Developing a Sustainability Rating Tool for Existing Residential Buildings of India

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Abstract: Sustainable building is a multidimensional concept, but attention to the issue often goes solely to environmental criteria, ignoring the substantial importance of social, economic and technical criteria. Inadequate research has been carried out till now to support the development of sustainable performance for existing residential buildings of India taking into consideration the local conditions. The purpose of this research is to provide a better understanding the concept of green building assessment tool and its role for achieving sustainable development through developing a holistic green building rating tool for existing residential buildings in India in terms of the dimensions of the sustainable development and according to the local context. This research assessed international green building rating tools such as LEED, CASBEE, BREEAM, and others and then defined new assessment criteria considering the local conditions of India. A total of 8 main criteria and 37 sub-criteria were adopted for the research. The main assessment criteria were categorized, into the four dimensions of sustainable development viz., environmental, social, economic and technical. Weightages of main criteria and sub criteria were calculated and were multiplied with each other to obtain credit points to be allocated to each sub-criterion and the parameters. Thus the outcome of the research was a suggested green building assessment framework that suits the Indian context in terms of environmental, social, economical and technical perspectives. A user-friendly software interface of the tool was developed in Dev-C++ to make it more easy to use. Finally the tool was validated by performing a case study of a residential hostel in Bangluru and the results were compared with that of GRIHA as the building has already been rated by same.

Key words: **Green building; sustainable development; main criteria; sub-criteria; credit points; dimensions of sustainable development.**

INTRODUCTION

Green building has currently become a flagship of property development during this century that takes the responsibility for reconciliation semi-permanent economic, environmental and social health[20][21]. It offers a chance to form surrounding ally economical buildings by victimization associate degree integrated approach of style so the negative impact of building on the environment and occupants is reduced. classification system provides an efficient framework for assessing building environmental performance and desegregation property development into building and construction processes, because it may be used as a style tool by setting property style priorities and goals, developing acceptable property style methods and crucial performance measures to guide the property style and decision-making processes. It also can be used as a management tool to prepare and structure environmental issues throughout the look, construction, and operations phases.

Green style doesn't solely build a positive impact on public health and therefore the surroundings, it additionally reduces in operation prices, enhances building and structure marketability, will increase resident productivity, and helps produce a property community. Typically inexperienced buildings are energy economical, water protective, sturdy and non-toxic, with high-quality areas and high recycled content materials that presents resolution for big a part of Indian resources issues.

Some of the successful international rating tools

Important successful international rating tools were studied and compared with each other. All the tools have considered different assessment criteria and rate the buildings differently based on their certification criteria. Some of the well-established tools are discussed in detail as following.

1. BREEAM Building analysis Establishment's Environmental Assessment methodology (BREEAM) was developed within the UK in 1990 and is one among the earliest building environmental assessment strategies. BREEAM covers a variety of building varieties as well as offices, homes, industrial units, retail units, and colleges. Once a building is assessed, points are awarded for every criterion and therefore the points are side for a complete score. the general building performance is awarded a 'Pass', 'Good', 'Very Good' or 'Excellent' rating supported the score. BREEAM has separate criteria (checklist) for analysis of style and procurance and for Management and Operation of buildings. There's additionally a group of core credits that may be applied for, just in case if the building desires to travel sure 'Core only' assessment for building performance.

BREEAM major categories of criteria for Design and Procurement include the following:

1). Management (commissioning period and process adopted, monitoring of commissioning, energy use in site activities, waste management, pollution minimization).

2). Health and comfort (adequate ventilation, humidification, presence of controllable blinds, energy efficient lighting, thermal and visual comfort, low noise levels).

3). Energy (sub-metering).

4). Transport (modes of transport to and from site, alternative transport facilities).

5). Water (consumption reduction, metering, leak detection).
6). Materials (asbestos mitigation, storage facilities, reuse of structures, specifications of envelope, use of crushed aggregate and sustainable timber).
7). Land use (previously used land, use of re mediated contaminated land).
8). Ecology (land with low ecological value or minimal change in value, maintaining major ecological systems on the land, minimization of biodiversity impacts).
9). Pollution (leak detection systems, on-site treatment, local or renewable energy sources, light pollution design, avoid use of ozone depleting and global warming substances).

2. CASBEE Comprehensive Assessment System for Building Environmental potency (CASBEE) was developed in Japan, in 2001. The family of assessment tools relies on the building's life cycle: pre-design, new construction, existing buildings, and renovation. CASBEE presents a replacement thought for assessment that distinguishes environmental load from environmental quality and building performance.

CASBEE major categories of criteria include:

Building Environmental Quality and Performance

1). Indoor atmosphere (noise and acoustics, thermal and visual comfort, and indoor air quality).
2). Quality of services (functionality and usefulness, amenities, sturdiness and reliability, flexibility and adaptability).
3). out of doors atmosphere on website (preservation and creation of biotope, townscape and landscape, native characteristic and out of doors amenities).

Building Environmental Loadings

1). Energy (Building thermal load, utilization of natural energy, potency in building service systems and economical operations).
2). Resources and materials (water conservation, materials of low environmental loads).
3). off-site atmosphere (air pollution, noise and vibration, odour, daylight obstruction, lightweight pollution, heat island impact, and cargo on native infrastructure).

3. LEED Leadership in Energy and Environmental style (LEED) was developed and piloted within the USA in 1998 as a accord primarily based building scoring system supported the employment of existing building technology. The scoring system addresses specific environmental building connected impacts employing a whole building environmental performance approach. The Indian inexperienced Building Council has tailored LEED system and has launched LEED India version for rating of latest construction. Additionally, Indian inexperienced Building Council (IGBC) has launched many alternative product for rating of various typologies of buildings as well as homes, factories, among others.

4. GRIHA stands for inexperienced Rating for Integrated environment Assessment, the National classification system of India. Internationally, voluntary building rating systems are instrumental in raising awareness. However, most of the present rating systems are tailored to suit the building trade of the country wherever they were developed. That's why The Energy and Resources Institute (TERI), together with the Ministry of latest and Renewable Energy (MNRE) of India, took the responsibility of developing a tool for activity and rating a building's environmental performance within the context of India's varied climate and building practices. GRIHA could be a building 'design analysis system' that is appropriate for every kind of buildings. The aim is to attenuate the demand for non-renewable resources by specializing in reducing water and energy consumption, limiting waste generation through use, and reducing pollution. The first objective of the classification system is to assist style inexperienced buildings and, in turn, facilitate appraise the 'greenness' of buildings. The classification system follows best practices beside national/international codes that square measure applicable to the inexperienced style of buildings. The stages of the life cycle that are known for analysis square measure pre- construction, building style and construction, and building O&M (operation and maintenance). GRIHA emphasizes value effectiveness and therefore the integration of ancient heritage with scientific tools. GRIHA could be a rating tool that helps individuals assess the performance of their building against bound across the country acceptable benchmarks. It'll appraise the environmental performance of a building holistically over its entire life cycle. Associate in nursing appraisal of the rules and criteria could also be done each 3 years. The govt of India, the MNRE specifically, has recently proclaimed that everyone government buildings should be at a minimum 3-star GRIHA compliant. Additionally, the Energy Conservation codification (ECBC) has been created necessary in eight States of India. GRIHA could be a 5 star classification system for inexperienced buildings that emphasizes on passive star techniques for optimizing indoor visual and thermal comfort. So as to deal with energy potency, GRIHA encourages optimisation of building style to cut back standard energy demand and more optimize energy performance of the building at intervals fixed comfort limits. A building is assessed on its expected performance over its entire life cycle from origination through operation.

Problem Statement

The construction sector poses a serious challenge to the setting. Globally, buildings are chargeable for a minimum of four-hundredth of energy use. Associate in Nursing calculable forty second of the world water consumption and five hundredth of the world consumption of raw materials is consumed by buildings once taking under consideration the manufacture, construction, and operational amount of buildings. additionally, building activities contribute Associate in Nursing calculable five hundredth of the world's pollution, forty second of its greenhouse gases, five hundredth of all pollution, forty eighth of all solid wastes and five hundredth of all CFCs (chlorofluorocarbons) to the setting. India too faces the environmental challenges of the development sector. The assessment ways created for one nation or region won't be applicable to different as a result of range of things could forestall the transfer of presently accessible setting assessment tools to other nations. a number of these factors embody website conditions, climate, geography, resource consumption and level of public awareness. India exhibits a spread of various climates, cultures and topographical options and would like implementing a domestic assessment methodology of activity building performance. But LEED tried to create their assessment tools compatible with conditions of various regions within the World. But

it's discovered that they weren't able to totally incorporate the social, economic and cultural components within the property assessment criteria. Considering the requirement for developing a domestic building assessment tool, GRIHA, the national inexperienced building scoring system, was developed by TERI (The Energy and Resources Institute) in 2007 when an intensive study and understanding of this internationally accepted inexperienced building rating systems and therefore the prevailing building practices in India. However from keen observations it absolutely was found that a number of the criterion like Transportation and Management weren't thought of in GRIHA for environmental assessment. Therefore there's a desire to develop a property criterion framework considering the complete assessment criterion appropriate to native website conditions. Complete details concerning the criterion insulating material in GRIHA are mentioned within the following chapters.

Moreover all the prevailing rating tools are minded towards environmental property assessment. There are presently no specific assessment tools that embrace the economic, social and technical aspects within the assessment criteria. This means disregard of the economic, social and technical aspects of property that could lead on to a loss of balance among property dimensions, thereby missing the important goal of property development. Hence, there exists a desire to search out the importance of environmental, economic, technical and social aspects of property.

Literature Review

1. Ali and Al Nsairat (2009)[1] recommended that Jordan is one of the countries with lack of water resources, thereby 'Water efficiency' criterion is given a higher priority in the rating tool. The water efficiency parameter included 27.7% of the credit points. This is then followed by the 'Energy efficiency' criterion. The main credit criteria for the rating tool have been identified as 'Site', 'Energy efficiency', 'Water efficiency', 'Material', 'IEQ', 'Waste and pollution' and 'Cost and economics'. In this research, it is argued that, for developing countries like Jordan, 'economic pillar' of sustainable development is essential and therefore, it is necessary to include the last credit criteria i.e. 'Cost and economics' to the rating tool. Therefore, in this green building rating tool, 10% of the credit points are attributed to economic criteria. In this green building tool all the three aspects, namely environmental, social and economic are represented through different credit criteria.

2. Anshul P Gujarathi (2016)[2] inexperienced Buildings may be created value neutral with the correct implementation of strategy at the proper facet. Maintaining the balance between {the value|the price} raise and price decrease a neutral approach may be earned wherever in an exceedingly premium rating at no extra cost may be realised. The advantages on the life cycle performance are the other advantage for the project with long terms savings. Each activity related to inexperienced is for the broader reason behind the property parameter and invariably proves helpful to each neutral directly or indirectly. An enough economic come on energy-efficiency investments is crucial for the property development of the inexperienced building business. The priority of setting and property development has been accumulated recently. These issues force the countries to adopt variety of policies that enhance energy potency and apply baseline parameters in accordance with international standards. Inexperienced building has currently become a forefront of property development during this century that takes the responsibility for reconciliation long economic, environmental and social health. It offers a chance to form environmentally economical buildings by victimisation associate degree integrated approach of style.

3. Apoorva V.Kotkar (2017)[3] the conclusion for the studies can be classified into three different categories i.e. definitions and scope of green building, benefits and costs of green building and ways to achieve green building. It has been observed that in most of the literature reviews, the focuses are on environmental aspects of sustainability such as energy consumption, water efficiency and greenhouse gas emissions and also with their technical solutions. Also, the life cycle assessment approach, which is extensively applied in the environmental aspects of green building can be a useful tool for social sustainability. New rating tools are developing rapidly worldwide. But more studies in these fields are required to support these new rating tools and also help in assisting the decision-making for the investors and the developers.

4. Dakhole Namita .G (2017)[4] conducted associate degree investigation into the international evolution of property rating tools for buildings, preponderantly workplace buildings. Whereas it's currently been wide acknowledged that buildings square measure a serious contributor to carbonic acid gas emissions, the main target is on a way to use rating tools from a world perspective. In associate degree era of international property investment wherever it's doable to directly compare values of individual buildings in several countries with a read to potential acquisition, sadly rating tools don't exhibit identical level of likeness thanks to their distinctive characteristics and focus. This successively might hinder the take-up rate of property rating tools and even be a barrier to increasing the data regarding property and buildings.

5. Elena Bernardi, et.al (2017)[5] discovered "all rating systems for assessing the environmental impact of buildings are suitable for both new and existing buildings and, apart from the SBTool, cover the refurbishment of buildings as well; BREEAM, CASBEE, DGNB, and HQETM can be used to assess all types of buildings, while LEED does not cover industrial buildings and the SB Tool is the most limited since it does not cover urban planning projects, and building types other than residential, office, commercial, and educational buildings; BREEAM, CASBEE, DGNB, and HQETM cover all the life cycle phases of a building; SB Tool is the only system that has also been designed for certifying a low performance level of a building; Regarding the categories assessed by the schemes, energy performance, solid waste management, material and water are the most considered categories from a quantitative perspective. The categories that are considered less are resistance against natural disasters, earthquake prevention, and olfactory comfort."

6. Hikmat H. Ali, et.al (2008)[6] studied international inexperienced building assessment tools like LEED, CASBEE, BREEAM, GB Tool et al.. Then outlined new assessment things respecting the native conditions of Jordan and mentioned them with varied stakeholders; five hundredth of them were specialists of property development. When choosing the assessment things they were weighted victimisation the AHP methodology. The end result of this analysis was a prompt inexperienced building assessment tool (SABA inexperienced Building Rating System) – that suits the Jordanian context in terms of environmental, social and economic views.

7. ILIYAS IKBAL SANDE (2015)[7] there square measure several factors that need to be thought of whereas constructing a inexperienced building. It's terribly necessary to grasp however effective a specific project is in term of its atmosphere friendliness. This temporary comparison would check the building on varied points therefore on provides a honest plan of wherever it stands in being an inexperienced building. Each rating systems square measure ok to be utilized in sure a part of the country however they're not distinctive in nature. Since these 2 systems square measure supported completely different parameters, there's an occasion of the each rating systems rate constant buildings otherwise. Conjointly they're quite advanced in nature and don't essentially provides a clear plan of the homes effectiveness. Every system has sure robust points and sure weak points and that they aren't specific on some assessment criteria. Because of this each systems square measure presently confusing the Indian developers, builders over the certification of their homes and buildings. As from on top of comparative study of LEED and GRIHA scoring system some appropriate points for inexperienced building that is straightforward and effective is usually recommended for little contractors to realize inexperienced agenda merely and economically. Now is Associate in Nursing integration of varied points like it carries the benefits of each system wherever because it overcomes the individual shortcomings.

8. Mohamed Taifour, et.al (2013)[8] set the objective of their research as to develop an environmental assessment methodology for existing buildings in Syria that represent the Syrian construction professionals' opinion which can be generalized to similar construction markets in other developing countries. This research concluded that the comparison between those standards coupled with those standards identified by the questionnaire reveals more interest to cover the main environmental aspects for its environment as identified by LEED with the highest weight given for energy while the lowest weight is given for water efficiency. "Innovation and Regional Priority" was largely excluded. This is why they want to develop a methodology that suits the current existing environmental aspects of buildings in Syria.

9. M. Chethana et.al (2017)[9] identified eight rating tools based on the extent of usage worldwide, namely, LEED, BREEAM, Green Star, GBI, Green Mark, BEAM Plus, IGBC rating, and CASBEE. The key credit criteria have been identified as 'Site', 'Energy', 'Water', 'IEQ', 'Material', 'Waste and pollution', and 'Management'.

The majority of the credit criteria of six out of eight rating tools could be successfully allocated into these key credit criteria except for IGBC and CASBEE. Therefore, these seven key credit criteria can be established as the main parameters in evaluating green buildings.

- 'Energy' criterion has the highest consideration followed by 'Water; and 'IEQ' criteria respectively in green building rating tools. In contrast, 'Management' criterion is not that much considered in the tools even though it is identified in the literature to a greater extent.
- CASBEE rating tool follows a different allocation of credit points, and also it focuses on many credit criteria which are not identified by others. The reason to this is the difference in geographical location, and CASBEE is developed to cater those requirements of that region.

10. Müjde Altın (2016)[10] Most of the GBRSs have similarities in common more than differences. This is due to the fact that all of these systems are trying to help us create a better world and leave our children a better and cleaner world. Therefore, the principles are and should be nearly the same: principles to decrease the harm given to the environment. GBRSs are assessing the buildings according to environmental/ecological and economic issues today. In addition to the environmental and economic aspects, there is also the social aspect of sustainability. In order to have a proper assessment, social aspect also has to be taken into consideration during the assessment process. Most of the GBRSs in the world are assessing the ecological therefore green building properties of the buildings. Therefore they are called as "Green Building Rating Systems". But the trend is towards creating "Sustainable Buildings" than "Green Buildings". As a result, towards the future real sustainability of the buildings will be assessed. It is seen in the change of the name of SB-Tool. Formerly, it was called as GB-Tool, short for "Green Building Tool". It was assessing how green the buildings were. But in time it was developed and social aspects are added inside the assessment criteria. Then its name was changed into SB-Tool, short for "Sustainable Building Tool". All the GBRSs are still being developed and most probably one day they will turn into "Sustainable Building Rating Systems" or "Sustainable Building Assessment Tools" as GB-Tool had turned into SB-Tool. The name doesn't matter, but they will be better than today and they will help creating more sustainable built environment by helping to create more sustainable buildings.

11. Neda Ziabakhsh and Maryam Bolhari (2012)[11] it's suggested to undertake more investigations among different widespread and widely-used rating systems to search out comprehensive solutions. Besides, the vital note is that in action, a number of the rating systems live environmental impacts and don't live property. So, the excellent answer need to be designed in a very thanks to live property focused. What is more, before the presentation of the excellent answer, the characteristics which may have an effect on its acceptance should be known and measured.

12. Ricardo Mateus et.al (2010)[12] recommended that the sustainable design, construction and use of buildings are based on the best trade-off between environmental pressure (relating to environmental impacts), social aspects (relating to users' comfort and other social benefits) and economic aspects (relating to life-cycle costs). Sustainable design strives for greater compatibility between the artificial and the natural environments without compromising the functional requirements of the buildings and the associated costs. This paper contributes to the evolution of generic methodology and international understanding by introducing an approach that takes the different dimensions of sustainability into account and incorporates a standardized LCA method to assess the environmental dimension. This paper presented the SB Tool methodology, whose scope is to assess the sustainability of existing, new and renovated residential buildings in urban areas, specifically in the Portuguese context. Although this paper only presented the SB Tool module to assess the sustainability of residential buildings, the approach used in the other modules is based in the same framework.

13. Richard Reed, Anita Bilos et.al (2009)[13] conducted an investigation into the international evolution of sustainable rating tools for buildings, predominantly office buildings. While it has now been widely acknowledged that buildings are a major contributor to CO2 emissions, the focus is on how to use rating tools from a global perspective. In an era of international property

investment where it is possible to directly compare values of individual buildings in different countries with a view to potential acquisition, unfortunately rating tools do not exhibit the same level of comparability due to their unique characteristics and focus. This in turn may hinder the take-up rate of sustainable rating tools and also be a barrier to increasing the knowledge about sustainability and buildings.

14. Raji Banani, et.al (2016)[14] projected a framework for developing domestic property non- residential building assessment criteria for Saudi Arabia. To make this framework, 5 major building assessment ways were compared with relevancy their application ways, major characteristics and classes. Surveys were conducted with a spread of Saudi property construction consultants. 9 criteria and thirty six sub-criteria were outlined during this study for inclusion because the most acceptable assessment criteria for property non-residential construction in Saudi Arabia. These criteria embody water potency and energy potency, indoor air quality, materials choice, effective management, land and waste, whole-life price, quality of service and cultural aspects.

15. Sharad R. Khese, M.N.Hedaoo, B.A.Konnur (2016)[15] all four rating systems are ok to be utilized in bound a part of the country however they're not distinctive in nature. Since these systems are supported totally different parameters, the higher than four rating systems rate a similar buildings otherwise. Conjointly they're quite complicated in nature and don't essentially provides a clear plan of the homes effectiveness. Every system has bound robust points and bound weak points and that they don't seem to be specific on some assessment criteria. We should always provide preference for choice of inexperienced building classification system in following manner LEED, BREEAM, GHRIHA and inexperienced STAR. However, it's not simply the ultimate conclusion that matters, however the total review method itself. The knowledge, analyses, valuations and comparisons throughout the method would facilitate architects, developers, managers, etc. to own higher insight into property rating tools. They supply a scientific and valuable reference supply for varied analysis that are associated with property development.

16. Shraddha Pandey (2016)[16] states that "In a developing country like Malaysia, the construction industry needs to develop and grow rapidly in the coming decades. In this era of real and anticipated energy crises, as the building sector continues to be one of the largest consumers of energy, it is extremely important that we optimize energy usage by buildings, all around the world. Green building rating systems can play a significant role in promoting this shift toward energy efficiency. But unlike the technologies called upon in other fields of endeavour, the technology needed to create energy efficient buildings demands indigenous knowledge, and different set of solutions in different parts of the world. Any green building rating system must strike a balance between the dynamics of user response, vernacular requirement, positive awareness, and the goal of large-scale energy saving. GBI as a rating system has a long way to go before it can become sufficiently successful in pushing building developers and architects to make efforts towards creating sustainable green buildings. It needs to reassess its structural framework, in light of users' response to it."

17. Vivian W. Y. Tam et.al (2013)[17] analyzed the credit points of the selected international green building rating tools based on the extent to which those credit points reflect the three pillars of sustainability. The main focus on green building rating tools was environmental sustainability. When considering the eight green building rating tools considered in the research, except for CASBEE rating tools, all tools allocated the majority of credit points to environmental sustainability. Social sustainability was considered by all the green building rating tools. Generally, up to 20% of the credit points reflected the social sustainability of buildings, which is evident from table:

Green building rating tool	Environmental sustainability (%)	Social sustainability (%)	Economic sustainability (%)	Other (%)
Green Star	75.00	18.00	0.00	7.00
LEED	74.59	18.03	0.82	6.56
BREEAM	74.62	16.15	2.31	6.92
Green Mark	77.40	18.64	0.00	3.95
GBI	69.57	21.74	0.00	8.70
BEAM Plus	56.43	29.29	0.00	14.29
IGBC	79.55	14.77	0.00	5.68
CASBEE	25.00	17.95	0.00	57.05

18. Yu et al., 2015 identified[18] seven credit criteria for developing a rating tool for green store buildings in China. These credit criteria are 'Landscape', 'Energy efficiency', 'Water efficiency', 'Material and resources', 'IEQ', 'Construction management' and 'Operation management'. It was illustrated that due to the specialized characteristics of stores, such as significant depth, high occupant density and intensive use of air conditioning, credit criteria such as 'IEQ', 'Energy consumption' and 'Operational management' should be given priority. The significance of these criteria depends on these specialized characteristics. Therefore, when identifying the credit criteria, it is a necessary focus on the type of building that is considered. In this green building rating tool, the weightages for these credit criteria are given as follows; Landscape – 15%, Energy efficiency – 35%, water efficiency 10%, Material and resources -15% and IEQ- 25%.

19. Vyas and Jha (2016)[19] evaluated widely used green building assessment tools such as BREEAM, LEED, SB-Tool, CASBEE, LEED India, Green Rating for Integrated Habitat Assessment (GRIHA) and Eco-housing to develop a suitable assessment tool for India. This research extracted nine components for green building assessment namely; site selection, environment, building resources and re-use, building services and management, innovative construction techniques, environmental health and safety, mechanical systems, indoor air quality and economy.

Inference of Literature Review

It is clear from the above mentioned works that there is not a single proper sustainability rating framework to assess the sustainability aspects for existing residential buildings of India. Such tools have been developed in foreign countries but all are framed in their respective native context. So to check the environmental degradation and reckless resource exploitation in India and along the globe, it is necessary to develop a tool in Indian context which could rate the sustainability level of buildings.

Research Methodology

The study was designed to first establish vast assessment criteria for sustainable buildings in India through qualitative research methods. Refinement of the assessment criteria was the next step to derive a suitable set of criteria. In this step the local context of India was discussed and it was agreed to consider the local site conditions, environment conditions, topography, economic and social aspects, criteria lagging in GRIHA and level of awareness. Based on content analysis, irrelevant criteria were excluded from the criteria list. The resultant criteria were then used to develop priorities and weights through quantitative research methods. The questionnaire technique was used by reconfiguring the refined criteria results into a set of pair wise comparisons in order to determine the relative weights of the derived criteria. This study adopted the Analytic Hierarchy Process (AHP) method to identify the relative importance of criteria through the development of a weighting system. Project data was drawn from three main sources literature, comparison of existing assessment tools and survey questionnaires.

To determine the initial set of criteria, an analysis of the major green building rating systems, which are considered by far the most comprehensive and methodological tools developed to examine sustainability issues was carried out. The review focused on the strengths and weaknesses, as well as the elements of success of implementation of these systems. The overall approach of the research is based on conducting surveys within focused group to identify the categories, indicators and parameters that should be involved in the assessment system and to define weighting for each of them. The focused group includes stockholders, designers, contractors, experts, decision makers, laymen, members of engineering association, etc.

The various assessment criteria were defined and benchmark values of various parameters were set to allocate credit points while building assessment process. This all resulted in development of a green building assessment tool for existing residential buildings in India, as the usage domain of the tool was already fixed. Finally this tool was validated by performing a case study of a residential building. All the stages of this research are shown in the following figure-1.

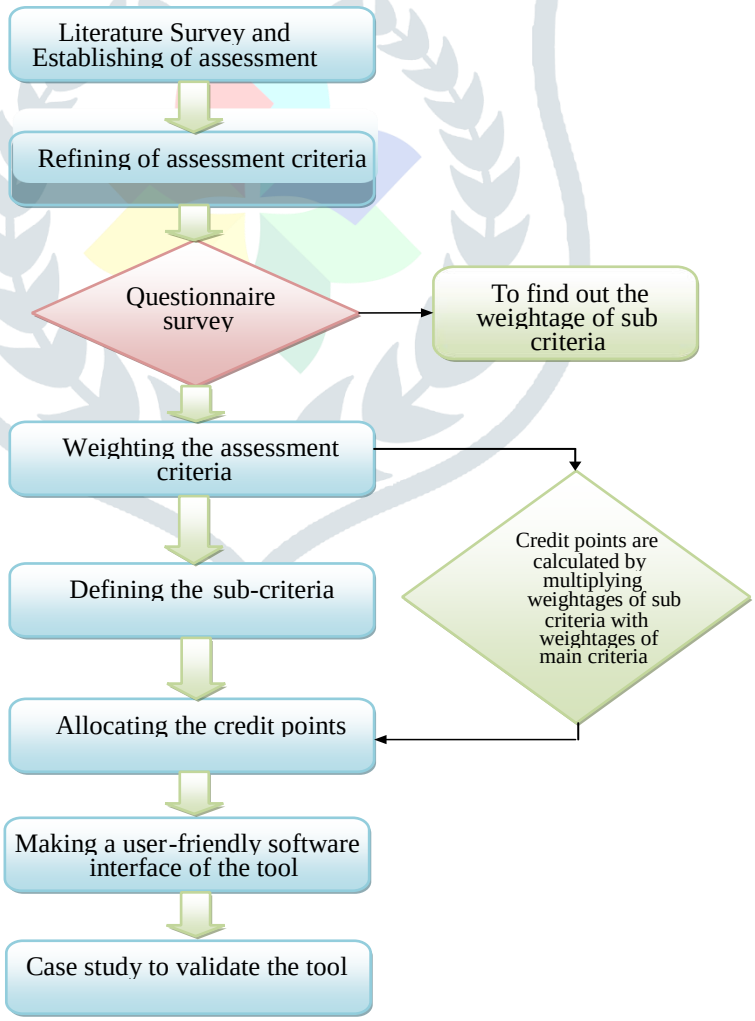


Figure-1 Flow Chart representing Research Methodology

● **Literature survey** from the literature review it is evident that there is not a single sustainability rating tool developed as per Indian context to access the sustainability aspects of the Indian residential buildings.

● **Establishing of assessment criteria** To determine the initial set of variables and indicators, an analysis of the major green building rating systems which are considered by far the most comprehensive and methodological tools, was carried out. The assessment focused on the strengths and weaknesses, as well as the elements of success of implementation of the systems. A wide literature review also helped to establish the assessment criteria more comprehensively. Three performance assessment tools were selected for appraisal, due to their popularity and widespread usage BREEAM which was the predecessor of all green building assessment tools, LEED which is one of the most comprehensive and widely recognized building environmental assessment schemes and GRIHA which is a popular Indian building rating framework developed by TERI. There are various categories comprehensively established by the building assessment tools for BREEAM and LEED. These categories are noted in Table-A, with their indicators and sub-indicators. These categories were reviewed with reference to the subject location (India) and the findings incorporated into the proposed framework.

Table-A Categories of Assessment

Categories	BREEAM	LEED
Sustainable site and Ecology		
Ecological status		
Biodiversity protection	✓	✓
Contaminated Land	✓	✓
Enhancing site Ecology	✓	✓
Ecological impact	✓	✓
Construction site		
Site protection	✓	✓
Site selection	✓	✓
Site Development	✓	✓
Energy		
Natural Resources		
Renewable energy strategy		
	✓	✓
Energy performance		
HVAC		
Lighting (internal)	✓	✓
Lighting (external)	✓	✓
Ventilation	✓	×
Heat transmission	✓	✓
	✓	✓
Operational		
Energy monitoring		
Optimizing energy		
CO2 reduction strategy	✓	✓
Insulant GWP	✓	✓
	✓	✓
	✓	×
Operational		
Energy monitoring		
Optimizing energy	✓	✓
CO2 reduction strategy	✓	✓
Insulant GWP	✓	✓
	✓	×
Water and Waste management		
Water		
Water consumption		
Indoor water reduction	✓	✓
Outdoor water reduction	×	✓
	×	✓
Irrigation system		
Rain water harvesting		
Water conservation/metering	✓	✓
Grey water recycling	✓	✓
Waste water technology	✓	✓
	✓	✓
	✓	✓
Waste		
Construction waste management		
Waste treatment	✓	✓

Recycling Activities	✓	✓
	✓	✓
Social aspect		
Equity		
Education	×	×
Participation	×	×
Social Cohesion	×	×
	×	×
Materials		
Low environmental impact materials		
Renewable natural materials	✓	✓
Insulation	✓	✓
Source of raw material	✓	✓
Re –use of structural material	✓	✓
Use of non- structural frame material	✓	✓
Use of finishing material	✓	✓
Efficient use of material over if life cycle	✓	✓
	✓	✓
Economic Aspect		
Operation and maintenance cost		
	✓	✓
Pollution		
Prevention of refrigerant leakage		
	✓	×
NO_2 emission		
CO_2 emission	✓	✓
Night light	✓	✓
Noise pollution	✓	✓
Watercourse pollution	✓	✓
Natural disasters	✓	✓
	✓	✓
Innovation		
Exceptional performance		
Innovation in design		
	✓	✓
Transport and Location	✓	✓
Accessibility		
Car park capacity		
Pedestrian access	✓	✓
Cycling safety	✓	✓
Density development	✓	✓
Community connection	✓	✓
	✓	✓
	✓	✓
Indoor Environment & Health		
Ventilation		
CO2 monitoring		
Provision of natural ventilation	✓	✓
Ventilation system	✓	✓
Fresh air supply	✓	✓
	✓	✓
Lighting and Illumination		
Daylight		
View out and Glare control	✓	✓
Lighting control	✓	✓
Illumination level	✓	✓
	✓	✓
Noise and acoustics		
Noise level		
Sound insulation		
	✓	✓
	✓	×
Contaminate level		
Volatile organic compounds (VOC)		
Microbiological contaminate level		
	✓	✓

	✓	✓
Thermal comfort		
Cooling/heating and humidity control	✓	✓
Proper zoned control	✓	✓
Management		
Commissioning		
Construction site management	✓	✓
Consultancy	✓	×
User guide	✓	×
Security	✓	×
	✓	×

✓-Considered
×- Not considered

Many of the parameters were not found in GRIHA which were identified as prominent in other international tools. Details about the criterion lagging in GRIHA are shown in Table-B.

Table-B Criteria lagging in GRIHA

Indicators	**GRIHA**	**LEED**	**BREEAM**
Light pollution reduction	×	✓	×
Site improvement plan	×	✓	✓
Water monitoring/water metering/water leak detection and prevention	×	✓	✓
Cooling tower water use reduction	×	✓	×
Visual comfort/ interior lighting/daylight	×	✓	✓
NO_2 emissions/ water runoff	×	×	✓
Alternative transportation/ Green vehicles/green transport/ Public transport accessibility	×	✓	✓
Proximity to amenities	×	✓	✓
Maximum car parking capacity/reduced parking footprint	×	✓	✓

● **Refining the assessment criteria** to refine the list of assessment criteria the local context of India has been discussed and considering the local site conditions, topography, economic and social aspects, criteria lagging in GRIHA and level of awareness. From the wide range of parameters following set of criteria, given in table-C has been finalized for the research. The set of criteria contains the parameters which are necessary to measure the contribution of greenness of an existing residential building in India towards the environment. After refining, eight main criteria and a total of 37 sub-criteria have been derived and considered in the assessment.

Table-C Assessment criteria

S.no	**Assessment Criteria**	**Assessment Sub-criteria**
1	Water Efficiency	● Water monitoring and leak detection ● Building water use reduction ● Recycle and reuse of water ● Rainwater management ● Reduction in landscape water requirement
2	Materials and waste management	● Low-energy materials ● Regionally available materials ● Recycled and re-use materials ● Responsible sourcing ● Efficient waste management
3	Health and well-being	● Water quality & water pollution ● Outdoor & indoor noise levels ● Sanitation/Safety facilities & Accessibility ● Minimize ozone depletion
4	Energy efficiency	● Renewable energy production ● Energy efficient appliances ● Energy monitoring ● Reduction in energy consumption associated with interior lighting ● Adequate daylight

		• Energy efficient Vertical transportation systems
5	Sustainable sites	• Site selection • Protect or restore habitat • Heat island reduction • Open space
		• Light pollution • Conservation of soil surrounding the building
6	Social welfare	• Awareness towards sustainable issues • Efficient ventilation • Design for durability
7	Transportation	• Public transport accessibility • Use of bicycles by the residents • Proximity to amenities • Environmental friendly pavements at the building site • Reduced parking footprint
8	Management	• Managing the balance between the building and its immediate surrounding • Managing fire prevention facilities • Preventing the reckless dumping of polythene products at building site

● **Weighting the assessment criteria** There are 37 sub-criteria distributed among 8 main criteria. These assessment criteria have been defined and credit points to each criterion have been allocated in the next chapter. It was necessary to have the weightages of these criteria in order to calculate the credit points. Weightages of main criteria have been tabulated in next chapter (table 4.3) and weightage of the sub-criteria is found by conducting a survey. In responding to the questionnaire, respondents were invited to indicate the level of significance of each assessment criteria obtained in the Table-C with respect to all sustainable dimensions (economical, environmental, social and technical) by assigning a score between 1 and 5. Table-D shows the scale used in the survey.

Table-D The scale to define the preference of criteria in AHP

Intensity of importance	Definition
1	Least important
2	Slightly important
3	Moderately important
4	Important
5	Very important

The survey was conducted to find the importance weightage of sub-criteria in the main criterion category under which they have been put. In this survey a total of 13 respondents have been taken and were asked to rank the sub-criteria according to their importance. In responding to the questionnaire, respondents were invited to indicate the level of significance of each assessment criteria by assigning a score between 1 and 5 (Likert's scale). The method of calculating the weightages is very simple and transparent. In this method weightage of a sub-criterion in a particular main criterion is found by dividing the summation of responses for that particular sub-criterion by the summation of responses of all the sub-criteria in that main criterion. The calculation method is explained below for the main criterion with the help of table-E and equations 1 and 2.

Table-E Designation of sub-criteria

	Sub-criteria	Sum of scores from responses
Criteria	Sub-criteria 1	X_1
	Sub-criteria 1	X_2
	Sub-criteria 3	X_3
	Sub-criteria 4	X_4
	Sub-criteria 5	X_5

X1+X2+X3+X4+X5= a **1**

Resultant weight of any sub-criteria = Sum of scores of that sub-criteria÷a **2**

● **Defining the sub-criteria and allocation of credit points** A total of 37 sub-criteria have been selected after going through an extensive literature review and a meticulous study of the most common and most dynamic sustainability building rating tools, like LEED, BREEAM, CASBEE, GRIHA, etc. In order to make the tool more easy to use, efforts have been given to make most of

the indicators quantifiable. The various sub criteria are described in next chapter. Credit points, to be allocated for each sub-criterion are calculated by multiplying the weightage of sub-criterion with the overall weightage of the corresponding main criterion to which the sub-criterion belong. From this it is clear that the total sum of the credit points is 100. Each sub-criterion is defined with the help of some parameters and the credit points are finally distributed among those parameters. Credit points are distributed either equally among the parameters or with the help of normalized scores obtained from various well established tools. The overall assessment result of a building (total sum of credit points obtained) is called *greenness value* and its value can always be less or equal to 100. The method of calculation of the greenness value is shown in figure-2.

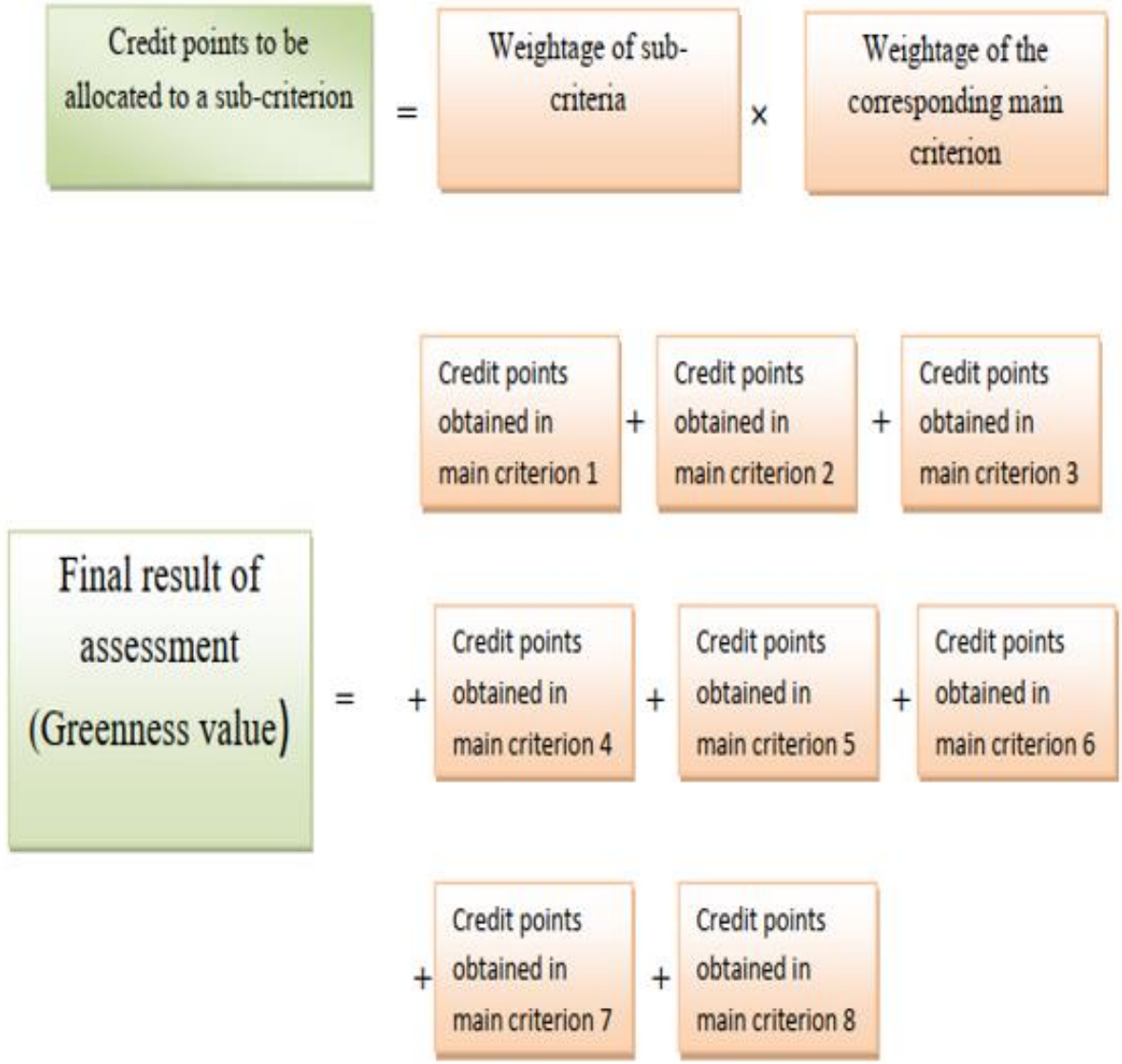


Figure-2 Formulae used to calculate the greenness value of a building

● **Weightage of main criteria** The calculated weightages of the main criteria are shown in table-G.

Table 4.3 Weightages of main criteria

Assessment criteria	Weightings (%)
Water efficiency	13.3
Materials and waste	13.4
Health & well-being	13.0
Energy efficiency	13.3
Sustainable sites	13.3
Social welfare	13.4
Transportation	11.6
Management	8.7

Source: Reddy A. Suchith, 2017, "developing a sustainable building assessment tool (sbat) for developing countries – case of india".

● **Allocation of credit points and tool development** after calculating the weightages of main criteria and sub-criteria, allocating credit points to the sub-criteria was the last step to complete the framing of the tool. Credit points for each sub-criteria were calculated by multiplying the weightage of main criteria with the sub-criteria.

The calculations and the results are shown in the following table.

Table-H Allocation of credit points

S.no.	Assessment Criteria	Assessment Sub-criteria	Weightages (%)	Credit points to be allocated
1	Water Efficiency (weightage=13.3%)	Water monitoring and leak detection	21.90	2.91
		Building water use reduction	17.34	2.31
		Recycle and reuse of water	21.48	2.86
		Rainwater management	21.90	2.91
		Reduction in landscape water requirement	17.34	2.31
2	Materials and waste management (weightage=13.4%)	Low-energy materials	16.60	2.22
		Regionally available materials	21.70	2.91
		Recycled and re-use materials	20.42	2.74
		Responsible sourcing	19.98	2.68
		Efficient waste management	21.30	2.85
3	Health and wellbeing (weightage=13%)	Water quality & water pollution	25.95	3.35
		Outdoor & indoor noise levels	23.77	3.15
		Sanitation/Safety facilities & Accessibility	25.95	3.35
		Minimize ozone depletion	24.33	3.15
4	Energy efficiency (weightage=13.3%)	Renewable energy production	17.68	2.35
		Energy efficient appliances	17.33	2.31
		Energy monitoring	15.65	2.08
		Reduction in energy consumption associated with interior lighting	14.28	1.90
		Adequate daylight	18.04	2.40
		Energy efficient Vertical transportation systems	17.02	2.26
5	Sustainable sites (weightage=13.3%)	Site selection	18.02	2.40
		Protect or restore habitat	17.08	2.27
		Heat island reduction	15.84	2.10
		Open space	15.18	2.02
		Light pollution	15.51	2.06
		Conservation of soil surrounding the building	16.34	2.44
6	Social welfare (weightage=13.4%)	Awareness towards sustainable issues	31.48	4.21
		Efficient ventilation	32.71	4.38
		Design for durability	35.81	4.80
7	Transportation (weightage=11.6%)	Public transport accessibility	21.47	2.48
		Use of bicycles by the residents	20.63	2.43
		Proximity to amenities	19.42	2.25
		Environmental friendly pavements at the building site	21.05	2.43
		Reduced parking footprint	17.42	2.01
8	Management (weightage=8.7%)	Managing the balance between the building and its immediate surrounding	32.68	2.84
		Managing fire prevention facilities	30.73	2.67
		Preventing the reckless dumping of polythene products at building site	36.59	3.18
Total				100

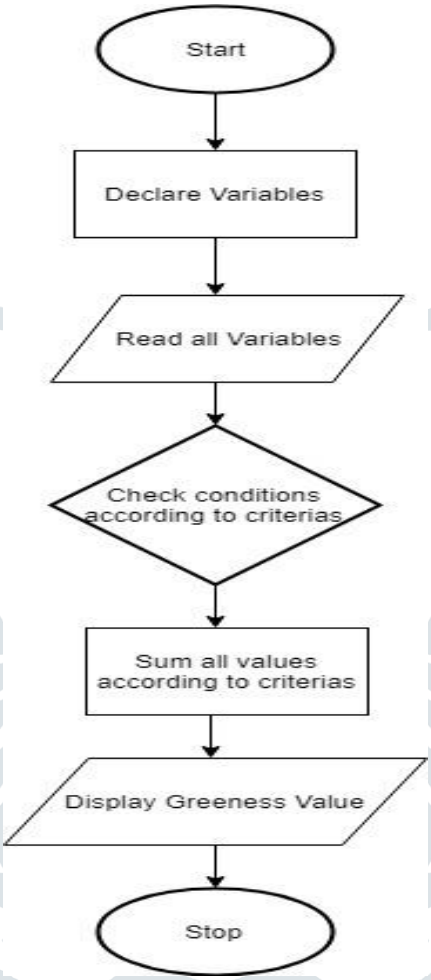
● **Certification criteria** The certification criterion is based on the summation of credit points of the sub-criteria of the assessment system. A maximum of 100 points are available. Five performance levels are considered including *outstanding, excellent, good, poor* and *unclassified*. The categorization criteria of the greenness (sustainability) levels were based on the analysis of the developing rating systems such as GRIHA, LEED and BREEAM. The range of the levels is shown in the table-F.

Table-F Certification criteria

Unclassified	**<20**
Poor	**≥20 and <40**

Average	**≥40 and <60**
Good	**≥60 and <80**
Outstanding	**≥80**

● **User friendly software of the tool** A user-friendly software interface of the tool has been developed in Dev-C++ to make the tool more easy to use. All the logics have been coded with the help of C++ to develop the software interface of this tool. The software displays different questions which have to be answered to arrive at a single assessment result. Each question generates a score and each question has to be answered otherwise the final result will not be displayed.



● **Case study** Hostel Block – 1 & 2 For Manipal Integrated Services Private Limited at Manipal County.

Location	Bengaluru
Site Area	25494 m^2
Built up Area	13536 m^2
Air-conditioned Area	6465 m^2
Non Air- conditioned Area	11020 m^2
Renewable Energy	150 KWph Solar PV installation

GRIHA provisional rating : 5 Stars
Year of completion : 2015

In our tool the building has achieved a score of **85.82**. Referring to the table-F, the building falls in the level of *outstanding*. The building has also been assessed by GRIHA and it has been rated as a 5 star building. This means the building is a green building which does not contribute towards the environmental degradation and resource exploitation.

Pic- Screenshot showing greenness value of case study

Conclusion

This research uses strengths of well-established tools and provides a more holistic assessment framework. The assessment criteria consist of main criteria, sub-criteria and indicators. Main criteria were defined by sub-criteria and sub-criteria were defined in detail by various parameters. Eight main criteria were adopted which include: *water efficiency, materials and waste, health & well-being, energy efficiency, sustainable sites, social welfare, transportation,* and *management*. These eight main criteria contain a total of 37 sub-criteria. A scoring system was developed which can measure the greenness of *existing residential buildings of India***.** The score obtained by a building in this tool is called *greenness value* of the building. A user friendly software interface of the tool was developed to make the tool more easy to use. A case study of a hostel building in Bengaluru was performed to validate the tool and the building was rated as *'outstanding'* after obtaining a score of **85.82**.

References

[1] Ali, H.H., Al Nsairat, S.F., (2009). Developing a green building assessment tool for developing countries Case of Jordan.

[2] Anshul P Gujarathi (2016) cost parameters of green residential buildings in pune, india.

[3] Apoorva V.Kotkar (2017) a review paper on green building research.

[4] Dakhole Namita .G (2017) need to decide the appropriate rating criteria according to zones, states of India.

[5] Elena Bernardi, et.al (2017)an analysis of the most adopted rating systems for assessing the environmental impact of buildings.

[6] Hikmat H. Ali, Saba F. Al Nsairat, "Developing a green building assessment tool for developing countries – Case of Jordan" in **(2008)**.

[7] ILIYAS IKBAL SANDE (2015) "comparative study of LEED and GRIHA rating system."

[8] Mohamed Taifour, Pascal Perrotin, Maad El Madlaji and Gerard Sauce, "Developing a Methodology to Evaluate the Environmental Performance for an Existing Building in Developing Countries" in **(2013)**.

[9] M. Chethana S., Vivian W. Y. Tam, (2017) "Environmental, Economic, and Social Parameters in International Green Building Rating Tools".

[10] Müjde Altın (2016) green building rating systems in sustainable architecture.

[11] Neda Ziabakhsh and Maryam Bolhari (2012) "Sustainable Rating Systems in Buildings: An Overview and Gap Analysis".

[12] Ricardo Mateus, Luis Bragança, 2010 "Sustainability assessment and rating of buildings: Developing the methodology SB Tool".

[13] Richard Reed, Anita Bilos et.al (2009) international evolution of sustainable rating tools for buildings.

[14] Raji Banani, et.al (2016) developing domestic sustainable non- residential building assessment criteria for Saudi Arabia.

[15] Sharad R. Khese, M.N.Hedaoo, B.A.Konnur (2016) "A Comparative Study of Rating Systems in Green Building."

[16] Shraddha Pandey (2016) impact of green building rating systems on the sustainability.

[17] Vivian W. Y. Tam, S. X. Zeng, (2013) "Sustainable Performance Indicators for Australian Residential Buildings".

[18] Yu, W., Li, B., Yang, X., Wang, Q., (2015). "A development of a rating method and weighting system for green store buildings in China".

[19] Vyas, G.S., Jha, K.N., (2016). "Identification of green building attributes for the development of an assessment tool: a case study in India".

[20] Sabih Ahmad (2015) "Salvage of ceramic waste and marble dust for refinement of sustainable concrete".

[21] M. Kashif Khan (2017) "effect on strength of concrete by partial replacement of fine aggregate by rubber dust and coarse aggregate by tyre chips".