A Decision-Making Model Synthesis for Sustainable Building Development

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Abstract
Life Cycle Costing (LCC) is a decades old practice, yet its implication for building sector is relatively new. While ground is getting ready to accept Life Cycle Analysis (LCA), Life Cycle Cost Analysis (LCCA) and Life Cycle Inventory (LCI) Analysis for building projects, there is a need to embrace these analysis types to realize sustainable construction of building projects. While considering Sustainable development as outcome of sustainability in economic, social as well as environmental dimension, a Decision-Making Model for sustainable building development is synthesized. This is achieved by using LCC Analysis, LCI analysis and social sustainability parameters as respective indicators of economic, environmental and social sustainability dimensions. Building Information Model (BIM) as a comprehensive model including plenty of building project information, will assist overall sustainability analysis of construction projects during design phase. The Decision-Making Model applied on two proposals for a community center building has provided decisive sustainability values in all three dimensions. Based on results, a rational decision can be made to select the proposal with higher cumulative sustainability value. Owing to increasing requirement of holistic assessment of sustainability in building sector, the Decision-Making Model will help mature the participatory role of economic, social and environmental sustainability dimensions.

Keywords
Life Cycle Cost Analysis (LCCA), Life Cycle Analysis (LCA), Life Cycle Inventory Analysis (LCI), Building Information Model (BIM), Sustainability

1. Introduction

We live, work and play in buildings. Buildings as man-built enclosures protect us from undesirable effects of nature; however, they have a large environmental footprint. It is because of major resource consumption accredited to the buildings; one-sixth of world's freshwater, one-quarter of world's wood harvest and two-fifth of world's material and energy flow to quote a few (Qian & Chan, 2008 ; Rodman & Lenssen, 1996). The increasing understanding of the harmful effects associated with traditional construction of buildings has helped in providing momentum to the very idea of "green building". The practice of "green building" directs itself towards creation and use of models which are intended to be healthier as well as more resource efficient. These models include construction, operation, renovation, maintenance and finally demolition (Chan et al., 2009). Nowadays, green building has a primary role in the drive for sustainable development and it commits to balance otherwise competing dimensions of economy, environment and society. The adverse impact of a building on its inhabitants as well as on environment could be reduced while using an integrated design approach to create buildings which are environmentally efficient (Ali & Al Nsairat, 2009). Green design has an obvious role in making positive effects on environment and public health. Furthermore, green design increases building and organizational marketability along with a reduction in operating costs, an increase in productivity of occupants and helping to create a sustainable community (Ali & Al Nsairat, 2009; Fowler & Rauch, 2006). Green buildings are associated with non-toxicity, water conservation, durability, energy efficiency as well as highly recyclable building materials (Ali & Al Nsairat, 2009).

Owing to the competing nature of sustainability dimensions, this paper synthesizes a Decision-Making Model aimed at incorporating the holistic sustainability assessment of building construction projects during design and planning stages. To achieve so, the model grasps the sustainability and life cycle essence of previously published material to provide a sense of continuity and maturity. The key research objectives are to bring social and economic dimensions of sustainability in line with the environmental sustainability of built environment. Moreover, another objective is to arrive at a research model which is user friendly, inclusive and ensures rapid sustainability assessment of building design proposals during early design stage.

2. Literature Review

2.1 Need of assessing Environmental, Economic & Social dimensions of Sustainability:

Long term benefits for building owners and occupants can be guaranteed by building life cycle based assessment measurements (Ali & Al Nsairat, 2009; Cole & Kernan, 1996). Such systems can play a major role in reducing cost of building operations, in creating places which are healthier and more productive, in solving existing building problems as well as in controlling environmental impacts. All costs related with acquisition, ownership and disposal of a building system are considered by life cycle analysis. It is particularly useful when different project proposals with varying initial and operating costs, yet same functionality, are to be evaluated to select one that can maximize net savings (Cole & Kernan, 1996).

Compared to building operations, building material production has more likely chances of toxic releases to water. Hence, a wider vision is needed to grasp full range of potential effects (Trusty & Horst, 2003). According to Shen et al. (Shen et al., 2007), eco-environmental sensitivity and air assessment are to be used as checklist elements of environmental sustainability during project inception stage. They also advocate consideration of air pollution and emission, energy and resource consumption and ozone protection as checklist elements of environmental sustainability during project construction stage. Air pollution, water pollution and various energy consumption are emphasized by them as checklist elements of environmental sustainability during project operation stage. All these checklist elements related to environmental sustainability can be analyzed using Life Cycle Inventory analysis for building projects.

Social sustainability can be described as *"a positive condition within communities, and a process within communities that can achieve that condition"* (Almahmoud & Doloi, 2012; Mckenzie, 2004). The scrutiny of existing frameworks in regards of social dimension has revealed that the social dimension lacks in robustness and its participatory function along with economic and environmental dimensions is not on equal terms (Almahmoud & Doloi, 2012; Missimer et al., 2010). However, in spite of this imbalance in developments, the concept as well as need of social sustainability is unquestionable.

LCI based tools can ease decision making process by providing data related to environmental implication indicators but do not include operating energy. However, LCC based tools can ease decision making by providing operational energy data of a facility but these tools seem to overlook environmental impact of a system. Hence, individually LCI and LCC provide a partial picture of the whole sustainability issue.

By overlaying view of environmental impact of a building project obtained from LCI tools, a view of economic viability of a building project obtained from LCC tools and finally a view of social sustainability of a building project obtained from social factor evaluation; a holistic and wholesome picture of sustainability can be seen on the basis of which informed decisions can be made.

To satisfy human needs by provision of social, environmental and economic benefits is the objective of sustainable development (Almahmoud & Doloi, 2012; Brundtland, 1987). Human needs have varying priorities, for instance if issues of inequity, health problems, poverty and illiteracy taken in account , it is argued that focus of sustainable development in developing countries is to be on socio-economic issues rather than environmental concerns (Almahmoud & Doloi, 2012; Talukhaba et al., 2005). Therefore, developing and developed countries are to be dealt differently in terms of sustainability (Almahmoud & Doloi, 2012; Du Plessis, 2002). As different dimensions of sustainability receive varying preferences in different world regions depending upon affordability, technological advancements and other such reasons, only a flexible decision making approach with regard to locality, neighborhood and region can fulfill requirements of a good sustainability assessment tool. This reason of adaptability has motivated the synthesis of the Decision-Making Model.

2.2 Use of BIM in sustainability analysis:

Most vital times to make decisions regarding sustainable features of a building are during early design phase and pre-construction phase (Azhar et al., 2010; Azhar et al., 2011). Sustainability analyses during early design development stages can hardly be performed using planning features of traditional computer aided design (CAD). Typically, after production of architectural design and production documents comes the stage of building construction performance analyses. Hence, during design process the incapacity to continually analyze sustainability results into the inefficient process of retroactive design modification to achieve set of performance criteria (Azhar et al., 2011; Schlueter & Thesseling, 2009). As per a recent survey in the United States, 145 design and construction firms indicated that from some to significant cost and time savings are being realized by practitioners implementing BIM based sustainability analyses as compared to traditional methods (Azhar, 2010; Azhar et al., 2011). A change in traditional design practices as well as efficient production of a high-performance facility design can be realized by combining BIM technology with sustainable design strategies. A similar effort made on Columbia campus of the University of South Carolina resulted in an approximate sum of $900,000 worth of savings over next ten years at current energy costs (Azhar et al., 2011; Gleeson, 2008).

3. Methodology

The Decision-Making Model, including plenty of indicators representing all three dimensions of sustainability is synthesized. This will help evaluate the level of sustainability in a building project which is still in design phase. For this model, sustainability will comprise of environmental, social as well as economic dimensions. The functional form of the model will facilitate the stakeholders involved in the project to evaluate various design alternatives and to base their decisions on empirical findings rather than subjective opinions of sustainability. A BIM model of the building project in consideration will be formed which will help in LCCA as well as LCI analysis required to populate the model. Furthermore, a checklist with social sustainability parameters will help assess social sustainability of project in hand. The results will be used as an input in the sustainability Decision-Making Model.

Despite the utmost efforts to formulate Decision-Making Model as a reliable assessment model, it is still exposed to some subjective inputs from stakeholders. This discrepancy will be improved during further development of the model. Furthermore, the workability as well as the information flow of the model will also be improved.

4. Model Development

Within the model, economic sustainability dimension will be primarily a measure of LCC values of projects. Environmental sustainability dimension will be a measure of LCI values and social sustainability dimension will be calculated against certain parameters tailored for each individual community according to the needs, constraints and limits of locality. By tailoring inputs to the model according to parameters unique for different localities, it will help in generalizing the model for varied conditions. Hence, holding good for not just resource rich localities and communities but also for resource scarce communities.

Table 1: Selected project features for Case Study-1 & Case Study-2

Project Features	Unit	Case Study-1	Case Study-2
Area available for building and open space (excluding parking space)	Square Feet	28567	28567
Building footprint	Square Feet	28567	9506.5
No. of floors	No.	1	3
Weather station	ID	7780	7780
Floor area	Square Feet	27531	28564
Exterior window ratio	Ext. wall area/ Window area	0.69	0.66

4.1 Difference among Case Studies

Two proposals for community hall facility project are considered as shown in Figure 1. Both the case studies will have some features in common with few variations as shown in Table-1. Both the case studies are alternate proposals of a community building project. Same plot area for building as well as open space development is available to both the buildings. There is no other constraint for both case studies except the minimum number of people who can use the facility. Both the buildings have to comprise of same gross floor area to accommodate approximately same number of people within the facility.

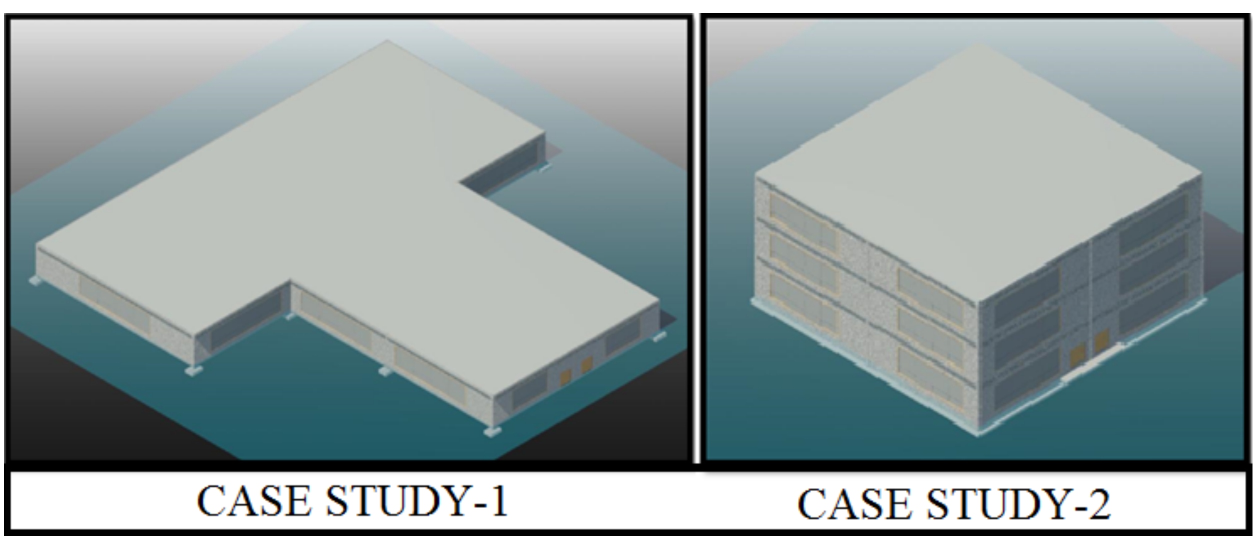


Figure 1: Axonometric view of Community hall (Case study 1 & 2)

4.2 Model development procedure

Following is the step by step approach in model development:

- Formation of a conceptual mass for the building project under consideration using Autodesk Vasari® and performing its energy analysis.
- Importing the conceptual mass into Autodesk Revit® for transforming it into a complete building form. Another round of energy analysis of complete building are performed with the help of Revit®.
- Assigning building information to a parametric cost estimating application for working out the capital cost of building construction.
- Assigning building capital cost information as well as probable energy use cost from Revit based energy analysis to an LCC based application to calculate Life Cycle Cost of building.
- Putting building information from detailed Revit based model as well as probable energy use cost of building from Revit based energy analysis into an LCI based application for calculating environmental footprint of building construction and operation.
- Evaluating building project in regards of social sustainability factors checklist.
- Performing normalization of parameter values and then merging parameter values into individual indicator values by associating different parameters with different weightings. After that, merging indicator values into individual sustainability dimension by associating different indicators with different weightings. As shown in Table-2, total sustainability value will be obtained by combining all sustainability indicator values with different assigned weights. Different sustainability indicators will have a further division in form of parameters.

Table 2: Various Indicators responding to three Sustainability dimensions

SUSTAINABILITY DIMENSIONS	**ENVIRONMENTAL SUSTAINABILITY**	**ECONOMIC SUSTAINABILITY**	**SOCIAL SUSTAINABILITY**
INDICATORS	Climate Change	LCC values	User comfort and safety
	Emissions	Affordability, Manageability & Adaptability	Functional, Aesthetic & Innovative design approach
	Water efficiency		
	Depletion of Resources		

4.3 Normalization of Parameter values responding to Sustainability indicators

There are two main problems associated with aggregation of parameters for sustainability assessment: first problem being the scale effects and secondly the varying nature of parameters as for some, higher values and for other lower values are preferable. Normalization of parameters, effectively provides solution for both these types of problems, and is performed using Diaz-Balteiro equation (Bragança et al., 2010; DíAz-Balteiro & Romero, 2004).

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^{*} - P_{*i}} \forall_i$$

Equation 1

For equation-1, P_i, P_i^* & P_{*i} will be the parameter value, ideal value and standard (or legal) value respectively for i th parameter. Particularly for this paper, the ideal and standard values will be fictitious, meaning that the parameter values of case study 1 and 2 will be normalized against imaginary numbers, since the purpose is to establish the functionality of model only. The above equation holds good for both kind of situations in which higher values of some parameters and lower value of other parameters are preferable. Instead of using individual parameter values for sustainability assessment, combined values of parameters within sustainability dimensions can be much more effective for the purpose (Allard et al., 2004; Bragança et al., 2010). The aggregation of normalized parameter values inside individual indicators are performed using equation-2:

$$I_j = \sum_{i=1}^{n} W_i \,.\, \overline{P_i} \qquad \textbf{Equation 2}$$

As apparent from the above equation, indicator *Ij* is weighting average of all normalized parameters. With sum of all weights equal to one, the indicator value will lie somewhere between 0 and 1. By taking weighting average of all indicators, performance value of different sustainability dimensions are calculated by equation-3:

$$P_{soc.} = \sum_{i=1}^{n} I_{soc_i} \,.\, W_{soc_i} \qquad \textbf{Equation 3}$$

Cumulative value of all three dimensions of sustainability are calculated by equation-4:

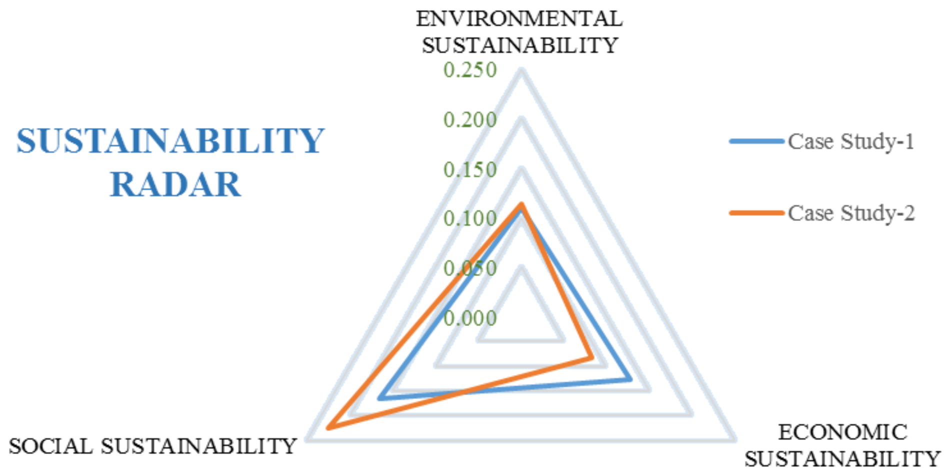
$$SUSTAINABILITY\ VALUE = P_{env}.W_{env} + P_{eco}.W_{eco} + P_{soc}.W_{soc} \qquad \textbf{Equation 4}$$

5. Results

Upon calculating sustainability values of case study 1 and 2, normalized values of all three dimensions of sustainability are summarized in Table-3 and plotted on Sustainability Radar as shown in Figure-2. However, it must be noticed that the weight assigned to all three dimensions are not equal. It is not only to establish the significance of social sustainability in case of community hall building but also to imply that in real life sustainability assessment has still an exposure to subjective judgment. As apparent in sustainability radar, both cases have differences of values mostly in terms of economic sustainability and social sustainability dimension.

Table 3: Final Sustainability Values of Case Study 1&2 responding to three sustainability dimensions

SUSTAINABILITY DIMENSION	Sustainability Dimension Weight (%)	Sustainability Values	
		Case Study-1	Case Study-2
ENVIRONMENTAL SUSTAINABILITY	30	0.110	0.114
ECONOMIC SUSTAINABILITY	30	0.127	0.082



SOCIAL SUSTAINABILITY	40	0.166	0.225
CUMULATIVE SUSTAINABILITY VALUE	100	0.448	0.468

Figure 2: Case Study 1&2 plotted on Sustainability Radar

6. Discussion

Preference to Vasari based energy performance analysis is useful when deciding among various conceptual masses. Otherwise, for use in Decision-Making Model, only Revit based energy performance analysis will be relied upon. Although, BIM applications can play a big role in establishing sustainability assessment, BIM integrated LCA assessment tools still need to be identified and authenticated. Furthermore, the standard and ideal parameter values used within the model are purely fictitious and are only intended to verify workability of model. True standard and ideal parameter values are still to be determined for a longitudinal study. The Decision-Making Model makes use of parameter value normalization using standard and ideal parameter values. Hence, not only the model can make comparative assessment of building projects as shown in the case studies above, it can also be used to perform individual assessments. Therefore, theoretically it can be useful for building projects in design and planning stages for comparative sustainability assessment of buildings and during operational stage for individual sustainability assessment. Since, sustainability expectations in environmental, economic and social aspects are varying for different building types, so a flexibility offered in the model will make it a valid Decision-Making Model for different building types situated in different regions.

7. Conclusion

Inclusion of important indicators such as those of LCI values, LCC values and social values within the Decision-Making Model can help assess different project alternatives in terms of all three dimensions of sustainability. For instance, case study 2 exceeds case study 1 in cumulative sustainability score only because of high weighting of economic sustainability, which also happens to be the only dimension of sustainability where, case study 2 performs remarkably well. Therefore, the individual representation of sustainability dimension score and cumulative values of sustainability can be used as situation demands. Establishing results on a three dimensional radar can visually assist in concise yet rapid assessment of various design proposals. For the decision-making sustainability assessment model to work effectively while still being a simple and rapid assessment tool is subject to some challenges. Key challenge in achieving performance merits for such a model is to establish a tradeoff between subjective judgment and objective values along with an effort to make inside working procedure of the model more consistent and inclusive so that more building related information is included in assessment with lesser information losses while the model is operational. The use of Decision-Making Model in planning stage of building construction projects will be helpful in evaluating level of sustainability in multiple design proposals. Consequently, rational decisions supported by this model will help in optimizing life cycle costs, ensuring adherence to social sustainability aspects as well as minimizing environmental degradation. The collection of indicator values in case of Decision-Making Model presents some challenges. For many indicators reliable simulation based data is available, yet some indicators especially from social sustainability dimension, require a method that can help eliminate subjectivity. Moreover, for this model to work effectively, a reasonable weighting needs be assigned to different sustainability dimensions, indicators and parameters for different building types. For this purpose, application of Analytical Hierarchy Process on a focused group is being evaluated along with Delphi technique and some other methods to collect reliable inputs for the model.

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