Towards Automation of Sustainable Green Building Materials in India

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Abstract
The AEC (Architecture Engineering and Construction) industry has had a reputation for being a major contributor to negative effects on the environment. Hence, the need for development of sustainable buildings is increasing. Sustainability in the construction industry has the utmost potential to effect change in current construction practices. In this paper, two stage assessment of material is conducted in one stage IGBC green materials rating system is developed in BIM for the ease in process and in second stage an analytical tool to assess the eco-efficiency of building facade materials is developed (ECO-DEA Green rating system-EDGRS). This two-stage process assesses sustainable criteria and optimization of material selection aspects and process automation of material selection through BIM approach in both stages respectively. The ECO-DEA tool evaluates the eco- efficiency of façade material by using data envelopment analysis (DEA), a linear programming-based mathematical approach. Life-cycle assessment (LCA) and life-cycle cost (LCC) is used to rank material alternatives. It provides a holistic approach combining two pillars of sustainability, economy and ecology which gives complete information to the decision makers. It is followed by quantitative cradle-to-gate approaches, since they cover multiple environmental criteria. Most of the important decisions regarding green building construction are taken before the construction process starts. The created framework is an expandable automation assessment of sustainable criteria and green building rating system in India. It offers a vital guidance to the decision makers to evaluate alternative construction material selection.

Keywords

Building Information Modelling (BIM), Green BIM, Sustainability.

1 Introduction

The AEC industry is known for being a key contributor to adverse effects on the environment. Nowadays, due to the deteriorating environment, the focus is shifted to improve and protect natural resources. So, the concept of green buildings is introduced to tackle environmental challenges. The advantages of green buildings are:

- Efficient usage of water, energy and other resources
- Optimizing energy efficiency and encouraging the use of renewable energy.
- Conserving natural resources and minimize the generation of waste.
- Maintaining a good indoor environment by using non-toxic, ethical, and sustainable materials.
- Considering the quality of life of occupants in design, construction, and operation.

A slight increase in upfront costs of about 2% to support sustainable design, on average, results in life cycle savings of approximately 20% of total construction costs; which is more than ten times the initial investment (Kats, et al., 2003).

Nowadays, the extensive use of computers, architecture and engineering software demonstrates their tremendous role in the architecture, engineering and construction (AEC) industry. Building Information Modelling (BIM) can support the collaboration between various stakeholders throughout the project lifecycle by providing facilities to insert, extract, update or modify information in the BIM model. BIM tools offer the AEC industry the ability to facilitate and ease design, construction management, and other activities related to a construction project (Motawa, 2013).

Currently, for green building ratings, the traditional computer-aided design (CAD) drawings are submitted and used for evaluation. For the evaluation of category under materials and resources, the calculations are entered into the template by calculating the quantities for Bill of Quantities (BOQs) or manually from CAD drawings. If there are some variations in the drawings then the evaluator has to manually change the values in the template, which sometimes might cause errors.
There are several international organisations which have developed the green building rating system based on the type of construction and performance of the building. The oldest is BREEAM (Building Research Establishment's Environmental Assessment Method) was launched in 1990 in United Kingdom, followed by LEED (Leadership in Energy and Environmental Design) in United States in 1998. Some of the green building agencies in India are Indian Green Building Council (IGBC), Leadership in Energy and Environmental Design (LEED) India, Green Rating for Integrated Habitat Assessment (GRIHA), Energy Conservation for Building Code (ECBC)Excellence in Design for Greater Efficiency (EDGE).

The BIM model can be 4D model by connecting model elements to time schedules, and it can be 5D model by integrating cost estimation with model components. Several researches have been conducted in the areas of construction optimization and decision-making, leading to the development of a number of optimization models using a variety of approaches. In this paper, initial rating system for green building is proposed to fit sustainable environment. This rating system is called **ECO-DEA Green Building Rating System (EDGRS).** The EDGRS would be integrated in a framework that is dedicated for selecting optimum sustainable building materials that was developed, expanding the features of BIM technology.

The framework utilizes Data Envelop Analysis (DEA) optimization technique and Life Cycle Cost (LCC) analysis in order to perform its designated functions as demonstrated in figure.
Although the importance of eco-efficiency as a sustainability assessment tool has significantly increased worldwide, there are few studies that adopted this concept in the construction domain Li, Hui, Leung, Li, & Xu (2010) developed a methodology for eco-efficiency evaluation for residential development at the city level, in which they linked the economic value and environmental effects together. They proposed a methodology that selects the ecological footprint as an aggregate environmental indicator to represent all resources consumed and all wastes produced by residential development. On the other hand, Saling (2002) developed a specialized form of an eco-efficiency analysis tool that focuses on quantifying the environmental effects of a product on the basis of six categories, such as raw materials and energy consumption, land use, air, water and solid emissions, potential toxicity, and potential risks. Economic data was also gathered, including all costs undertaken in manufacturing or the use phase of the product. The aim of their tool was to compare similar products and processes to simultaneously improve environmental and economic performance. They derived the overall eco-efficiency score on the basis of normalizing respective categories and applying an overall weighting scheme. In another study, utilizing BASF method, Takamura, Lok, & Wittlinger (2010)

compared the eco-efficiency of three preventive maintenance technologies of existing roadways: traditional hot-mix overlay, polymer modified hot-mix overlay, and cold mix micro surfacing. In this study, LCA and LCC will be utilized as the denominator and numerator for an eco-efficiency ratio in this study.

Eco-efficiency ratio = LCC/LCA

The approach of utilizing LCC to represent the economic value added was adopted in several research studies (de Haes, et al., 2004). The primary advantage in utilizing LCC is to be able to account for all costs associated with the life cycle environmental effects.

The objective of the study is to develop framework for green building sustainable rating system (GRS) integrating BIM technology that is dedicated for selecting sustainable green material selection. The framework utilizes ECO-DEA optimization approach and life cycle cost analysis for a sustainable façade material in order to perform its designated functions.

The scope of the research is limited to the new commercial buildings constructed in India. The objective of this paper is to develop an analytical tool that can be used to assess the eco- efficiency of building facade materials. This tool is used to evaluate the materials using data envelopment analysis (DEA), a linear programming-based mathematical approach.

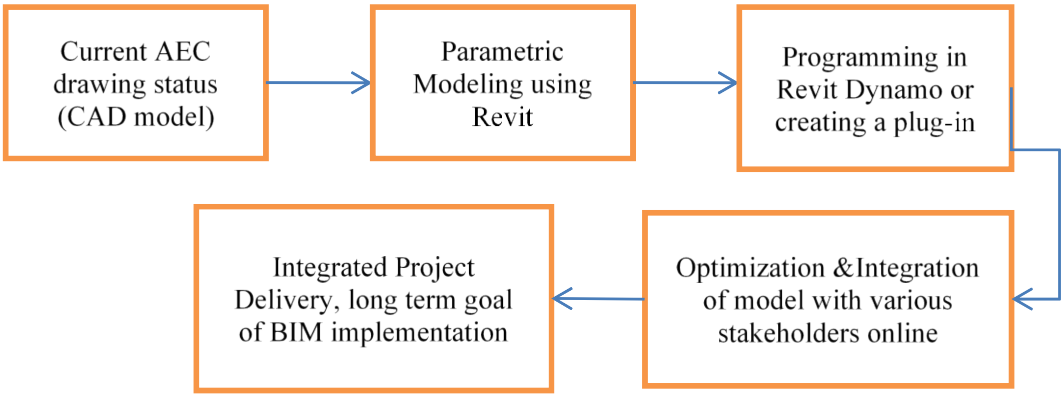

Figure 1 Proposed objective of the study

2 Objective and Scope of Work

The objective of the study is to develop framework for green building sustainable rating system (GRS) integrating BIM technology that is dedicated for selecting sustainable green material selection. The framework utilizes ECO-DEA optimization approach and life cycle cost analysis for a sustainable façade material in order to perform its designated functions. The scope of the research is limited to the new commercial buildings constructed in India.

A two-step methodology was adopted for the research:

1 First stage to develop a BIM model for an existing green building to establish a relation between BIM and IGBC rating process.

2 Second stage to develop and Eco-DEA mathematical model approach for optimizations and selection of sustainable material criteria for building façade material

3 To create and Integrated conceptual framework for assessment of green building material selection process (BIM-Model) and sustainable material optimization and selection criteria (ECO-DEA)

The green sustainable rating system (AHGRS) would be integrated in a framework that is dedicated for selecting optimum sustainable building materials that was developed, expanding the features of BIM technology. The framework utilizes ECO-DEA optimization technique and Life Cycle Cost (LCC) analysis in order to perform its designated functions.

2.1 First Stage Approach

Autodesk Revit 2020 has been used as a BIM modelling software and Dynamo for analysis. The major reason to use Revit and Dynamo is that majority of AEC professionals in India use Revit for creating BIM models.

Dynamo is graphical programming tool for design and BIM. It helps the AEC professionals to write the algorithm to enhance a design by giving more functionality to Revit that would otherwise be limited due to the nature of the software. Instead of typing out lines of code, your algorithm is composed of a series of what Dynamo calls nodes. The set of problems that Dynamo is most often used to solve are analysing BIM data, automating tedious and repetitive documentation tasks, and exchanging information between software formats. There are many advantages of using Dynamo such as user can reuse graphs from project to project, run the same process on multiple inputs, work with greater precision. Moreover, it has interpolability between different software formats.

2.2 Dynamo Plug-in

The scripting is done for a BIM model to demonstrate the practical approach. Scripting is done in dynamo to extract the information from BIM model to MS Excel for evaluating the green building score as per IGBC. A dynamo script is prepared for the evaluation of five parameters of the green building as per IGBC. These parameters are Reuse of salvaged material, Materials with recycled content, Local material, Wood based material and Green Pro certified materials.
Following Shared Parameters are created in the model:

- Distance from source (in km): This parameter takes a number input which specifies the distance of the materials of the element from manufacturing site to the project site. If the manufacturing of all materials is done within the range of 400 km, take the distance from where the maximum materials are manufactured or take the average of the distances where different materials are manufactured.
- FSC certified wood: This parameter is applied to all new wood-based products. For this calculation, the total cost of all new wood-based material should be more than 50%. This parameter takes a text as an input (Y for yes and N for no).
- Green Pro: This parameter is applied to the elements certified by CII under Green Product Certification Product (Green Pro). This parameter takes a text as an input (Y for yes and N for no).
- Recycled contents used: This parameter states whether the element has recycled content or not. This parameter takes a text as an input (Y for yes and N for no). According to this parameter at least 10% of the material cost should have recycled contents in the building to achieve the credit.
- Salvaged Materials used: This parameter is used to determine whether the element has used salvaged material. This parameter takes a text as an input (Y for yes and N for no). According to this parameter at least 2.5% of the material cost should have recycled contents in the building to achieve the credit.

The key to solving problems computationally is figuring out how to take the problem and break it down into a series of mini problems that are easier to accomplish with just a few Dynamo nodes each.

Figure 2 shows the roadmap created to extract and analyze the data from BIM model.

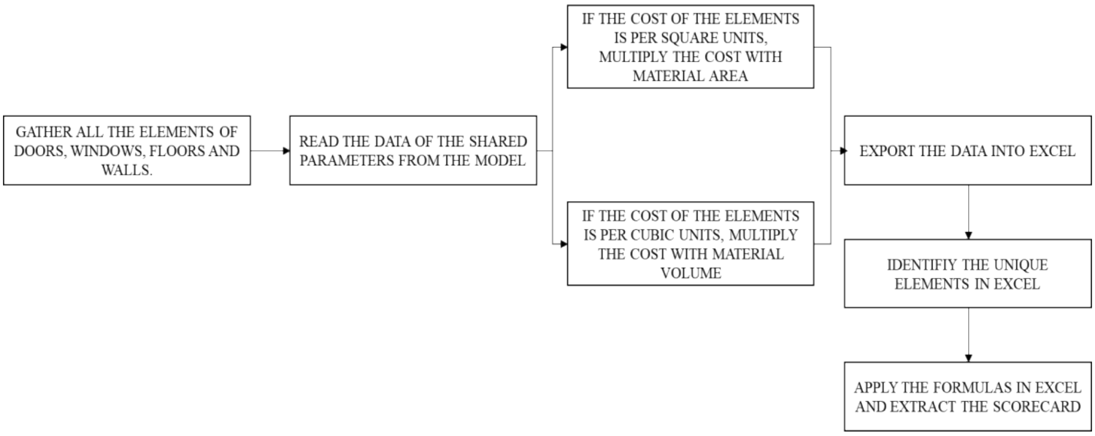

Figure 2 Roadmap for development of Plug-in

2.3 Second Stage Approach

2.3.1 Eco-Efficiency

Eco-efficiency emerged as a management philosophy by the World Business Council for Sustainable Development (WBCSD) in 1993, following the 1992 Rio Summit (Saling, et al., 2002). In the Summit, eco- efficiency was defined as "the delivery of the competitively priced goods and services that satisfy human needs and enhance the quality of life while progressively reducing ecological effects and resources intensity throughout product life cycles to a level appropriate with the estimated capacity of the Earth" (Kibert, 2013). Consistent with the aforementioned WBCSD definition, the eco-efficiency ratio consists of two independent variables: an economic variable measuring the value of products or services added, and an environmental variable measuring their added environmental effects. The eco-efficiency ratio expresses how efficient the economic activity is with regard to nature's goods and services. According to the definition, eco-efficiency is measured as the ratio between the added value of what has been produced (e.g., income, high quality goods and services, jobs, and gross domestic product (GDP) and the added environmental effects of the product or service (Zhou, et al., 2008). Eco-efficiency improvement can be accomplished by reducing the environmental effect added while increasing the economic value added for products or services during their life cycle. Although the importance of eco-efficiency as a sustainability assessment tool has significantly increased worldwide, there are few studies that adopted this concept in the construction domain. Li, Hui, Leung, Li, & Xu (2010) developed a methodology for eco-efficiency evaluation for residential development at the city level, in which they linked the economic value and environmental effects together. On the other hand, Saling (2002) developed a specialized form of an eco-efficiency analysis tool that focuses on quantifying the environmental effects of a product on the basis of six categories, such as raw materials and energy consumption, land use, air, water and solid emissions, potential toxicity, and potential risks. Economic data was also gathered, including all costs undertaken in manufacturing or the use phase of the product. They derived the overall eco-efficiency score on the basis of normalizing respective categories and applying an overall weighting scheme. The approach of utilizing LCC to represent the economic value added was adopted in several research studies (Saling, et al., 2002, de Haes, et al., 2004).

2.3.2 ECO-DEA Analysis

This tool evaluates the eco- efficiency of facade material by using data envelopment analysis (DEA), a linear programming-based mathematical approach (Jyoti & Arpana, 2014). The ECODEA model framework consists of Inputs of Life Cycle Assessment (LCA) environmental categories based on TRACI (TRACI User's guide and system Documentation1) viz. Acidification potential (ACD),

Toxicity Potential (TOX), Eutrophication potential (EUT), Global warming potential (GWM), Fossil fuel depletion (FFD), Smog (SMG), Water Intake (WTI), Human health criteria (HHL), Criteria air pollutants (CAP), Ozone depletion (OZD), and the output constitutes Life Cycle Costing (LCC). As LCC is the only output, output multipliers are not needed for the model. This model does not force any weight restrictions on the environmental effects. Thus, the flexibly chosen weights for environmental effects enable to maximize the relative eco-efficiency of the decision-making units (DMU) with respect to other compared DMUs. BEES' software was utilized because of the availability of construction material data and build-in capability of presenting the results on the basis of life cycle environmental effect categories.
DEA compares eco-efficiency by analysing other sections in the data set. This is the major drawback of DEA because the eco-efficiency ratios are relative to the eco-efficiency of other materials in the data set. LCA methodology undergoes some uncertainties, it does not compare the criteria based on which the decision making depends i.e., which environmental category is more important in selection of facade material.

3 Third Stage: Integrated Framework-Implementation and Results

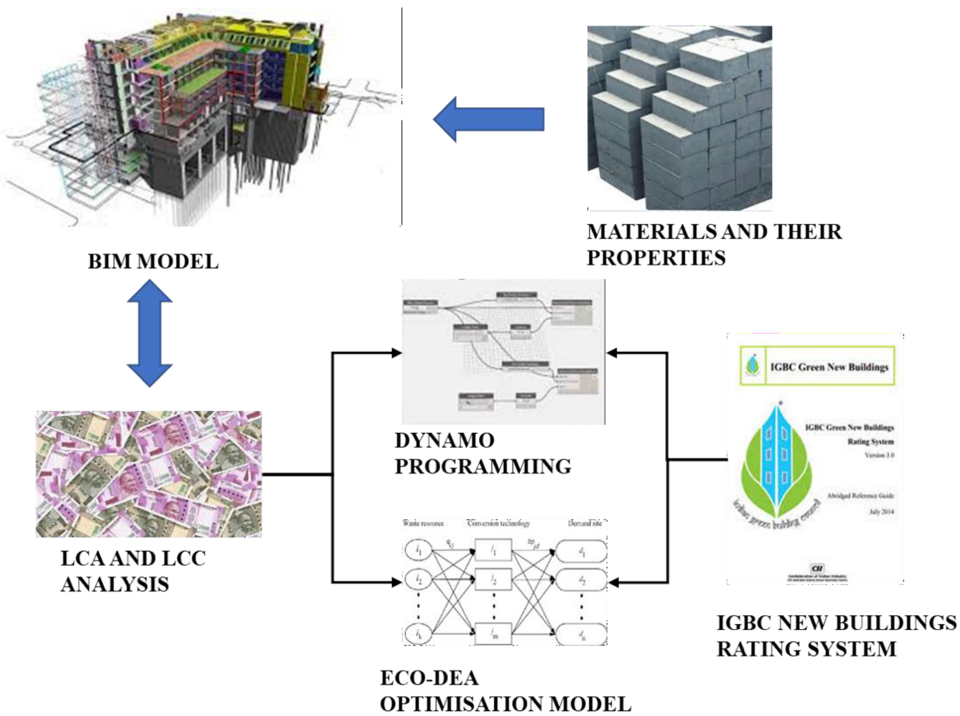

Figure 3 System Components of Integrated Framework System

The automated green building rating system plug-in for IGBC can be developed through the following three stages (as shown in Figure 3):

1) The IGBC knowledge framework is understood and deciphered into a simple format suitable for flowcharts.
2) Flowcharts are drawn as per the sequence of information required for the green building assessment.
3) Scripting is done in dynamo.

After the scripting is done in dynamo, the data is extracted from the model to MS Excel and analysed.

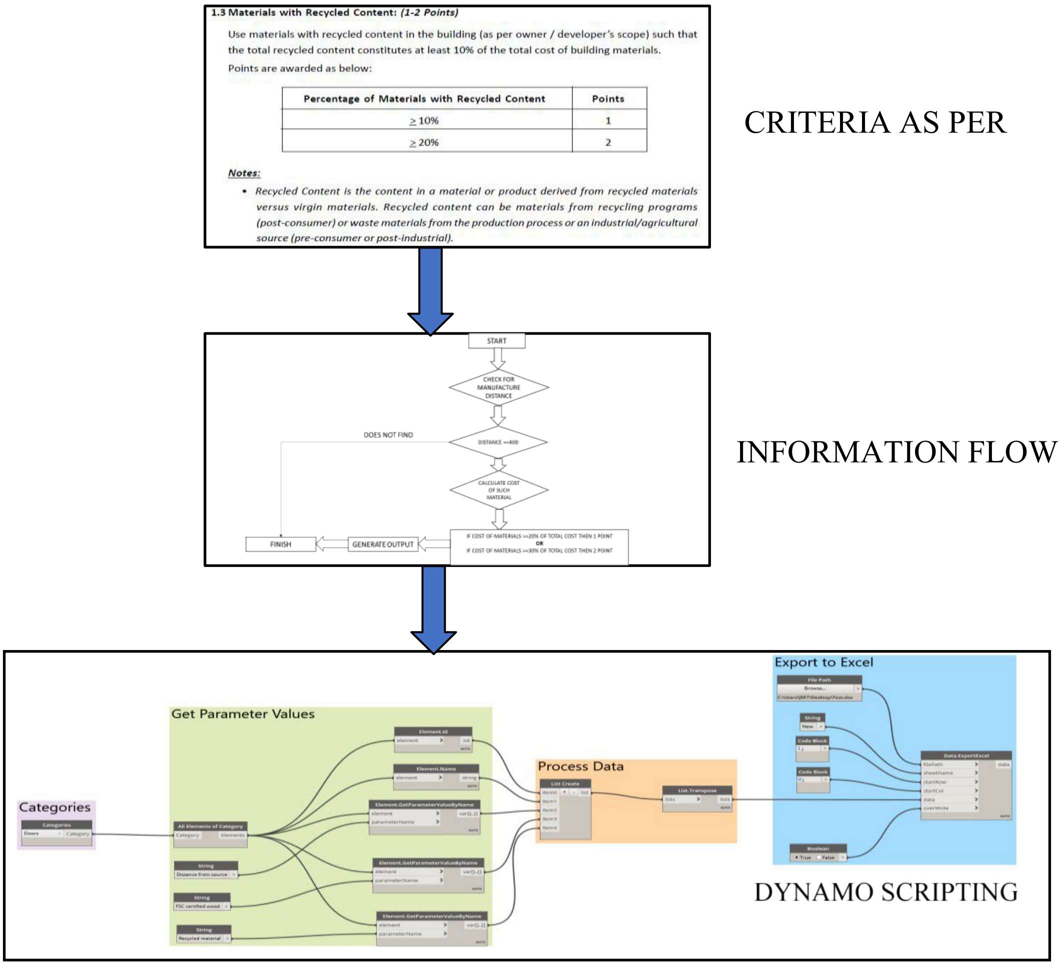

Figure 4 Stages for plug-in development

SCORECARD			
Credit	Parameter	IGBC Points Required	IGBC Points Achieved
BMR Credit 1.2	Reuse of salvaged material	2	0
BMR Credit 1.3	Materials with recycled content	2	0
BMR Credit 1.4	Local Materials	2	2
BMR Credit 1.5	Wood based material	2	1
BMR Credit 4	Use of Certified Green Building Materials, Products & Equipment	5	2
Total		13	5

Figure 5 Final IGBC Rating

4 Findings and Discussion

The calculated optimal weights (v_r) (Table 3) show which inputs were utilized for each DMU for their calculation. For instance, for DMU 1, the weights show that eco-efficiency was calculated by using only GWP, whereas other effect categories were all 0. The ECODEA results indicate that the ratios range from 2.34 to 1.17. Among wall finishes, cement plaster was found to be the most eco-efficient. The structural glazing was found to be the least eco-efficient when compared with the other exterior

wall finishes in the study.
The results showed that DEA is an effective tool to evaluate construction material alternatives and offer a critical insight to the decision maker that can lead to buildings that use much more eco- efficient materials.
In this study, a DEA-based eco-efficiency assessment framework is presented as an effective and practical way to evaluate building façade materials.

1. The developed framework utilized LCC and LCA as the numerator and denominator for calculating the eco-efficiency ratio and solved LP models to calculate eco-efficiency ratios for exterior wall finishes.
2. The ECODEA model calculated the ratios without enforcing any weight restrictions.
3. The said model predicted cement plaster to be the most eco-efficient with ECODEA ratio of 2.34. It has the least global warming potential of all the materials studied.
4. Though it has more acidification potential, toxicity but its eutrophication potential, water intake, human health and emission of criteria air pollutant is less as evident from Table 1.
5. The structural glazing is found to be least eco-efficient as per the study with ECODEA ratio of 1.17. Its acidification potential is lower (6500 mg H+ equivalents, as per Table 1) than other materials is but it has high global warming potential, smog, human health criteria and ozone depletion potential as given in Table 2.

This paper makes several contributions to construction research, including developing a mathematical model that does not require subjective weighting to assess the sustainability of construction materials and presenting a practical way to apply eco-efficiency to construction materials. The analysis of DEA results could be very helpful to decision makers to compare relative eco-efficiency of building facade materials.

ACD: Acidification Potential
GWP: Global Warming Potential
SMG: Smog
HHL: Human Health Criteria
OZD: Ozone Depletion
TOX: Toxicity potential EUT: Eutrophication potential
FFD: Fossil Fuel Depletion
WTR: Water intake
CAP: Criteria Air Pollutants

Table 1 Environmental effect categories

	Environmental effect categories									
Exterior wall finishes	ACD	TOX	EUT	GWP	FFD	SMG	WTR	HHL	CAP	OZD
1. Cement plaster (1:3)	9110	52.8	2.69	1460	9.84	733.11	1.3	138.34	2.57	0.072
2. ACP cladding	7110	19	2.79	3410	5.74	267	2.2	140	3.56	0.065
3.Exterior grade PVC panel cladding	7500	11.9	2.3	4560	6.2	322	2.5	160	2.78	0.031
4. Film coated structural glazing	6500	32	2.4	5600	3.4	600	2.1	172.5	2.35	0.055
5. Clear glass window with Aluminium Frame	6750	28	2.26	3570	3.2	523	2.6	148.9	2.5	0.036

Note: Units of measurement: ACD (mg H+ equivalents/unit), TOX (g 2, 4-dichlorophenoxy-acetic acid equivalents/unit), EUT (g nitrogen equivalents/unit), GWP (g CO2 equivalents/unit), FFD (MJ/unit), SMG (g NOx equivalents/unit), WTR (L/unit), HHL (g benzene equivalents/unit), CAP (micro disability adjusted) life years/unit), LCC (present value Rs/unit).

Table 2 Normalised Data Set

	Environmental effect categories										
Exterior wall finishes	**ACD**	**TOX**	**EUT**	**GWP**	**FFD**	**SMG**	**WTR**	**HHL**	**CAP**	**OZD**	**LCC**
1. Cement plaster (1:3)	1.23	1.84	1.08	0.39	1.73	1.50	0.61	0.91	0.93	1.39	0.28
2. ACP cladding	0.96	0.66	1.12	0.92	1.01	0.55	1.03	0.92	1.29	1.25	2.35
3. Exterior grade PVC panel cladding	1.01	0.41	0.92	1.23	1.09	0.66	1.17	1.05	1.01	0.60	1.41
4. Film coated structural glazing	0.88	1.11	0.96	1.51	0.60	1.23	0.98	1.14	0.85	1.06	0.45
5. Clear glass windows with Aluminum Frame	0.91	0.97	0.91	0.96	0.56	1.07	1.21	0.98	0.91	0.69	0.52

Table 3 Solution set

	Environmental effect categories										
Exterior wall finishes	**Ratio**	**v1**	**v2**	**v3**	**v4**	**v5**	**v6**	**v7**	**v8**	**v9**	**v10**
1. Cement plaster (1:3)	2.34	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
2. ACP cladding	1.29	0.00	0.00	0.00	1.25	0.00	1.24	0.00	0.00	0.00	0.00
3. Exterior grade PVC panel cladding	1.60	0.00	2.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4. Film coated structural glazing	1.17	0.00	0.00	0.00	0.00	0.15	0.00	0.30	0.00	0.00	0.00
5. Clear glass windows with Aluminium Frame	1.34	0.00	0.00	0.00	0.22	0.31	0.00	0.00	0.00	0.00	0.00

5 Conclusions and Further Research

BIM plays a vital role in AEC industry to facilitate the process related to construction of green buildings. With the passing time, this technology is evolving rapidly. Still, only some of the green building parameters are evaluated using software. Different parameters are evaluated using different software (e.g. eQuest for energy analysis, EcoTect for daylight analysis). The current market practice is to create a Revit model and then export the file as IFC to other evaluation software like eQuest, EcoTect, DOE2 etc. From the questionnaire analysis it was observed that Revit can be used to evaluate a lot of green building parameters. This is helpful for all the stakeholders of the construction industry as it saves a lot of time, efforts and resources.

BIM provides a platform to implement additional features for green building properties and evaluation of those properties. Visual Programming tool Dynamo can be used to evaluate the additional parameters. It allows the user to evaluate the properties of the building as per his/her requirements. In this paper, the parameters regarding building materials and resources had been added and evaluated. Although, the evaluation was done for different elements and not as different materials. In future, with complex programming and development of new nodes in dynamo, it will be possible to analyse the

materials separately and not as a whole element. So, the chances of ambiguity of rating calculation through the script will reduce. For this a complex programming needs to be developed in Dynamo.
In this study, a DEA-based eco-efficiency assessment framework is presented as an effective and practical way to evaluate building facade materials. The developed DEA framework utilized LCC and LCA as the numerator and denominator for calculating the eco-efficiency ratio and solved LP models to calculate eco-efficiency ratios for exterior wall finishes. The ECODEA model calculated the ratios without enforcing any weight restrictions. The said model predicted cement plaster to be the most eco-efficient with ECODEA ratio of 2.34. It has the least global warming potential of all the materials studied as seen in appendix. Though it has more acidification potential, toxicity but its eutrophication potential, water intake, human health and emission of criteria air pollutant is less as evident. The structural glazing is found to be least eco-efficient as per the study with ECO-DEA ratio of 1.17. Its acidification potential is lower (6500 mg H+ equivalents) than other materials is but it has high global warming potential, smog, human health criteria and ozone depletion potential. The accuracy of DEA results depends on the accuracy of the data extracted.
So, materials selected for applying the model were:

1) Cement plaster (1:3)
2) ACP cladding
3) Exterior grade PVC panel cladding
4) Structural glazing
5) Clear glass windows

Through literature review, it was established that LCC and LCA data will be required to calculate eco-efficiency ratio. LCC is calculated by finding first cost of installation from vendors in Ahmedabad and to it adding future cost of the materials. Life Cycle Impact Assessment is calculated using BEES Software. It has a huge inventory of building materials ranging from structural materials to external cladding.

In this study following assumptions regarding LCC have been made:

1) Discount rate: 8% *(Source: Reserve Bank of India)*
2) Inflation Rate = 8.31% *(Source: Ministry of Commerce and Industry, India)*
3) Total life assumed = 50 years
4) Salvage value = 0
5) Cement plaster facade has to be maintained approximately every ten years at 50% of the cost of first-time installation.
6) ACP cladding has a life of fifteen years, so every fifteenth year it is replaced.
7) PVC cladding has also a life of fifteen years and has to be replaced after that.
8) Structural glazing (clear and coated) has longer life. We have taken it as twenty years.

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