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Facilitating Green Building Adoption - An Optimization Based Decision Support Tool

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Abstract

The US Environmental Protection Agency defines green buildings as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from site selection to design, construction, operation, maintenance, renovation and deconstruction.

The adoption of green building norms in India is a relatively new phenomenon. The Indian Green Building Council (IGBC) has been the torch bearer for this effort since 2001. There are three major green building guidelines currently being adopted in India: (1) LEED®-New Construction (LEED-NC); (2) GRIHA® by The Energy and Resources Institute (TERI) that was established voluntarily to rate buildings; and (3) LEED®-INDIA released by the Indian Green Building Council which is inspired by LEED-NC and includes alterations based on Indian construction environment.

The decision to opt for green construction and the level of green aspirations is constrained by the extra cost of going green, i.e. the green premium. The level of environment friendliness, given by the rating of the building, is not arrived at in a scientific manner by considering the options and their cost implications. Risk averse owners, in spite of their desire to go green, are hindered by a lack of information on the various options and ability to decide which options to choose. This information, if made available as a decision support tool, can be valuable in bringing green buildings into the mainstream. The non availability of such a tool is a major barrier in the growth of the green building movement (USEPA report "Removing market barriers to green development").

The objective of this work is to develop an optimization based decision support tool that can be used to either arrive at the optimal green rating given the budget and choice constraints; or at the optimal green premium given the green rating aspirations. These can help a builder optimize green ratings or greening costs, as desired, or by a policy maker to come up with appropriate and effective policies. The Indian GRIHA rating guidelines are used as inputs for measuring the green rating of a building. In addition sensitivity to costs, of socially important parameters such as use of solar energy, fly-ash etc., of choices made for achieving desired green ratings are studied. This can help drive appropriate policy initiatives for adoption of such technologies.

Keywords: Green building, Rating systems, Cost structure, Environment, decision support system and Optimization

1. Introduction

1.1 What is a Green Building

The US Environmental Protection Agency, defines green building as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from site selection to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green buildings are also known as sustainable or high performance buildings (US EPA website).

Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by efficiently using energy, water, and other resources, protecting occupant health and improving employee productivity, encouraging environmentally preferable building material selection, and reducing waste, pollution and environmental degradation. For example, green buildings may incorporate sustainable materials in their construction (e.g., reused, recycled-content, or made from renewable resources); create healthy indoor environments with minimal pollutants (e.g., reduced product emissions); and/or feature landscaping that reduces water usage (e.g., by using native plants that survive without extra watering).

The construction industry contributes around 11% of India's GDP and underpins the economic growth of the country. The building and real estate forms a considerable part of the construction industry. The technological typography of the building industry various from one region to the other. Given the size of the industry, environmentalists have turned their attention on the processes in this industry that contribute to the overall carbon footprint of the economy. The outcome is the energy efficient buildings that have popularly come to be known as Green Buildings. In India, the Green building industry started in 2001 and today there is roughly 20,000 sq. feet of green building space in the country (IGBC website).

From the usage point of view, buildings can be broadly categorized into residential buildings and non residential buildings. The residential sector is large but disjointed, i.e. ownership units are small and initial and operating cost considerations are varied. The non-residential buildings, which include office buildings, schools, hospitals and community centres, form a more homogeneous group in the sense that they have a large initial cost and considerable operating costs. In this study, the office buildings only are being considered for the sake of homogeneity.

1.2 How Green is Green – Rating Systems

Developing countries like India have practices that are sustainable in nature due to the scarcity of resources; however, most are not uniform practices. As a result, certain aspects of sustainable strategies for building design and construction become the focus in these countries, depending on the regional characteristics and needs (e.g. not establishing new developments in dense areas as a site selection strategy, use of low flow fixtures for water efficiency, and utilization of solar water heating as renewable energy technologies), while other approaches are not practiced systematically.

To establish a systematic use of all sustainable approaches, uniform, recognized, and internationally compatible standards are needed. This need is more evident in developing countries where the economy and national organizations are growing, and investments are being made that increase construction activities. The introduction of such guidelines to establish uniform standards for the application of sustainable practices and their acceptance has been a recent trend in the developing countries.

India has witnessed major progress in the context of green building guidelines since 2001. There are two major green building guidelines currently being adopted in India: (1) GRIHA® by The Energy and Resources Institute (TERI) that was established voluntarily to rate buildings according to three categories, namely preconstruction planning, construction and building operation & maintenance stages; and (2) LEED®-INDIA released by the Indian Green Building Council - the structure and content of which is based on LEED-NC and includes alterations based on Indian construction needs.

1.3 Cost Structure of Buildings

The building projects have costs associated with land, designing and planning, execution and operation / maintenance which extend over its lifetime. The cost of land is mostly invariant as options for sites are limited. For public projects, the time gap between the decision to procure land and actual execution of work is generally so large that it remains an activity outside the planning scope of the project. This is due to changes in the external environment like changes in prices of material and technology, availability of new technology, change in the needs of the owner and often a change in the set of decision making people. However, if options are available over different locations, comparisons can be drawn for more energy efficient shape, orientation and other architectural features of the building. This aspect is beyond the scope of this work.

Costs associated with designing, planning and project management are small compared to the cost of the building. For example, to achieve a green rating for the building, architects with experience of integrated design of buildings and green technology will have to be chosen. Inputs from electrical, structural, HVAC and acoustic experts are required at the initial stages itself. This will show up as cost increase for the planning stage.

The important variable cost is what comes from the choice of material and technology. Different materials have different embodied energy. Embodied energy of a material is defined as the energy used up in creating the raw materials, manufacturing processes and transportation at various stages. (Debnath, 1995, Chani et. al, 2003). Very little research has come to my notice that records the embodied energy of the finished items that are commonly used today or the energy utilization of the on site processes (Reddy and Jagadish, 2003). Some work has been done in the US to document the energy footprint of commercially available brands and making it available through a commercial software in the public domain (BEES Ver 4.0). However, the energy requirements of material production in the US are very different considering the climatic conditions there. Still, the choice of materials remains a major determinant of the achievable green rating of a building. It forms the focus area of this research.

Cost of operations and maintenance is intimately linked to the technology and materials chosen for construction. This is especially true for fully air conditioned or ventilated buildings, that require continuous energy use over its life cycle. This aspect of operation cost is also not considered in this research due to the non availability of enough data. However, as the green building movement catches up in the country, and the requirement to validate the rating is met, better monitoring of system performance is likely to be achieved and more and more data should be available.

1.4 Parameters Impacting the Decision to build Green Buildings

The decision to go for a green construction and the level of green aspirations is constrained by the extra cost of going green, i.e. the green premium as well as the real and perceived benefits from such an option. The important parameters that are required to be considered are:

- The availability of green materials and technology
- The extra cost of such material and technology, i.e. the green premium
- The availability of consulting and project management expertise.
- The uncertainties and risk involved in terms of cost, quality and time – the first mover disadvantage.
- Perceived benefits from green buildings.
- The operation and maintenance costs of such technology, which is not measurable upfront.
- The uncertainties in the owners’ needs and requirement of flexibility in usage and scope change potential of the various options.

In this research, the different materials and technologies that are required by the TERI-GRIHA rating system are being considered as decision variables.

2. Research Idea and Objective

The building owner’s decision to go for green building is today supported only by his commitment towards sustainable development. The level of sustainability, given by the rating of the building, is not arrived at in a scientific manner by considering the options and their cost implications. The risk averse owners, in spite of their desire to go green, are hindered by a lack of information on the various options. This information is required to be made available in a usable form in the shape of a decision support tool. The non availability of such a tool is a major barrier in the growth of the green building movement. (USEPA report “Removing market barriers to green development”). It is an objective of this work to develop such a decision support tool and explore the impact of green building choices on the policy landscape.

3. Literature Review

3.1 Background

The decision to go for green construction is constrained by time, budget and risks – all of which determine the level of adoption. The popularity of the concept therefore requires that decision support tools are available that give a realistic projection of the above three factors. The extent of sustainability desired is a collaborative one amongst the owner/financier, architects and engineers. It is also impacted by the likely behaviour of the buyers and occupants. Each of these stakeholders occupy a different standpoint on the issue of environmental quality of the building. There are significant trade offs between short-term investment and long-term pay-offs (Ewing and Baker, 2009). Whether in the case of office buildings or residential complexes, the financial cost of construction of the building is still the most important variable that determines the owner's behaviour in this context. Some of the other important factors could be operational cost savings, lower maintenance cost, capturing government incentives, improved indoor environmental quality, green buildings providing brand value to the developers or owners, etc.

As can be seen, the spectrum of variables is diverse and often leads to difficulties in comparing the benefits of adoption of environmental norms across the available options. Owners, especially the early adopters, find it difficult to perform a cost benefit analysis when the benefits remain un-quantified or intangible. It is mainly to address this issue of informing the adopters that a decision support tool is envisaged.

A Decision Support Tool (DST) has been defined as "any tool that informs the decision making process by helping actors understand the consequences of different choices." (Keysar and Pearce, 2007). A good decision support tool can be thought of as an innovation and hence have good attributes of relative advantage, Compatibility, Complexity, Trialability and Observability (Rogers 2003). These are explained later in the chapter while discussing the tool being offered in this study.

3.2 Functions of a Decision Support Tool in the Green Building Context

The main functions of a decision support tool can be enunciated as under (Cole et.al. 2008):

(i) To provide a mechanism for the intending adopter to navigate the solution space and arrive at a realistic green building goal within his own set of constraints. The design team can work in a focussed manner given the structure and prioritization in a DST.

(ii) To provide an evaluation tool to quantify and compare the environmental performance of buildings in a comprehensive manner. It also impacts on the design process itself which orients itself towards better and greener design output - through more communication and collaboration amongst the various disciplines.

(iii) DSTs enable policy formulators to direct their strategies towards a better managed scenario. For example, the rating agencies like TERI can be a rich source of data for prioritising policy initiatives in certain areas. Similarly, corporate membership of IGBC provides a good indicator of growth in the green building products market.

It is pertinent to point out here that DSTs for green buildings can be categorised in many different ways. The Annex 31 Study by CMHC in 2004 describes two broad categories of DSTs : (Keysar and Pearce, 2007)

Interactive e.g Life Cycle Assessment Tools for Buildings, Energy and Ventilation modelling software, etc.

Passive e.g. Rating systems like LEEDS and GRIHA, Codes and Manuals, Environmental Product Declarations, Catalogues, Reference information, Certifications, etc.

The different tools address different aspects of the problem and there is considerable overlap in the scope of the DSTs. Keysar and Pearce have organised an inventory of various decision support tools (DST) that help the adopters make the right choice of DST that is aligned with their requirements (Keysar and Pearce, 2007). In all, 275 DSTs were documented into different categories like Life Cycle Costing, Life Cycle Assessment, Energy Analysis, Product and Material Specifications, Rating Tools, Compliance /Code checking /Standards, Case Studies, etc. The type of tools considered were Websites, Publications, Software, Databases and Checklists. The authors commented that for the uninitiated adopter, it is a time consuming and costly affair to zero in on the appropriate DST that will get him closer to his goal (say getting a certain LEED rating for his building). Accordingly the tools were rated on the basis of *relative advantage (degree to which a tool directly provides the necessary ability to calculate a LEED credit or documentation to support a LEED credit claim)* and *trialability (availability of the tool for free via the web, cost being a negative)* as high, medium or low (Keysar and Pearce, 2007).

However, amongst the various tools to assess the performance of a building, green rating of a building has been given considerable importance (Biswas and Krishnamurti, 2009)

3.3 Green Building Rating System as a Decision Support Tool

The rating systems provide a roadmap for the achievement of diverse environmental goals, viz. energy efficiency, water efficiency, indoor environmental quality, protection of vegetation and soil cover, etc. They provide a platform for assessment of building and design performance that is easily understood and lead to better aligned efforts from the various stakeholders. The role of a rating system like LEED or GRIHA as a decision support tool can be broadly categorised as below (Biswas and Krishnamurti, 2009):

(i) Rating systems summarize building performance that is easily comprehended by the stakeholders. The environmental issues in a building are prioritised keeping the societal goals and objectives in mind. This not only prevents vested interests from skewing the performance indicators in favour of a certain sector, but also opens up healthy debate and dialogue in the realm of sustainable building practices.

(ii) Rating systems, due to their success as a DST, promotes adoption of green norms. With increasing adoption, they motivate innovation; encouraging goods and services suppliers to switch to greener products and practices, thereby bringing down their costs.

(iii) They provide a vehicle for both public and corporate policy making, where policy initiatives can be linked to rating levels achieved.

3.4 Other Approaches in Decision Making in the Realm of Green Buildings

Among the tools found in the literature, researchers have endeavored to optimize material selection using environmental, social and economic factors. The environmental factors are generally categorized as embodied energy of materials used in construction, energy utilization in building operation, GHG and waste generation, etc. For a given cost, material and technology availability and codes / standards environment, there is opportunity to apply optimization techniques to arrive at preferred and feasible solutions.

The optimization approaches used by researchers is to a) hold one set of variables as a constraint and vary the other (Castro-Lacouture et. al., 2009); or b) use weighted sum technique to vary both set of variables together (Abeysundara 2009, Soebarto 2001). Both approaches need some estimation of the boundary values of the constraints or weights associated with each criteria. Some researchers have also used Genetic algorithm based search techniques (Wang et. al, 2005), however, the technique is difficult to implement where issues like population size, mutation ratio, etc. will impact the chances of convergence. Also there is no way to tell if it is a global optimum solution.

In the literature survey, a linear programming approach was found to be used with LEED rating system developed by USGBC (Castro-Lacouture et. al., 2009). In this study, the mixed integer program has been developed which takes the cost as a constraint and varies the choice and rating variables or holds the rating as constraint and varies the choice and cost variables. Here the authors have proposed a system that improves green construction decision making through selection of materials.

The environmental properties required by the LEED based system are mainly obtained using the Building for Environmental and Economic Sustainability Software – BEES as well as local studies in Columbia where information on materials is not available in BEES.

The basic problem here is the comparison of design solutions that have embodied energy parameters as well as cost parameters. The embodied energy approach forces the researcher to consider the quantity of fuel and energy associated with various processes involved in the manufacture, transportation and use of a material which is considered as end energy or embodied energy (Cole 1999, Debnath 1995, Reddy 2003). This data is difficult to capture given the various technologies and practices and forces huge assumptions.

Another approach is to try and capture the green rating system directly with the assumption that it is a reliable proxy for the environmental friendliness of the building (Castro-Lacouture et. al., 2009) as explained above.

4. Research Gap

The available research in this area is very limited and tends to be more on the technical side rather than towards facilitation of the practical measures for green construction. The research gap can be enumerated as follows:

1. Poor availability of information about green construction materials

2. Poor availability of information about the energy footprint of various building technologies

3. New technology to make renewable energy economically viable is not available

4. Performance evaluation of building systems during operations

5. Cost evaluation of green practices

6. Impact of green policies on consumer behavior

7. Willingness to pay for green projects and factors influencing such willingness

5. The GRIHA Rating System – A Brief Overview

Internationally, voluntary building rating systems have been instrumental in popularising green building design. However, these rating systems have been tailored to suit the building industry specific to the country where they are developed. The priorities of the green design are set in the specific social context. For example, in the US, where energy consumption in heating is a major concern, energy efficiency has high priority in the LEED-NC system. The Hong Kong Building Environmental Assessment Method (HK-BEAM) is a performance based system, which apart from the percentage of overall credits, also requires a minimum percentage points of Indoor Environmental Quality (IEQ). This is in keeping with the highly urbanised environment of Hong Kong, where IEQ is a major concern.

The Energy Research Institute (TERI) in India has developed the Green Rating for Integrated Habitat Assessment (GRIHA) system which takes into consideration both established building practices and emerging technologies. The rating applies to new building stock – commercial, institutional and residential. Endorsed by the Ministry of New and Renewable Energy, Govt. of India as on November 1, 2007, it is a five star rating system. GRIHA was developed to address and assess non-air conditioned or partially air conditioned buildings. The emphasis is on indigenous solutions using local materials and construction practices, to the extent possible. GRIHA also integrates all relevant Indian codes, National Building Code 2005, Energy Conservation Building Code 2007, etc. and acts as a tool to facilitate implementation of the same. The various criteria and the concerns they address can be found in the GRIHA Manual.

The Evaluation system of GRIHA criteria are tabulated below:

Criterion No.	**Description**	**Points**	**Remarks**
Criterion 1	Site Selection	1	Partly Mandatory
Criterion 2	Preserve and protect landscape during construction / compensatory depository forestation	5	Partly Mandatory, if applicable
Criterion 3	Soil conservation (Post conservation)	2	
Criterion 4	Design to include existing site features	4	
Criterion 5	Reduce hard paving on site	2	Partly Mandatory
Criterion 6	Enhance outdoor lighting system efficiency	3	
Criterion 7	Plan utilities efficiently and optimise on site circulation efficiency	3	
Criterion 8	Provide at least minimum level of sanitation / safety facilities for construction workers	2	Mandatory
Criterion 9	Reduce air pollution during construction	2	Mandatory
Criterion 10	Reduce landscape water requirement	3	
Criterion 11	Reduce building water use	2	
Criterion 12	Efficient water use during construction	1	
Criterion 13	Optimise building design to reduce conventional energy demand	8	Mandatory
Criterion 14	Optimise energy performance of building within specified comfort limits	16	Partly Mandatory
Criterion 15	Utilisation of flyash in building structure	6	
Criterion 16	Reduce volume, weight and time of construction by adopting efficient technology, for example, pre-cast systems, ready mix concrete, etc.	4	
Criterion 17	Use low energy material in interiors	4	
Criterion 18	Renewable energy utilization	5	Partly Mandatory
Criterion 19	Renewable energy based hot water system	3	
Criterion 20	Waste water treatment	2	
Criterion 21	Water recycle and reuse (including rainwater)	5	
Criterion 22	Reduction in waste during construction	1	
Criterion 23	Efficient waste segregation	1	
Criterion 24	Storage and disposal of wastes	1	
Criterion 25	Resource recovery from waste	2	
Criterion 26	Use of low VOC paints/adhesives/sealants	3	
Criterion 27	Minimize ozone depleting substances	1	Mandatory
Criterion 28	Ensure water quality	2	Mandatory
Criterion 29	Acceptable outdoor and indoor noise levels	2	
Criterion 30	Tobacco and smoke control	1	Mandatory
Criterion 31	Universal accessibility	1	
Criterion 32	Energy audit and validation	0	Mandatory
Criterion 33	Operation and maintenance protocol for electrical and mechanical equipment	2	Mandatory
Criterion 34	Innovation (beyond 100)	4	
	Total	104	

Note: The points for Innovation are provided to the adopter to make up for low score by adopting a suitable innovation like Environmental education, Life cycle cost analysis, Alternative transportation, etc. The project can apply for 104 points but points will be awarded on a 100 point scale only.

Table 1 - Evaluation Criteria of GRIHA Rating System

Different levels of certification (one star to five star) are awarded based on percentage of points earned. The minimum percentage required for certification is 50. The points earned and rating are tabulated below:

Points Scored	Rating
50 to 60	One star
61 to 70	Two stars
71 to 80	Three stars
81 to 90	Four stars
91 to 100	Five stars

Table 2 - Rating of a Building for Different Ranges of Points Scored

It is also important to know which criteria pertain to which aspect of environmental friendliness. The following table thus throws some light on which aspects are given priority in the rating system.

S.No.	Aspect of Green Building	Criteria Nos	Total points
1	Sustainable Site Planning	C1, C2, C3, C4, C5, C7	17
2	Water Management	C10, C11, C12, C20, C21	13
3	Energy Optimization	C6, C13, C14, C18, C19	35
4	Sustainable building Materials	C15, C16, C17	14
5	Waste Management	C22, C23, C24, C25	5
6	Health and Well Being	C8, C9, C26, C27, C28, C29, C30, C31	14
7	Building Operation & Maintenance	C32, C33	2
8	Innovation	C34	4

Table 3 - Total Points allocated to Different Aspects of Sustainability

It can be seen from above distribution of points that whereas extreme importance is given to energy optimization, issues like site planning, water conservation, building materials and health and well being have more or less equal weightage. Waste management does not receive much importance as municipal waste disposal issues are still not critical in the operations of human settlements in India, though this may have long term detrimental effects. Surprisingly, building operation and maintenance issues also score low, which shows the building industry’s focus on upfront costs. The Calculation of cost for various criteria is explained in the Appendix.
The details of the commitments, deliverables and appraisal of each criterion can be seen in the TERI-GRIHA Manual Volume-I.

6. Green Rating for Integrated Habitat Assessment (GRIHA) based DST

GRIHA is a system of green building rating developed and maintained by The Energy Research Institute (TERI). In this study an effort has been made to use the GRIHA system to develop a decision support tool. The main features of this tool are:

(i) The various criteria, their commitment, compliance documentation and appraisal are the goals in the model.
(ii) Each criterion or part of it has a cost of compliance. These costs are only indicative and will vary largely from place to place. For mandatory criteria, the costs are taken as zero as these costs have to be borne in any case.
(iii) The overall premium that the adopter is willing to pay for going green is fixed as a constraint. This could be a percentage of the total cost of the building or a lump sum figure.
(iv) The relative cost of attaining each criterion will lead to a situation where linear programming technique can be used to arrive at the optimal selection of targeted criteria. The important point to be noted here is that the cost associated with each criterion will vary from project to project depending on location, size, functional category, etc. The effort involved in arriving at these costs may act contrary to the utility of this tool. However, with more green building experience, the consultants may be able to readily provide an educated guess. Also, the accuracy of the costs associated with each criterion will determine the decision process. Within the overall cost constraint, we can maximise the points adopted using a Linear Programming technique. The Solver module of Excel has been used.
(v) The output determines the mix of criteria that the cost driven adopter will choose to arrive at a green rating. A plot can be developed between the 'green premium' and points achieved in the GRIHA system, for the given choice of costs.
(vi) In addition to this a plot is developed for 'green premium' vs. the savings in electricity, savings in water and utilization of flyash. This can be an important input for informing policy decisions i.e. what level of extra investment will bring forth sizable reductions in environmental impact in the above three areas.

In addition this also gives the level of environmentally friendly attributes of the decision that have social benefits as well. For example, a certain level of investment may lead to utilisation of flyash, saving in water and electricity, provision of additional green areas, etc. that are beneficial to the society. In case of savings in water and electricity, these also lead to an annual saving that can be considered over the building lifecycle, though such analysis is not attempted in this study.

To have an evaluation of the decision support tool, we can look at it as an innovation. The parameters from Theory of Diffusion of Innovation (Rogers 2003) can be used to arrive at the chances of its adoption.

Attribute	**Definition**	**Attribute Value**	**Remarks**
Relative Advantage	The extent to which this innovation is better than the alternatives it is replacing	High	There are no similar DSTs that indicate GRIHA criteria vis-à-vis cost of adoption
Compatibility	The degree to which the innovation fits within the existing processes and culture of potential adopters	High	The building industry is very much a cost-benefit driven industry and green building adopters see cost as a major cause of concern
Complexity	The degree of difficulty an	Medium	The criteria are spread over different

	adopter has in understanding / using the innovation		disciplines, like architecture, civil engineering, electrical engineering, landscaping, etc. The adopter has to have an understanding of all of them
Trialability	The degree to which an adopter can test an innovation before making a commitment	Low	The costs have to be calculated every time for each project. Hence large effort is required before any trial can be conducted.
Observability	The degree to which the benefits resulting from the adoption are apparent as an outcome of such adoption.	Medium	Difficult to see the direct impact of the tool on the decision making process.

Table 4 - The Attributes of the DST Affecting its adoption

It can be seen from above that the overall chances of adoption of the tool is medium to high.

7. A Decision Support Tool for GRIHA Rating - Methodology for Developing the DST

The following method is proposed to be adopted for arriving at the best possible rating given the cost and choice constraints:

1. The green-ness or environment friendliness of a building is held as a proxy by its TERI-GRIHA rating
2. The ratings in the TERI-GRIHA system depend on the buildings features as categorized below :
   Site Planning (Criteria 1 - 8)

   Building Planning and Construction stage (Criteria 9 - 29)

   Building operation and maintenance (Criteria 30 - 33)

   Bonus Points (Criteria 34)
3. In the TERI - GRIHA system of rating there are three types of variables that lead to points –
   - To satisfy or not to satisfy a criterion or sub-criterion – Binary Variable
   - Discrete domain of materials (like solar energy equipment) – Integer set
   - Continuous domain of variables (like area under different landscape options) – Continuous variable
4. Each alternative when chosen as part of a mix of materials and technologies from the given domain leads to a feasible solution to the design problem.
5. Each feasible solution has a cost (the green premium) over the base line cost. The base line cost is determined for specifications of standard office building as envisaged in the GRIHA manual.
6. There are a large number of solutions due to the various combinations of variable values.
7. Linear programming technique is found fit for formulating and solving the problem. The problem is formulated as:

Model A: Given the budget constraint (max limit on the green premium), what is the maximum number of points achievable and what are the corresponding criteria to be satisfied.

Rating -> dependent variable

Green premium (Cost) -> constraint

Choice of Material / Technology (To get or not to get the rating point) -> independent variable

Model B: Given the GRIHA rating aspiration, what is the minimum green premium that can achieve the objective and what are the corresponding criteria to be satisfied.

Green premium (Cost) -> dependant variable

Rating -> constraint

Choice of Material / Technology (To get or not to get the rating point) -> independent variable

The cost of satisfying various criteria may be classified into three types :

1. *Cost of carrying out certain items of work including materials :* The cost per unit of various items are found by using the CPWD Schedule of Rates 2010. In case of items not directly available, the rates are analyzed using a combination of items. The CPWD Analysis of Rates, 2007 can also be used to arrive at rates of new items. For some items, rates have been taken from rate contracts of the Directorate General of Supplies and Disposal (DGS&D). Initially, a smaller set of materials can be used, which can be expanded later with more data being available.
2. *Cost only in the form of design effort :* In cases where the cost is only from the design effort, the number of man-hours required for such activities are enquired from working experts.
3. *Cost of substituting conventional systems with high efficiency system :* In cases like HVAC system, solar PV cells, etc. where the cost varies depending on the feasibility and choice of the systems, rough indicative costs have been taken which need to be corroborated on a case to case basis.

The cost being considered here is the green premium. The cost of compliance of mandatory criteria have been taken as zero and these are kept out of the optimization problem. In this analysis, the points for innovation (Criteria 34 – GRIHA) are not considered as they are in the nature of points for the environmentally responsible conduct of the owner and have little to do with building performance.

The methodology for arriving at the costs is given in Appendix. The optimization problem has been solved using the MS-Excel Solver.

8. Results and Discussions

The Excel Based tool was run with a set of values taken from diverse sources. The building considered here is an office building with a floor area of 4000 sq.m. built on a plot of area 10,000 sq.m. The cost of the building (excluding that of the land) is taken as Rs. 15,000/- per sq. m. of floor area, i.e. Rs. 60 million. It is presumed that the site is given and it is within 0.5 km of an existing bus / metro station. The area of the plot is 10,000 m^2 and the ground coverage is 1000 m^2. The building coming up here is an office building and the number of working days is 260. The air conditioned space is approx. 40% of the floor area in the building.

Model A: The points achieved at various levels of green premium, as a percentage of basic building cost, are tabulated below:

Green Premium	0	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
GRIHA Points	28	46	52	57	61	67	72	81	86	90	92	94	95	97	98

Table 5 - Green Rating Points (GRIHA) for a given Green Premium – Model A

It is seen from Table 5 that a GRIHA rating (1- star) can be obtained at as low a premium as 0.39% of the basic building cost. A three star rating, that is now mandated for all central government buildings in India, should cost around 1.80% of the basic building cost. Similarly a five star rating can be obtained at 5.27% of the basic building cost. This finding matches well with a study conducted in the US on the LEED certified buildings (Kats, 2003), wherein it was found that the lowest rated buildings (Certified) have an average green cost premium of 0.66% whereas the highest rated buildings (Platinum) have a premium of 6.50%. It may be noted here that for the costs calculated here are indicative and will vary from place to place. Accordingly, the green premium values may vary.

Model B: The other formulation of the problem gives the minimum cost of achieving a desired rating level (one star to five star) as defined in the GRIHA documents and the social benefits that accrue from that decision. The results are tabulated below:

GREEN PREMIUM (% of Basic Building Cost)

GRIHA Rating Points	Green Premium (% of Basic Building Cost)	Annual Solar Energy (% of Baseline Energy Use)	Annual Energy saving thru Design (% of Baseline Energy Use)	Fly-ash Utilization (% of cement by weight)	Annual Saving in Water (% of Baseline Water Demand)
28	0.00%	1.46	0	0	4.82
30	0.01%	1.46	0	0	4.82
40	0.10%	1.46	0	0	4.82
50 (1-star)	0.39%	1.46	0	10.65	25.87
61 (2-star)	0.96%	1.46	0	30.00	44.59
71 (3-star)	1.80%	2.44	9.90	30.00	44.59

81 (4-star)	2.73%	2.64	39.60	30.00	60.22
91 (5-star)	5.27%	3.62	39.60	30.00	60.22
100	12.41%	14.93	39.60	194.75(*)	60.22

*Note 1 : The value of fly-ash use is shown in this table as a percentage of cement substituted by fly-ash.

9. Summary of Conclusions and Recommendations:

The main conclusions of this study can be summarised as below:

1. The Excel based decision support tool indicates that we can get a one-star rating at a premium as low as 0.33% of the building cost. Similarly, a three-star rating (which is the professed goal of some government departments) can be achieved at ~ 2% and a five-star rating at 5.3% of the building cost. However, these costs may vary from project to project and place to place, and need to be estimated on case to case basis.
2. At an additional investment for green features of around 3% of building cost (which implies a four star GRIHA rating), there are considerable savings in water demand and energy demand (including renewable energy use). This is likely to bring down the life cycle cost of the building. The savings over the years can be brought forward to its present value by using a suitable discount rate and a factor representing the depreciation of performance. Since cost is perceived as the most important barrier to adoption, demonstrated saving in costs is likely to increase stakeholder's buy-in to the concept of sustainable buildings.

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APPENDIX

Calculation of Green Cost for Various GRIHA Criteria

The decision of the adopter of green building norms regarding the choice of criteria that he may find achievable within his cost constraints will depend on the relative costs of fulfilling the respective commitments. These costs have been collected from interviews held with various architects (both personally and over telephone), electrical engineers and from rate analyses available in CPWD. However, these costs will vary from place to place and project to project.

It is pertinent to point out that we are looking at the costs that will drive our LP formulation to select the maximum no. of points within our cost constraint. Hence, the cost here is the extra or additional cost for adopting green building norms. Since some of the criteria are mandatory, their cost premium has been taken as zero. These criteria are, by virtue of their being mandatory, part of the base line cost.

In the cost computation, the following basic parameters are taken as known :

(i) Total area of plot (P-Area) in sq.m. (say 1000)
(ii) Area of ground coverage (GC_Area) in sq.m. (say 400)
(iii) Paved area including all types of paving/roads/walkways (P_Area) in sq.m. (say 150)
(iv) Area of water bodies within the plot (W_Area) in sq.m. (say 20)
(v) Cost of land (Rs.)
(vi) Cost of building project (Rs.)
(vii) Max. liquidated damages (Rs.) = 10% of building project cost
(viii) Duration of building project (days)

All incumbency variables Y_i are binary. For the sake of brevity, the cost calculation of only a few criteria have been explained here.

Criterion 1: Site Selection

This criterion is mandatory and hence no extra cost is involved.
Green Premium: 0 Points achieved : 0
No constraints.

Criterion 5: Reduce hard paving on site

Green Premium:

(i) Cost of roof garden includes cost of membrane water proofing & drainage @Rs. 400/- per m^2 , supplying and laying mix of 90% good earth and 10% manure (DSR item no. 23.2 and 23.4.1 respectively = Rs.137.94 per m^2), greening of the roof garden by grassing (DSR item no. 23.11 = Rs.7.42 per m^2). Add 50% extra for doing the job at roof level, except for water proofing & drainage (=Rs.218.04 per m^2) Total cost Rs.618.04 per m^2.

[Incumbent Variable Y12 for paving limit, Y13 for imperviousness]

Indicative cost = Rs. 25,000/-

(ii) Cost of pervious paving over and above normal (baseline) paving by paving blocks = Rs. 100 per m^2. [Incumbent Variable Y14 for pervious paving]

(iii) Cost of paving with SRI > 0.5 over and above normal (baseline) paving by paving blocks = Rs. 357.1 per m^2. [Incumbent Variable Y15 for pervious paving]

(vi) Cost of shaded paving by erection of steel shed over and above normal (baseline) paving by paving blocks=Rs.1500 per m^2.[Incumbent Variable Y16 for shaded paving]
Points : 2
Constraints :
(i) Total paved area <= 25% of site area
(ii) Imperviousness factor provided <= Max. imperviousness factor allowed; here imperviousness factor = ∑ (Surface area x Runoff Coeff.) / Site area
(iii) Both above conditions to occur together (AND condition) ; Y12-Y13 <= 0
(iv) Variables J36, J37 and J38 are introduced as non-negative variables and defined as the areas of pervious paving, paving with SRI . 0.5, and shaded paving.
(v) Total paving area provided J36+J37+J38 <= Paving area required.
(vi) Total paving area provided J36+J37+J38 <= 50% of the paving area required.
(vi) For each type of green paving ;
Incumbency variable (say Y14) <= Quantity of that type provided (say J36)
Incumbency variable (say Y14) >= Fraction of type of paver to site area (J36/Site area). This set of constraints ensure that incumbency variable is set to 0 if quantity provided is 0, and is set to 1 when the quantity is non zero.
Similar two constraints each for Y15 and Y16.
(viii) The cheapest option is chosen first i.e. J36, J37 >= J38 and J36 >= J37
(vii) Variable Y17 >= (Y14 + Y15 + Y16)/3 to ensure that Y17 is set to 1 if any one is non zero. Y17 is the incumbency variable for the second part of the criterion.

Criterion 6: Enhance outdoor lighting system efficiency

Green Premium:

There are 4 type of outdoor lamps in common usage, i.e. Metal Halide (MH), High Pressure Sodium Vapour (HPSV), Fluorescent Lamps (FL) and Compact Fluorescent Lamp (CFL). The various extra costs are enumerated below:

Type of Lamp	Minimum Luminous Efficacy of Lamp (Lumen/Watt)	Addl unit cost of high efficiency lamps & low wattage ballast	Addl unit cost of Automatic Controls	Addl unit cost of Solar Electricity Provision
MH	75	750	250	30000
HPSV	90	1000	250	9900 (LED)
FL	75	25	250	15000
CFL	50	500	250	9900

(Source: GRIHA Manual and Training Material)
Note: Luminous Efficacy = Lamp lumens / Wattage of Lamp plus Ballast

(i) Minimum Luminous efficacy of all lamps shall be as specified. Thus high efficiency lamps are to be provided along with low wattage ballast. The extra cost is as given above. [Incumbent Variable Y18]
(ii) All outdoor lamps are to be provided with automatic controls. [Incumbent Variable Y19]
(iii) – At least 25% of all lamps are solar powered. [Incumbent Variable Y20]

and - At least 15% of connected load for outdoor lighting to be solar powered. [Incumbent Variable Y21]
This leads to another variable defined as Y22 <= Y20, Y21, so that
Y22 = 0 if either Y20 or Y21 is zero, and Y22<=1 if both Y20,Y21 are =1.
In case of solar powered outdoor lights, LED lights have been considered in lieu of HPSV lamps, as these have high luminous efficacy with low wattages (~90 lm/W). Also the lamps are provided in two groups, to bring in the possibility of a fraction of these to be powered by solar cells.
Points : 3
Constraints :
No constraints for Y18 and Y19.
For Y20 : Y20 <= Total no. of solar lamps & Y20 >= 25% of total lamps.
For Y21 : Y21 <= Total solar lamps wattage & Y20 >= 15% of total outdoor lamp wattage.
If the above criteria are satisfied, then the solar lighting criterion is triggered.
Also the order of solar lights are given as low cost of solar provision to high cost of solar provision, i.e. LED > CFL > FTL > MH

Criterion 8: Provide at least minimum level of sanitation / safety facilities for construction workers
This criterion is mandatory and hence no extra cost is involved.
Green Premium: 0 Points achieved: 0
No constraints.

Criterion 15: Utilisation of fly-ash in building structure
Green Premium:

Extra cost of use of fly ash will be the difference of cost of cement and fly ash, both delivered to site, i.e. cost at source plus cost of transportation.
The cost of cement is taken as Rs. 3500/- per MT and the royalty for fly-ash is taken as Rs. 500/- per MT. The rates of cement have been taken as delivered to site as most cement companies provide this service to high value clients through their local dealers / depots. For finding out the cost of transportation, the method given in the CPWD Analysis of Rates is taken. The following items are taken as given as per the CPWD practice:

i) Cost of diesel (Rs. /litre) = 40
ii) Cost of mobil oil (Rs./litre) = 150
iii) Wages of beldar / coolie (Rs./day) = 250
iv) Hire charges of truck (Rs. / day) = 5000
v) Consumption of diesel @ 5 km / litre and mobil oil @ 140 km / litre
vi) Each work day is 8 hours and 1 hour is allowed for loading and unloading.
vii) An allowance of 6.0 km per day is given for movement of truck from place of parking to place of duty and back.
viii) Also each truck carries 9 MT and Contractor's Profits and Overheads are payable to the tune of 15%

Distance (KM)	For 1 km	For 2 km	For 3 km	For 4 km	For 5 km	For every km from 5 to 10 km	For every km from 10 to 20 km	For every km beyond 20 km
Cost (Rs./MT)	120.09	133.96	147.54	160.49	172.87	10.94	8.45	6.47

(For more details please see Delhi Analysis of Rates, 2007)

For fly ash bricks, the extra cost would be as per prevailing rates of burnt clay bricks and fly ash bricks. In case the fly ash option is cheaper than the conventional option, the green premium shall be considered as Nil.
Points: 6
Constraints: No

Criterion 17: Use low energy material in interiors
Green Premium: ((At least 70% of quantity of each item shall be low energy option)

(i) Sub assembly / internal partitions/ panelling / false ceiling, etc.
Base line cost (per sq.m.) is that of kiln seasoned / treated hollock wood -12mm thick (DSR Item No.9.36) = Rs.54377x0.012 = Rs. 652.52 per m^2

Cost of Green option (per sq.m.) is that of 25 mm thick particle board (DSR Item 9.35.3) = Rs.1099.65 per m^2

Extra cost of green option = Rs. 447.13 per m^2 Indicative Quantity = 150 m^2

Extra cost for this sub head = Rs. 67070/-

(ii) Doors / windows and frames
- Base line cost (per sq.m.) is that of kiln seasoned / treated hollock wooden door 35mm thick including panelling (DSR Item No. 9.5.2.1 + No. 9.7.2) = Rs.54377x0.012 = Rs. 1610.95 per m^2

- Cost of door frame (100mmx75mm) of same wood (DSR Item No. 9.1.3) = Rs. 235 per m.

For a typical door (2.1mx1.5m) total cost = 2.5x1610.95 + 5.7x235 = Rs. 5366.88

Cost of Green option (per sq.m.) is that of 25 mm thick particle board (DSR Item 9.35.3) = Rs.1099.65

- Cost of steel profile door frame (DSR Item 10.14.1) = Rs.251.90 per m.

For a typical door (2.1mx1.5m) total cost = 2.5x1099.65 + 5.7x251.9 = Rs. 5119.58

Extra cost for this sub head = Nil as the green option is cheaper.

(iii) Flooring
- Conventionally, for an office building, the mix of flooring is 50% Kota stone, 40% terrazzo tiles and 10% Granite flooring. The base line cost (per m^2) is calculated by taking weighted cost of corresponding DSR items (DSR Item No. 11.26, No. 11.16.4, No. 8.2.2.1) = 0.50x694.40 + 0.40x467.50 + 0.10x2480.20 = Rs. 782.22 per m^2

- As the green option, the suitable substitute would be 60% vitrified tile flooring, 20% kota stone flooring and 20% ceramic tile flooring (DSR Item No. 11.41.2, No. 11.26, No. 11.37). The cost is calculated similarly as 0.60x1031.85 + 0.20x467.50 + 0.20x598.65 = Rs. 877.72

Extra cost for this sub head = 95.50 The quantity is taken as 80% of plinth area on all floors. Indicative cost = 0.8x4000x95.50 = Rs. 305600/-

Points: 4
Constraints: No