbanization is likely to impose tremendous pressure on the available natural resources due to their depletion, seriously affecting the Social, Environmental, Economic and Technological (SEET) indicators. The identification of criteria and indicators to achieve Sustainable Construction (SC) is a challenging task in terms of balancing and interrelating them. The present study while investigating the most significant criteria that contribute to SC, establishes inter-relationship between them and SEET indicators by utilizing the Fuzzy Analytical Hierarchy Process (AHP), a Hybrid Multi-Criteria Decision Making (MCDM) method. Based on Delphi Technique (DT) and Relative Importance Index (RII), eight criteria have been identified including Water Efficiency, Materials and Waste Management, Health and Well-being, Energy Efficiency, Sustainable Sites, Social Welfare, Transportation, and Management. The findings of the study reveal that the criteria Materials and waste management and Energy Efficiency have attained the highest relative weights of 13.96 and 12.63 respectively. Similarly, among SEET indicators, the Environmental and Technological indicators have secured 30.15 and 28.52 relative weights respectively. This well-established inter-relation between indicators and criteria will facilitate the decision-makers/stakeholder to understand the degree of performance between sustainable criteria and indicators for achieving sustainable buildings. In addition to this, a computerized building assessment tool which can facilitate the formulation of guidelines by policy-makers was also developed.

Keywords Sustainable construction · Environment · Building assessment tool · Green buildings · Multi-criteria decision method · Fuzzy · AHP

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1 Introduction

Compared to developed countries, developing countries have got a new trend of accepting green building guidelines [1–3]. Every country is in the process of developing its own rating system or guidelines to achieve an overall sustainable built environment. For example, prominent assessment tools like the Leadership in Energy and Environmental Design (LEED) scheme in the US, and the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan. Based on the LEED revision, India introduced the Indian Green Building Council (IGBC) assessment method in the year 2000. The Green Rating for Integrated Habitat Assessment (GRIHA) in India [4] and the Building Research Establishment's Environment Assessment Method (BREEAM) in Australia also uses the country-specific format of Norway, Sweden, Spain, and the Netherlands. The assessment method developed created for one nation or region might not be directly applicable to others, because, a number of factors may prevent the transfer of currently available environment assessment tools to other nations [5]. Some of these factors include regional differences, climatic conditions etc.

1.1 *Need for Sustainability in Indian Built Environment*

From a case study conducted by Gesellschaft für Internationale Zusammenarbeit (GIZ), it was acknowledged that developing countries need further action and development in policy, regulation, and strengthening the regulatory authorities and reinforcing the existing laws towards sustainability. There is lack of awareness on sustainability/green practices and their benefits [6]. Most of the issues of sustainability are interrelated in existing methods, and the focus is mainly given to environmental aspects [7]. This clearly specifies disregard for the economic, social, and technological aspects of sustainability, which could further lead to ecological imbalance and thereby, miss the real goal of sustainable development. For example, though GRIHA has attempted to make green building assessment tools, it was not able to fully incorporate the social, economic and cultural elements in the sustainability assessment criteria [8]. The existing building assessment tools are hence, limited to uni-dimensional sustainability. Some of the assessments were based on a Triple Bottom Line (TBL) approach i.e., Environment, Social, and Economic dimensions [9, 10]. An in-depth study of the literature indicated that the Technological component's significance could be enhanced by incorporating recent technological advances in sustainability in the construction sector. Technological advances have always been the cornerstone in mitigating the unavoidable side effects of development and in surpassing the limits/constraints dictated by the other indicators of sustainability. For instance, a shift from working stress method to limit state method in the design philosophy led to thinner and more economical sections without compromising the safety and durability, and introduction of steel columns and steel beams in lieu of

stonewalls as structural materials made the towering skyscrapers possible. The technological dimension can be incorporated by rejuvenating ideas of Reuse, Recycle, Reduce, Renew, and Regenerate (5R’s) into implementable solutions to the existing TBL to achieve sustainable construction [3]. In other words, various methods and approaches are required for benchmarking the threshold values and targets to transform a theoretical concept into practical implementation. Secondly, policies and guidelines for proper governance are needed. Finally, it is essential to recognize the advantages of supporting techniques and technology for achieving sustainable harmony in the construction industry. The present study encompasses the Social, Environmental, Economic, and Technological (SEET) aspects in achieving sustainable construction. This study is a continuation of the author’s work [3] to quantify the building performance. The present study concentrates on quantifying the interdependency between SEET indicators and criteria using the Fuzzy Analytical Hierarchy Process (FAHP), a Hybrid Multi-Criteria Decision Making (MCDM) method considering local context, climate conditions, culture, topography and ethical aspects prevailing in developing countries.

1.2 Fuzzy Numbers and Linguistic Terms

Lofti Zadeh (1965), introduced the Fuzzy set theory in order to make decisions for problems dealing with vagueness, subjectivity, and impreciseness [11]. Consider a TFN defined by $\tilde{A} = (a, b, c)$, where $\mu_A(x)$ is the degree of belonging or membership value of the element in the universe of discourse. The fuzzy triangular scale adopted in the study is shown in Table 1.

$$\mu_A(x) = \begin{cases} \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

Table 1 Linguistic terms and corresponding triangular fuzzy numbers

Saaty scale	Definition (level of importance)	Fuzzy triangular scale
1	Equal	(1, 1, 1)
3	Weak	(2, 3, 4)
5	Fair	(4, 5, 6)
7	Strong	(6, 7, 8)
9	Absolute	(9, 9, 9)
2	Intermediate values	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

Consider two fuzzy numbers \tilde{A}_1 and \tilde{A}_2 , where $\tilde{A}_1 = (a_1, b_1, c_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2)$ whose operations of addition, multiplication, division, and reciprocal are defined by Eqs. 2 to 5.

$$\tilde{A}_1 \otimes \tilde{A}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (2)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (a_1 \otimes a_2, b_1 \otimes b_2, c_1 \otimes c_2) \text{ for } a_1 > 0, b_1 > 0, c_1 > 0 \quad (i = 1, 2) \quad (3)$$

$$\tilde{A}_1 / \tilde{A}_2 = (a_1/c_2, b_1/b_2, c_1/a_2) \text{ for } a_1 > 0, b_1 > 0, c_1 > 0 \quad (i = 1, 2) \quad (4)$$

$$\tilde{A}_1^{-1} = (1/c_1, 1/b_1, 1/a_1) \text{ for } a_1 > 0, b_1 > 0, c_1 > 0 \quad (5)$$

1.3 Analytical Hierarchy Process (AHP)

The AHP is a qualitative and quantitative MCDM technique used to evaluate the relationship between two or more components [12], in a logical way. The decision problem is analyzed at various levels of hierarchy structure, to enable them to be evaluated independently. The human perception involved with uncertainty and ambiguity can be resolved with the fuzzy logic concept. In the present study, to establish the interrelationship among the criteria, indicators, and criteria to indicators, the Fuzzy Analytical Hierarchy Process (FAHP) has been employed in decision making.

2 Comparison of Existing Building Assessment Tools

Based on the credibility and recognition of the rating system, four assessment tools were selected, compared, and analyzed for similarities and dissimilarities present in the developed, and developing countries. Though these rating systems seem to have some criteria in common (names), they differ in their meaning and understanding. This is mainly due to varied climate, culture, region, awareness, practices and assessment method. In addition to this, the rating systems are not unique in nature, dimension and do not comply with the requirements. The assessment tools in the developed countries i.e., LEED and BREEAM being the most prominent and globally established assessment tools in the domain of sustainable construction are considered in the present work. Also, assessment tools used in developing countries like GRIHA and IGBC have been considered for comparison. The specific purpose to compare these tools is to check whether these assessment criteria and attributes are transferrable and adaptable to suit the circumstances for developing countries like India. Table 2 compares and summarizes, the components, features, and criteria of

Table 2 Criteria comparison of existing Assessment tools

Criteria	Attributes	Factors	BREEAM	LEED	IGBC	GRIHA
Sustainable site and ecology	Construction site	Selection of site	✓	✓	✓	✓
		Protection of site	✓	✓	✓	✓
	Ecological value	Land contamination	✓	✓	✓	✓
		Mitigating ecological impact	✓	✓	✓	✓
		Balancing site ecology	✓	✓	✓	✓
		Protecting biodiversity	✓	✓	✓	✓
	Transport	Ease of accessibility	✓	✓	✓	✓
		Developing density	✓	✓	✓	X
		Intercommunity network	✓	✓	✓	X
		Safety of pedestrian	✓	✓	X	X
		Car parking facility	✓	✓	✓	X
	Energy efficiency	Energy performance	HVAC	✓	✓	✓
Rate of ventilation			✓	✓	✓	X
Internal and external lighting			✓	✓	✓	✓
Provision of hot water			✓	✓	✓	✓
Heat transmission			✓	✓	X	X
Renewable technology on energy			✓	✓	✓	✓
Monitoring energy			✓	✓	✓	X
Energy saving			✓	✓	✓	✓
CO ₂ Strategy			✓	✓	✓	X
Water efficiency and water management	Water	Reducing the consumption of water	✓	✓	✓	✓
		Harvesting water	✓	✓	✓	✓
		Recycling of water	✓	✓	✓	✓

(continued)

Table 2 (continued)

Criteria	Attributes	Factors	BREEAM	LEED	IGBC	GRIHA
		Innovative water recycling technology	✓	✓	✓	✓
		Water conservation technique	✓	✓	✓	✓
		Water irrigation technique	✓	✓	✓	✓
		Groundwater recharge	✓	✓	✓	✓
Material	Material category	Low impact environment material	✓	✓	✓	✓
		Use of non-renewable resources	✓	✓	X	X
		Material reuse	✓	✓	✓	X
		Using innovative technology for non- structure	✓	✓	✓	X
		Insulating component	✓	✓	X	X
		Material finishing	✓	✓	✓	X
		Local resources utility	✓	X	✓	X
		The efficiency of material over LC	✓	✓	X	X
Pollution and risk	Emissions and disaster	Global warming potential for refrigerant	✓	✓	✓	X
		Noise pollution	✓	✓	✓	X
		Preventing pollution leaks	✓	X	✓	X
		Water pollution	✓	✓	X	X
		Effect of heat island	✓	✓	✓	X
		Source of NO _x emission	✓	✓	X	X
		Carbon emission	✓	✓	✓	X
		Fire safety	✓	✓	X	✓
Natural Disaster	✓	✓	X	X		

(continued)

Table 2 (continued)

Criteria	Attributes	Factors	BREEAM	LEED	IGBC	GRIHA
Indoor environment quality	Noise and acoustics	Level of noise emitting	✓	✓	X	✓
		Insulation to sound source	✓	X	X	✓
		Absorption of sound acoustics	✓	X	X	✓
	Lighting and illumination	Active lighting	✓	✓	✓	✓
		Lighting control	✓	✓	✓	✓
		Open view	✓	✓	✓	X
		Measuring and control on glaring	✓	✓	X	X
		Level of illumination	✓	✓	✓	X
		Daylight factor	✓	✓	✓	X
	Ventilation	Natural ventilation	✓	✓	✓	✓
		Type of ventilation	✓	✓	✓	✓
		Supply of purified and fresh air	✓	✓	✓	✓
		Air monitoring sensor	✓	✓	✓	X
		Monitoring on carbon emission	✓	✓	✓	
	Contamination level	Unstable compounds	✓	✓	✓	✓
		Pollution of electromagnetic waves	X	X	X	X
		Level of microbiological content	✓	✓	X	X
	Thermal comfort	Controlling zone	✓	✓	X	X
Heating, cooling, humidity, vaporcontrol, and comfort		✓	✓	✓	✓	

the existing assessment tools (BREEAM, LEED, IGBC, and GRIHA) to understand the depth of each of the criteria and their related attributes. The tick mark symbol '✓' represents that the criteria are included in the respective assessment tool, whereas cross mark 'x' represents that it does not. Some of the criteria, which contribute to building sustainability, are neither included in IGBC nor GRIHA. Similarly, the attributes, which are included in IGBC, are not included in GRIHA and vice-a-versa, for example, ventilation, CO₂ emissions, and material efficiency. Also, some criteria like topographical consideration, climatic conditions, local context, and regional variations are not at all considered.

For instance, energy is considered as a key category for all assessment methods and is given the highest possible points. BREEAM measures Building Energy Performance (BEP) along with CO₂ emission reductions with the target of net-zero emissions. On the other hand, LEED emphasizes reduction of energy costs for BEP rather than CO₂ emissions, which is in line with the standards of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). LEED mainly focuses on renewable energy utilization for measuring BEP and energy optimization. However, energy monitoring and enhanced commissioning are not considered in the GRIHA rating system. The three assessment methods (LEED, BREEAM, and GRIHA), evaluate most of the major water quality and quantity parameters. Indoor water use reduction, potable water use reduction, water recycle and reuse, wastewater treatment and efficient landscaping are the common criteria considered in all the three rating tools. Water leak detection and water metering are considered important criteria, but they are not considered in GRIHA for water efficiency evaluation. Waste related criteria and their parameters are integral to all three-assessment methods. Within this broad criterion, waste management and recycling emerge as the most important parameters, due to their importance in minimizing the negative impacts of waste generation for humans and the surrounding environment. Construction materials, is another important element of the environmental assessment method due to the impact of material consumption on building users and the environment. BREEAM and LEED emphasize sourcing of raw materials, but it is not considered in GRIHA. Renovation of abandoned buildings is considered in LEED, but not considered in GRIHA evaluation criteria for assessment. Indoor environmental quality (IEQ) is considered as a key objective for all building assessment methods. BREEAM and GRIHA include this category under Health and Well-being section. LEED assesses this category through low-emitting materials, indoor air quality, and quality views. Similarly, BREEAM assesses this category through visual comfort, the impact of refrigerants and noise pollution. GRIHA assesses this category through air quality; low-VOC paints, sanitation/safety facilities, but at the same time omits visual comfort, quality views, and hazards in its criteria. Tobacco smoke control, pollution, thermal comfort, and air quality are commonly considered in all three assessment methods. Light pollution reduction and joint use of facilities are considered in LEED but not considered in GRIHA. All the tools evaluated in this study offer credits to encourage and support sustainability measures. BREEAM considers Management as a separate category for its assessment, while LEED distributes management parameters across several assessment categories. BREEAM covers sustainable management

principles more comprehensively than LEED. Transportation is considered as a separate category in LEED and BREEAM. LEED addresses transportation through factors Location and Transportation criterion with 16 possible points whereas, BREEAM, assesses the same with 13 possible points. From the observations, it was found that the criterion Transportation and Management was not considered in GRIHA for environmental assessment.

3 Methodology

The identification of criteria related to sustainable construction from various sources including existing building rating systems was carried out to address Agenda 21 and UN initiatives towards sustainability. The methodology to assess the relative weights of criteria and attributes and establish interrelationship among them is shown in Fig. 1. The significant criteria that can assess the sustainable performance of a building are identified based on the existing assessment tools, guidelines, and policies. Based on the comparison of tools like BREEAM, LEED, IGBC, and GRIHA, the criteria and sub-criteria are assessed and checked for the possibility of transferring and adopting to developing countries. While diagnosing the similarities and differences in various existing tools, the study emphasized on the suitability of potential and possible criteria to be considered. Further, the diagnosed criteria are refined and screened out using Delphi Technique (DT) to reach a consensus decision. Based on the comparative discussion carried in the paper by the same authors ([3, 5]), the significant criteria and attributes are adopted. The identified list is then refined and was utilized to develop priorities and weights through quantitative research methods and MCDM techniques.

To determine the relevant attributes for building assessment, data collected from the DT has been evaluated using the Relative Importance Index (RII) based on Eq. 6.

$$RII = \frac{\sum_{i=1}^N P_i R_i}{N \times n} \quad (6)$$

where

- RII Relative Importance Index;
- P_i Respondent's rating;
- R_i Number of respondents placing identical weighting/rating;
- N Sample size;
- n Highest attainable score.

The attributes whose RII value is more than or equal to 0.7 has been screened out for selecting the most significant parameters to assess the performance of the building. The ultimate criteria and attributes for sustainable building assessment are determined as shown in Table 3.

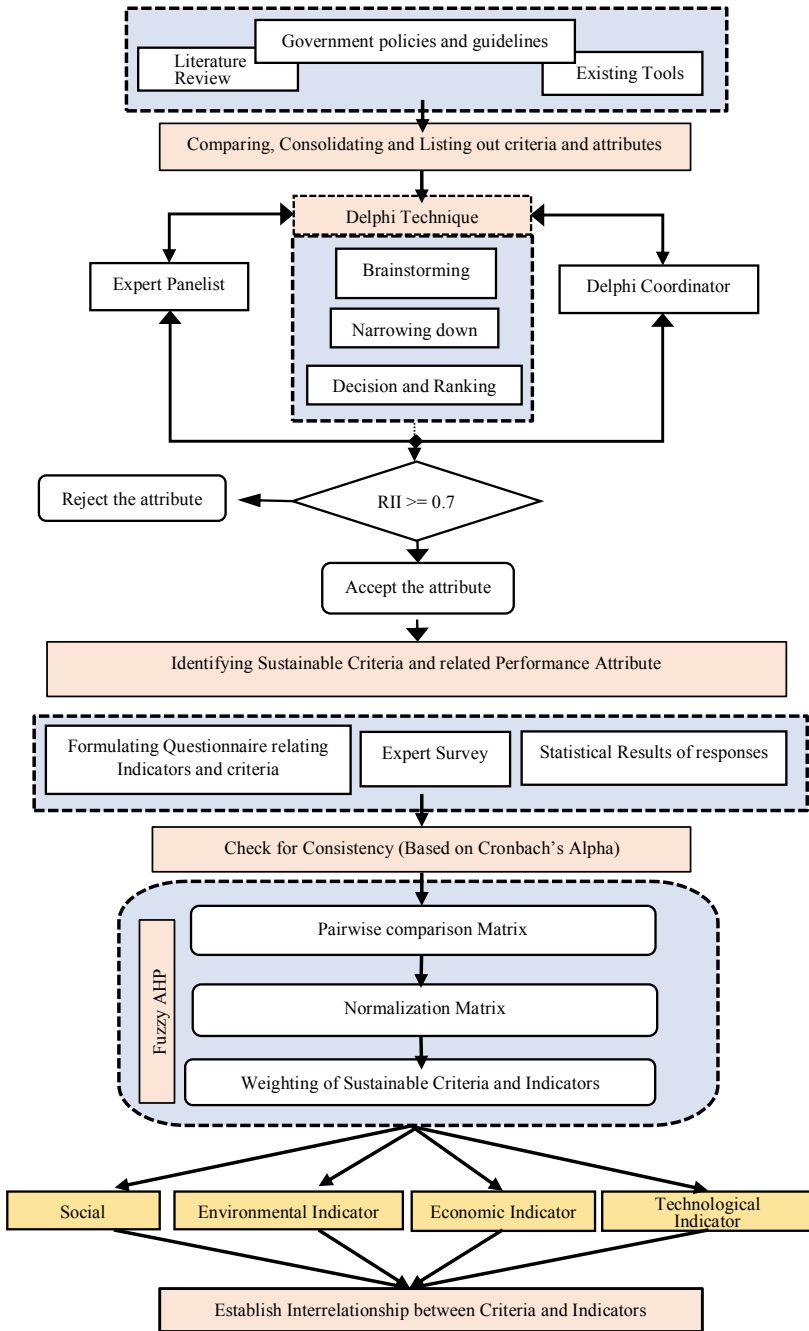


Fig. 1 Methodology to assign relative weights and establish interdependency for criteria and indicators

Table 3 Most prominent sustainable criteria and sub-criteria for developing countries

Code	Criteria	Attributes
WE	Water efficiency	Water monitoring and leak detection (A1) Building water use reduction (A2) Recycle and reuse of water (A3) Rainwater management (A4) Reduction in landscape water requirement (A5)
MW	Materials and waste management	Low-energy materials (B1) Regionally available materials (B2) Recycled and re-use materials (B3) Responsible sourcing (B4) Efficient waste management (B5)
HW	Health and well-being	Water quality & water pollution (C1) Outdoor & indoor noise levels (C2) Sanitation/Safety facilities & Accessibility (C3) Minimize ozone depletion (C4)
EE	Energy Efficiency	Renewable energy production (D1) Energy-efficient appliances (D2) Energy monitoring (D3) Reduction in energy consumption associated with interior lighting (D4) Adequate Daylight (D5) Energy-efficient vertical transportation systems (D6)
SS	Sustainable sites	Site selection (E1) Protect or restore habitat (E2) Heat island reduction (E3) Open space (E4) Light Pollution (E5) Efficient ventilation (E6) Conservation of soil surrounding the building (E7)
SW	Social welfare	Knowledge and Awareness towards sustainability (F1) Local Economic Development (F2) Design for durability (F3)
T	Transportation	Public transport accessibility (G1) Use of Bicycles (G2) Proximity to amenities (G3) Environmentally friendly pavements at the building site (G4) Reduced parking footprint (G5)
M	Management	Managing the balance between the building and its immediate surrounding (H1) Managing fire prevention facilities (H2) Preventing the reckless dumping of polythene products at the building site (H3)

To determine the priority weights of criteria towards each of the indicators, pairwise comparison of the criteria and indicators is performed for each individual judgments and then averaged. To evaluate the relative weights of criteria and indicators, the present study collected data from a structured questionnaire survey responses (147 no's) from all the stakeholders of the construction industry, each belonging to categories such as Academicians, Engineers, Designers, Architects, Consultants, Contractors, and Others. Further, the study utilized the FAHP for assigning the relative weights to criteria and indicators.

4 Data Collection, Results and Discussion

The respondents were invited to assess the level of importance of criteria and indicators by assigning a score on the seven (7) point Likert scale and converted to a fuzzy triangular scale as suggested by [13]. A score of '1' indicates as 'not important' whereas, '7' indicates 'highly important'. This includes professionals from all domains of civil engineering. Among the 147 responses, incomplete data and data which is not reliable to be considered have been neglected. As required from population size, 96 reliable and complete responses were selected for further investigation. The consistency of the data is checked using Cronbach's alpha coefficient calculated using the following Eq. 7.

$$\alpha = \frac{N \times c}{v + (N - 1) \times c} \quad (7)$$

N is the number of items, c is the average inter-item covariance among the items, and v is the average variance. In general, the alpha score of more than 0.70 is considered acceptable [14]. In the present study, the Cronbach's alpha was calculated for four different groups (Social, Environmental, Economic, and Technological), from the information provided by 58 valid respondents. In all the groups, the ' α ' values were found to be more than 0.80. Thus, the data provided was found to be reliable and was of good quality. The procedure adopted by the authors [5, 15] was used to evaluate the relative weights using Fuzzy AHP. To de-fuzzy, the obtained relative weights, center of the area method is proposed. The relative weights for sustainable criteria and indicators for four no's of 8×8 matrices were evaluated for 58 respondents (Fig. 2). The average of individual priority weight is evaluated, using arithmetic mean operation. Similarly, the relative weights of sustainable indicators (SEET) with respect to sustainable criteria; where eight no's of 4×4 matrices for 58 respondents are performed and the final weights are obtained as shown in Fig. 3. The interrelated weights are obtained by multiplying the relative weights of sustainable indicators and criteria (Fig. 4).

From Fig. 2, considering Social indicator, the criteria Sustainable Sites (SS) has attained the highest weight (i.e., 13.93) and overall rank sixth among all the 32 criteria (say 8 criteria \times 4 indicators). Following this, the criteria, Transportation (T)

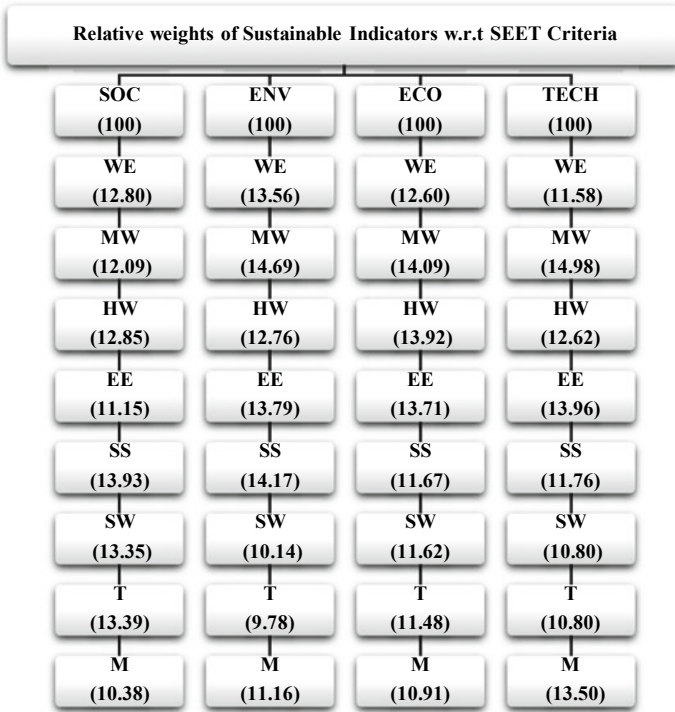


Fig. 2 Relative weights of sustainable criteria w.r.t sustainable indicators

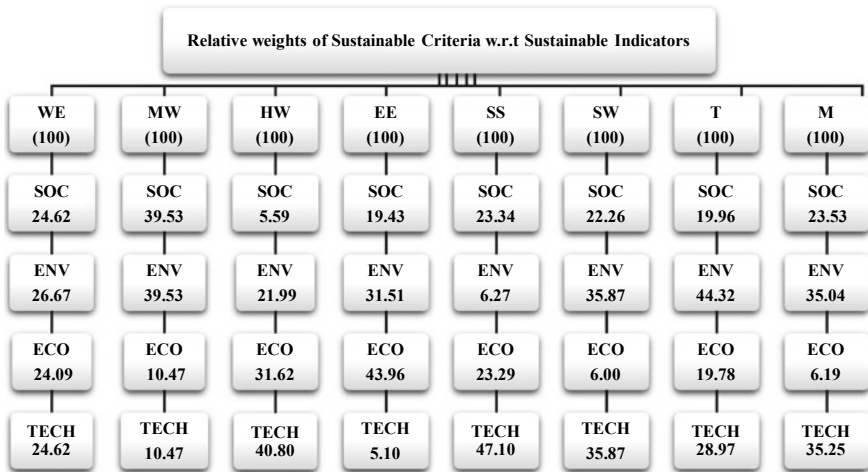


Fig. 3 Relative weights for sustainable indicators w.r.t sustainable criteria

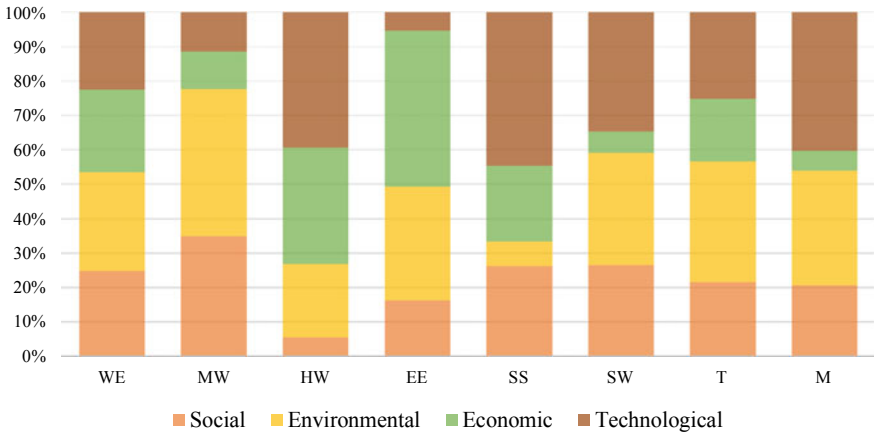


Fig. 4 Interrelated weights for SEET indicator w.r.t sustainable criteria

and Social Welfare (SW) has achieved a nearby weight of 13.39 and 13.35 with an overall ranking of 12 and 13 respectively.

Considering Environmental indicator, the criteria, Materials and Waste Management (MW) has attained the highest weight (i.e., 14.69) and overall rank second among all the 32 criteria. The criteria, Sustainable Sites (SS) and Energy Efficiency (EE), achieved a weight of 14.17 and 13.76 with an overall ranking of eight and three respectively. Considering the Economic indicator, the criteria MW has attained the highest weight (i.e., 14.09) and an overall rank of fourth among all the 32 criteria. Next, to it, Health and well-being (HW) and Energy Efficiency (EE) have achieved a weight of 13.92 and 13.71 with an overall ranking of seven and nine respectively. Similarly, in the Technological indicator, MW and EE have attained the highest weight (i.e., 14.98 and 13.96) and ranked first and fifth among 32 criteria respectively.

From Fig. 3, it can be observed that the criterion MW has a major role in creating social justice in the built environment. It also reveals that with the use of efficient, non-pollutant, and eco-friendly vehicles, there will be a reduction in the emissions and pollutants, further leading to reduced environmental impacts. Similarly, it can be noticed that the use of EE materials and technologies will benefit the user over a period of time. The initial cost may be high, but the cost to benefit ratio would be very low, due to a reduction in operational and maintenance costs. With proper implementation of guidelines and policies with respect to sustainable design principles of the buildings (technological indicator), the criteria, SS, eventually provides the source to attain the allotted weight.

From Fig. 4, it can be noticed that for assessing the performance of a building towards sustainability, the criteria EE has the highest interrelationship weight (6.03) corresponding to Economic indicator, Secondly, MW corresponding to Environmental indicator has a higher weight (5.81). Similarly, SS in Technological indicator (5.54), MW in Social (4.78), and Management (M) in Technological (4.76) indicator. Considering the interrelated weights of criteria and indicators, the average

weights obtained by pooling along with the criteria with regard to Social, Environmental, Economic and Technological indicators (i.e., 2.77, 3.67, 2.66 and 3.45) is taken as a cut off value to observe the effective or most significant criteria responsible for indicator performance. Then, the normalized weights are calculated for criteria and indicators. It is noteworthy to observe that the Technological indicator incorporated along with the Triple-Bottom line (Environmental, Social and Economic) has the highest weight (28.4) among SEET indicators. Similarly, Sustainable sites (SS) and Materials and Waste Management (MW) have achieved higher weights (16.91 and 15.56 respectively) among the 8 criteria.

5 Conclusions

Based on the comparison of LEED, BREEAM, IGBC, and GRIHA assessment tools and guidelines undertaken, the adaptability of various criteria and their corresponding attributes in developing countries like India were observed considering regional variation, culture, heritage, climatic conditions, and topographical aspects. This enabled to explore and bring out the similarities and dissimilarities that exist in the building assessment tools of developed and developing countries.

- The study defines 37 attributes broadly under eight major criteria that are most appropriate for assessment of sustainable performance for construction in developing countries. These criteria include Water Efficiency (WE), Materials and Waste Management (MW), Health and Well-being (HW), Energy Efficiency (EE), Sustainable Sites (SS), Social Welfare (SW), Transportation (T), and Management (M) using Delphi technique and Relative Importance Index.
- The relative weights of criteria and indicators along with the interdependency are calculated using the Fuzzy Analytical Hierarchy Process, a subjective pairwise comparison.
- Among all the criteria, MW has attained the highest relative weight of 13.96 and subsequently, EE attained 13.15 using Fuzzy Analytical Hierarchy Process. It is noteworthy to observe that both these criteria belong to the Technological indicator.
- Among SEET indicators, the Environmental indicator has secured the highest relative weight of 30.15 and the Technological indicator is next to this with a weight of 28.52. The importance of Technological indicator which was not finding a deserved place in the Triple bottom line approach. In this way, the study brought out the significance of the proposed 'Technological' indicator and encouraged the Quadra-Bottom Line approach in implementing and achieving sustainable construction.

Thus, the findings facilitate the incorporation of innovative ideas and implement the concepts of 5R's into sustainable design principles. This interdependency obtained in the study between criteria and indicators facilitates the scope for the development of a framework for a sustainable building assessment in developing countries

like India. These criteria facilitate policymaking, guidelines, and development of a comprehensive green building rating tool.

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