

VIBGYOR: A SUSTAINABILITY ASSESSMENT TOOL FOR RESIDENTIAL BUILDING

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Abstract

Sustainable development is forward looking and also a continuous mission for the development of human society. This paper intends to identify the key indicators of sustainability for residential projects by maintaining a proper balance between the environmental, economic, social and cultural aspects in the design, construction and use of the buildings. A survey has been conducted to identify the principal indicators leading to the success of sustainability principles. Based on extensive literature work, 73 indicators concerning sustainability were summarized. Software Package for Social Science and relative importance index technique was used to find the ranking of the variables. This paper also aims at simulating a tool for the sustainability assessment of residential buildings which can be used by the architects, designers, planners and local bodies as well as it acts as a auditing tool.

Keywords: Sustainability, Indicators, Domains, Relative Importance Index, SPSS, Questionnaire Analysis

1. INTRODUCTION

The Indian construction industry is one of the fastest growing sectors and the current growth rate is more than 10%. Reports say that India is one of the top spending nations of construction in the world. The report 'Global construction 2020', estimates that India will be the third largest global construction market after China. But the current construction management system in the country is suffering from an unplanned economic growth and excessive resource consumption that limits the building a more sustainable infrastructure which is essential for suitable human life [1]. So, now there is a need to highlight the need of sustainability in the present construction industry. The sustainable development movement has been evolving worldwide for almost two decades, and has caused significant changes in the construction industry.

Sustainability is the foundational principle underlying various efforts to ensure a decent quality of life for future generations, i.e. meeting the needs of the present without compromising the ability of the future generations to meet their needs [2]. A subset of sustainable development, sustainable construction, addresses the role of the built environment in contributing to the overarching vision of sustainability. The Council International du Batiment (CIB), an international construction research networking organization defines the goal of sustainable construction is to create and operate a healthy built environment based on resource efficiency and ecological design. The aim is to identify the key indicators of

sustainability and to frame a sustainability assessment tool for residential buildings.

2. SCOPE OF STUDY

The paper aims to develop an effective methodology for assessing the sustainability of the buildings and to develop a strategic model for implementing sustainable aspects in construction. The purpose of the sustainability assessment tool is to gather and report information for decision making during different phases of the design, construction, operation and maintenance of the building. A variety of sustainable assessment tools presently available in the industry are widely used in environmental product declarations. The assessment tools either environmental or performance based, is under evolution because of their limitations. The main goal, at present is to develop and implement a methodology that helps in the designing phase itself. This methodology keeps a proper balance between all the dimensions of sustainability, namely environmental, economical and social aspects. The method will be easily adaptable to all types of building and here especially focusing on residential building.

According to Ness et.al [3], "the purpose of sustainability assessment is to provide decision makers with an evaluation of global to local integrated nature-society systems in short term and long term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable". Ricardo Mateus and Luis Braganca have found out that the average performance level of a

sustainable building is 10% higher than the conventional building practice [4].

In developing countries like India, the increasing population and increasing standards of living due to urbanization, has been a reason in increase of the construction activities [5]. The building along with the resources uses energy and raw materials which are scarce. Also they generate more amounts of solid waste and harmful atmospheric emissions. So the sustainable building and its assessment is aiming to achieve growth in the urban area. The assessment method helps the design engineers, planners, developers, architects, local bodies and the client to understand the principles of sustainable building and its design. The construction industry worldwide has already started adopting the sustainable construction.

3. DESIGN AND RESEARCH METHODOLOGY

The initial step was to choose the most appropriate criteria to formulate an indicator set which will consider the building's performance in relation to the dimensions of sustainability namely environmental, social, culture and economy. The appropriate indicators which forms the basis of framing the questionnaire surveys were selected by reviewing the literatures and the importance of the indicators was found by the survey with a number of professionals by inviting the key people from each of the following disciplines to participate namely architects, engineers and the builders group. A flow chart representing the methodology of tool formulation is shown in fig. 1.

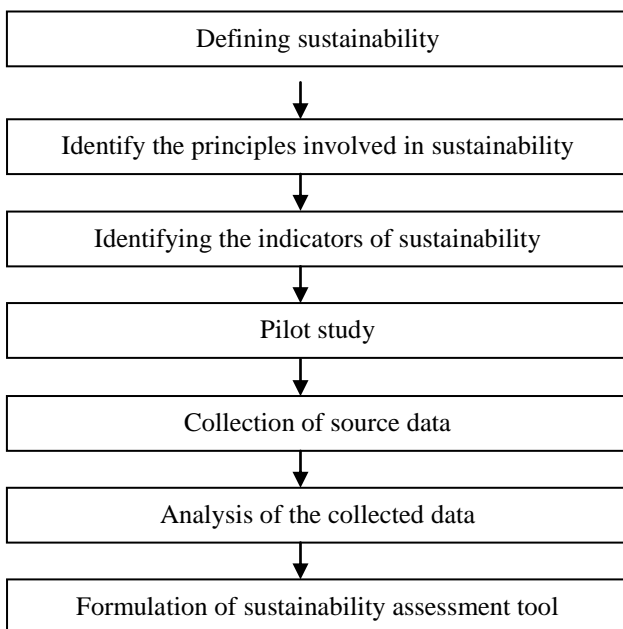


Fig -1: Methodology of the Tool Formulation

The questionnaire was framed which included about 73 indicators under 9 domains. The respondents were asked to

indicate the basic data (which included their name, organization, designation, experience etc.) and rate the indicators as 'very important', 'important' and 'less important'. About 90 questionnaires were circulated in various regions of Kerala and Chennai. 51 responded back indicating a response rate of 57%. The questionnaires were analysed using 'the Software Package for Social Sciences' (SPSS, version 20.0) developed by IBM.

3.1 Development of Indicators

The initial step of framing the sustainability assessment tool is to identify the key indicators of sustainability. Literatures were used to identify the indicators of sustainability. The building assessment methods used for the identification of indicators include BREEAM, LEED, CASBEE and Estidama. Table 1 highlights the features that distinguish each assessment tool. BREEAM and LEED are the most commonly used tools, internationally. Not all the tools consider all the dimensions of sustainability. Estidama is the only tool, among the study, which considers the economic and cultural aspects of sustainability.

Table -1: Comparison of Rating Tools Categories

Items	BREEAM	LEED	ESTIDA	CASBEE
Energy	√	√	√	√
Water	√	√	√	√
Waste	√	√	√	√
Materials	√	√	√	√
Indoor environment quality	√	√	√	√
Economics			√	
Management	√		√	√
Mobility and transportation	√	√	√	
Emission and pollution	√	√	√	√
Land use, site and ecology	√	√	√	
Resources		√		√
Cultural and social			√	

The indicators chosen for this particular study cover all the dimensions of sustainability. For this tool, there are mainly nine domains of sustainability indicators selected and are shown in table 2. Initially about 80 indicators were selected and through iterations it was reduced to 73. Iterations were done by the pilot study in order to check the practicability of the set of indicators.

Table -2: Domains of Sustainability Indicators

Code	Domains
A	Sustainable Site
B	Economic Aspects
C	Water Efficiency
D	Energy Efficiency
E	Material and Resources
F	Indoor Environmental Quality
G	Environment Loading
H	Social and Cultural Aspects
I	Service Quality

There are sub-domains for sustainable site and indoor environmental quality. Sustainable site has got three sub-domains namely site selection, project planning, urban development; indoor environmental quality has got air quality, ventilation, thermal comfort and acoustics as the sub-domains. Questionnaires was preferred as the best effective tool for data collection as it gives each individual as well as company's opinion regarding each indicator of sustainability. The relevant data was collected by a structured, close-ended questionnaire survey.

3.2 Method of Analysis

The software package for social science was used to analyze the information obtained from the questionnaire survey. A 3-point Likert scale was used in which 3 represents 'very important', 2 for 'important' and 1 for 'less important'. The numbers assigned neither indicate that the intervals between scales are not equal nor they indicate absolute quantities. The indicators were measured on ordinal scale as they can be ordered or ranked according to their mean. An ordinal scale is a ranking or rating of data that normally uses integers in ascending or descending order. The reliability analysis was done to check the internal consistency of the responses among the 51 questionnaires and the reliability of the Likert scale. The Cronbach's alpha is used to measure the reliability of the questionnaire between each field and the mean of the whole fields of the questionnaire. The normal range of Cronbach's alpha value is between 0.0 and +1.0 and a higher value reflects a higher degree of internal consistency. The Cronbach's alpha (α) was obtained as 0.947 indicating that the questionnaire is excellent ($\alpha > 0.9$ excellent) and the three-point scale was reliable for the study.[6]

When the statistical data is described in numerical measures it is called descriptive statistics. The descriptive statistics is obtained from the SPSS which include the measures of central tendency and measures of dispersion. The most common and useful measure of central tendency is arithmetic mean. The mean scores for the data obtained were used to find the rank of the indicators. Similarly the relative importance index (RII) for each indicator was found out using equation 1.

$$RII = \frac{\sum W}{A \times N} \times 100 \quad (1)$$

Where 'W', is the weighting or the scale given by the respondent on the Likert scale. A is the highest weight (3, in this case) and N is the total number of sample (51, in this case). The relative importance index percentage was also used to rank the indicators. The relative importance of the indicator set was found out and based on the results obtained the tool was framed.

4. RESULTS AND DISCUSSION

Among the responders, 7 were architects, 13 were builders and 31 were identified as engineers. The engineer category includes project managers, estimation engineer and planning engineer. 39% of the responders were having an experience more than 10 years and 25% of the responders have an experience below 5 years. The mean of the indicators was obtained in the descriptive statistics. The ranking by domain and the overall ranking was done. Similarly the RII for each factor was determined and were ranked accordingly. The results for each domain are shown separately in table 3.

Based on the samples, when the mean rankings of the indicators comprising each domain are added up and divided by the no. of indicators, the average ranking of the domain was obtained, indicating the relative importance. The results show that the indicator 'water quality' has got the highest mean value 2.39 suggesting that this was the most important indicator from the indicator set and has got the rank one. Water quality comes under the sub-domain project planning. Indian construction industry is a water intensive industry. Water quality is followed by effective ventilation in naturally and mechanically ventilated areas. Increasing the ventilation rate can improve the indoor environmental quality. It is followed by Retention of rain water, optimum energy performance and green spaces and trees for shading with rank five. Rain water harvesting is the activity of direct collection of rain water. The main aim of the indicator, optimum energy performance, is to optimize the use of energy systems in buildings that maintain a specified indoor climate conducive to the functional requirements of the building. Trees and green spaces are very important because of the increasing pollution and carbon footprint. The least priority indicator was found to performance indicators with a mean value of 1.31 suggesting that most of the respondents have marked a lesser scale for the indicator.

Table -3: Ranks of the Indicators

Domain	Sub-domain	Indicator	Mean	Rank by domain	Overall ranking	RII ranking
A. Sustainable Site	A1. Site Selection	A1a. Ecological value	1.78	5	54	54
		A1b. Agricultural value	1.61	8	67	67
		A1c. Flooding possibility	2.2	1	8	8
		A1d. Potential to contaminate nearby bodies of water.	1.9	3	34	34
		A1e. Brownfield development	1.69	6	61	61
		A1f. Proximity to public transport	1.98	2	21	21
		A1g. Near to residential area	1.82	4	44	44
		A1h. Near to recreation area	1.59	9	69	69
		A1i. Near to commercial area	1.67	7	63	63
	A2. Project Planning	A2a. Environmental impact of development	1.9	6	35	35
		A2b. Conserve existing natural area	1.9	5	33	33
		A2c. Surface water management system	1.94	4	25	25
		A2d. Water quality	2.39	1	1	1
		A2e. Potable water system	2.18	2	11	11
		A2f. Site orientation	1.98	3	20	20
	A3. Urban Development	A3a. Development density	1.88	4	36	36
		A3b. Provision of public open spaces	1.96	3	24	24
		A3c. Encouragement of walking	1.71	6	59	59
		A3d. support for bicycle use	1.51	7	72	72
		A3e. Alternate transportation	1.78	5	53	53
		A3f. Green space and trees for shading	2.24	1	5	5
A3g. Parking facility		2.14	2	15	15	
B. Economic Aspects	B1a. Initial cost	1.82	4	43	43	
	B1b. Minimize life-cycle cost	2.06	2	17	17	
	B1c. Minimize construction cost	1.98	3	19	19	
	B1d. Minimize operation and maintenance cost	2.22	1	6	6	
	B1e. Renovation and destruction cost	1.8	5	48	48	
C. Water Efficiency	C1a. Effective water use in construction and building activities	2.2	1	9	9	
	C1b. Reduced waste water generation	2.1	2	16	16	
	C1c. Water efficiency in air conditioning system	1.96	3	23	23	
D. Energy Efficiency	D1a. Optimum energy performance	2.25	1	4	4	
	D1b. Use of renewable energy	2.14	2	14	14	
E. Material and Resources	E1a. Reuse of existing structure	1.76	7	56	56	
	E1b. Avoidance of toxic substances	1.92	2	28	28	
	E1c. Use of recycled material	1.8	5	47	47	
	E1d. Cement supplementing material use in concrete	1.76	6	55	55	
	E1e. Minimize finishing material	1.65	8	64	64	
	E1f. Use of local and renewable material	1.92	1	27	27	
	E1g. Use of environmentally compatible material	1.88	3	38	38	
	E1h. Use of certified wood	1.82	4	45	45	
F. Indoor Environmental Quality	F1. Air Quality	F1a. Construction indoor air quality management plan	2.18	1	12	12
		F1b. Minimum exposure to chemical pollutants	1.88	2	37	37
		F1c. Low-emitting interior finishing material	1.78	3	52	52
	F2. Ventilation	F2a. Effective ventilation in naturally and mechanically ventilated spaces	2.27	1	2	2

Table -3: Ranks of the Indicators (continued)

Domain	Sub-domain	Indicator	Mean	Rank by domain	Overall ranking	RII ranking
	F3. Thermal comfort and humidity	F3a. Temperature in naturally and mechanically ventilated spaces	2.18	1	10	10
		F3b. Humidity control	1.92	2	31	31
	F4. Acoustics	F4a. Illumination-light quality	2.2	1	7	7
		F4b. Lighting system degree of control	1.84	4	41	41
		F4c. Noise acoustics	1.92	3	30	30
		F4d. Exterior noise	1.92	2	29	29
		F4e. Efficiency of HVAC system	1.69	5	60	60
G. Environmental loading		G1a. Greenhouse gas emissions during construction and building operations	1.9	4	32	32
		G1b. Annual greenhouse gas emissions from facility operations	1.84	6	40	40
		G1c. Solid waste from construction and building operations	2.16	2	13	13
		G1d. Retention of rain water	2.27	1	3	3
		G1e. Construction impact to soil erosion	1.98	3	18	18
		G1f. Impact on access to daylight to adjoining property	1.86	5	39	39
		G1g. Heat island effect	1.73	7	58	58
H. Social and cultural aspects		H1a. Minimize construction accidents	1.82	2	42	42
		H1b. Access to handicapped persons	1.82	3	46	46
		H1c. Social utility of primary building function	1.8	4	49	49
		H1d. Sanitation to construction workers	1.94	1	26	26
		H1e. Provision of employment opportunities	1.51	5	51	51
		H1f. Cultural value of existing building	1.78	6	65	65
		H1g. Maintain heritage value	1.63	7	71	71
I. Service quality		I1a. Safety and security	1.78	2	50	50
		I1b. Spatial efficiency	1.55	7	70	70
		I1c. Limitation of future risk, exposure and liability	1.61	6	68	68
		I1d. Service life planning and costing	1.69	4	62	62
		I1e. Ability to modify building management system	1.63	5	66	66
		I1f. Adaptability to future changes	1.96	1	22	22
		I1g. Performance incentives	1.31	8	73	73
		I1h. Skilled operation staff	1.73	3	57	57

The results of relative importance index suggest that the ranking was same as that of the mean ranking. The figure 2 shows the mean ranking of the domains of sustainability. On the account of its impacts on the environment as well as its vitality for construction sector; energy efficiency was the domain which is considered to be the most significant domain followed by water efficiency, indoor environmental quality, environmental loading, economic aspects, sustainable site, material and resources, social and cultural aspects. Water preservation as well as efficiency is one of the most important elements in human life and construction sector consumes about 15% of the overall fresh water resources.

The quality of indoor environment is considered as an important domain due to its overlapping features with other domains. It aims at providing a healthy and comfortable indoor place with respect of visual comfort, sound comfort and thermal comfort. The prime goal of the domain environmental loading is to protect the surrounding environment from the negative impacts of the building . in addition it provides healthy and comfortable environment for the building users. The domain service quality obtained the lesser mean ranking. The results suggest that in residential building these domains should be given the priorities in order.

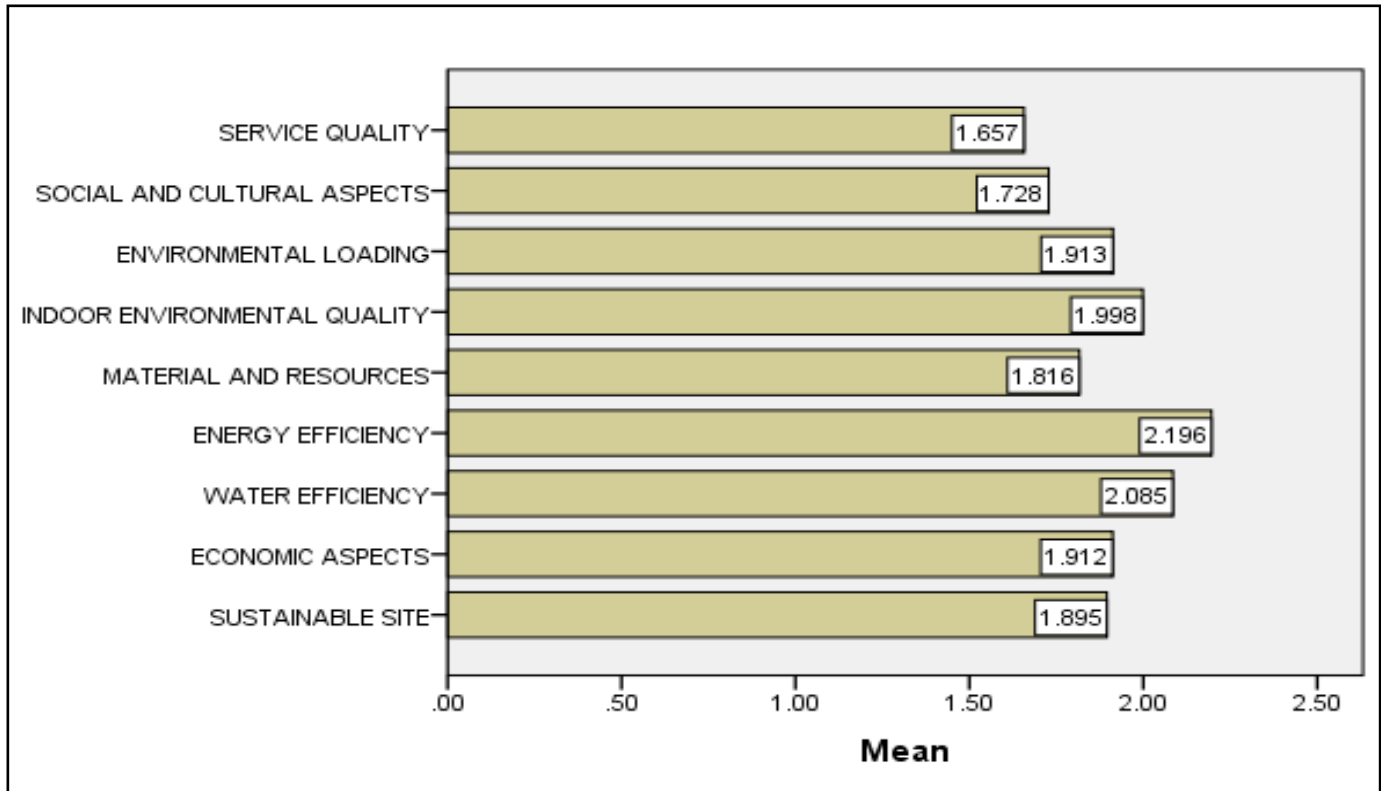


Fig -2: Mean Rankings of the Domains

5. FRAMING OF SUSTAINABILITY ASSESSMENT TOOL

The sustainability assessment tool is an evaluation tool that measures the performance of the building through its life cycle. Based on the mean values obtained from the SPSS, the levels of indicators were fixed. Three levels of indicators were made depending on the ranks. Level one consists of indicators having a mean in the range of 2.00-3.00 because these are the indicators for which the most of the respondents have given a scale of 3 (very important). Level two consists of the indicators with a mean value ranging from 1.80- 1.99. The level three consists of indicators having a mean less than 1.80. According to Lee et.al. [7] weighting is the heart of all assessment schemes since it will dominate the overall performance score of the building being assessed. A three point credit system was awarded to the indicators based on the levels. A level one indicator was awarded with 3 credits, level two with 2 credits and level three gets 1 credit. The credits are awarded only if the criteria lay down by the tool is satisfied by the building. The criteria were fixed with reference to the following manual namely, GRIHA Manual, IGBC rating systems and LEED. These criteria were framed in such a way that it complies with the rules and regulations of the Indian Government and also the practicability of these criteria were considered. Table 4 represents the credits awarded to the

indicators. The code of the indicator is given. The total credits accounts to 133 and for each innovation in any domain one extra credit awarded.

The new tool is given the name 'VIBGYOR'; each colour indicates the badge given to the buildings. If, the building under assessment satisfies all the criteria, then it is awarded with a 'VIOLET' badge indicating that the building is highly sustainable. As the credits obtained reduce, the colour badge obtained is changed. The minimum and maximum credit to each colour badge is given in table 5. For a building to be said as sustainable and to get a sanction, at least it should get a colour badge from 'GREEN'. GREEN indicates the neutral level of the colour badge system. A system which has got a RED badge signifies that it has given least importance for sustainability and the principles of sustainability are not adopted or the least adopted. Unlike the other assessment tools available in the present construction market, this tool considers all the dimensions of sustainability equally and a proper criterion is laid down for all the indicators. The assessment tool VIBGYOR provides a methodological framework to evaluate the sustainability in a building throughout its entire life-cycle design, construction and operation.

Table -4: Credits Assigned to the Indicators

Code	Level	Credits	Code	Level	Credits
A1a	Level 3	1	E1f	Level 2	2
A1b	Level 3	1	E1g	Level 2	2
A1c	Level 1	3	E1h	Level 2	2
A1d	Level 2	2	F1a	Level 1	3
A1e	Level 1	1	F1b	Level 2	2
A1f	Level 2	2	F1c	Level 3	1
A1g	Level 2	2	F2a	Level 1	3
A1h	Level 3	1	F3a	Level 1	3
A1i	Level 3	1	F3b	Level 1	3
A2a			F4a	Level 1	3
A2b	Level 2	2	F4b	Level 1	3
A2c	Level 2	2	F4c	Level 2	2
A2d			F4d	Level 2	2
A2e	Level 1	3	F4e	Level 3	1
A2f	Level 2	2	G1a		
A3a	Level 2	2	G1b	Level 2	2
A3b	Level 2	2	G1c	Level 1	3
A3c	Level 3	1	G1d	Level 1	3
A3d	Level 3	1	G1e	Level 2	2
A3e	Level 3	1	G1f	Level 2	2
A3f	Level 1	3	G1g	Level 3	1
A3g	Level 1	3	H1a	Level 3	1
B1a	Level 2	2	H1b	Level 3	2
B1b	Level 1	3	H1c	Level 3	2
B1c	Level 1	3	H1d	Level 3	2
B1d	Level 2	2	H1e	Level 3	1
B1e	Level 2	2	H1f		
C1a	Level 1	3	H1g	Level 3	1
C1b	Level 1	3	I1a	Level 3	1
C1c	Level 2	2	I1b	Level 3	1
D1a	Level 1	3	I1c	Level 3	1
D1b	Level 1	3	I1d	Level 3	1
E1a	Level 2	2	I1e	Level 3	1
E1b	Level 2	2	I1f	Level 3	2
E1c	Level 2	2	I1g	Level 3	1
E1d	Level 3	1	I1h	Level 3	1
E1e	Level 3	1			

Applicability of the tool: The sustainability assessment tool discussed here can be used to assess the sustainability of residential buildings. This constitutes both single and multi-dwelling units, which includes, single homes, apartments, villas, and bungalow. The local bodies can make use of this tool as checking tool before giving sanctions to the construction of these kinds of buildings. Especially in India, the numbers of multi-dwelling units are increasing as there is an increase in the population of the country resulting in urbanization. The tool will help in perceiving the acceptability of the stakeholders including government, clients, architects, engineering consultants, contractors and suppliers. They can refer as a guide and can help the country to increase the sustainability in construction.

Table -5: Marks Allotted to Each Badge

Badge code	Badge	Range of marks
V	Violet	120-133
I	Indigo	106-119
B	Blue	93-105
G	Green	80-92
Y	Yellow	67-79
O	Orange	53-66
R	Red	< 52

6. CONCLUSIONS

In this paper, the current status of sustainability in the country was studied with the help of the indicators of sustainability. The results from the analysis indicate that individual indicators were given different levels of significance in practice. Among the indicators considered in the building sector, water quality was found to be the most important. The domain which is given the highest priority is energy efficiency. Use of the sustainability assessment tool will greatly simplify the measurement of sustainable development. Even though there are different tools available in the market to assess the building in terms of sustainability, this tool stands for its simplicity. The tool provides a methodological framework to measure and monitor the performance of the building. It can be used as an auditing tool by the local government authorities and as a verification tool too. This tool, similar to the LEED and GRIHA is additive in nature, but the credits awarded were different and aims to develop a common approach to modelling all criteria appropriately for carrying out sustainability. The current research study was limited to the residential buildings and multi-dwelling units in India. In recommendation, the implementation of this new tool requests for the participation of all the stakeholders involved in construction.

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