Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-1-7

BUILDING SUSTAINABILITY ANALYSIS: ANALYTICAL HIERARCHY PROCESS TO ANALYZE COST, LEED CREDITS, AND CARBON NEUTRALITY

RYAN DOCZY and YASSIR ABDELRAZIG

Dept of Civil & Environmental Engineering, FAMU-FSU College of Engineering, Tallahassee, U.S.A

For building owners, there are several factors that must be considered when considering whether or not a building has achieved its goals. One such problem building owners facing during a project's design phase is the creation of a proper balance between reducing immediate costs and increasing the sustainability of a building. Due to the implications these decisions will have on buildings' owners and occupants, owners need to have decision support tools to be able to assist them in determining how well a building will meet their goals and preferences. The model described by this paper utilizes the Analytical Hierarchy Process and Multiple Attribute Utility Theorem to compare a project's competing alternatives in terms of their ability to meet the project's LEED, carbon neutral/Net-Zero, and cost/benefit goals. Utilizing a combination of user preferences and data on an alternative's anticipated costs and level of sustainability, a score will be generated that allows the user to determine how well the alternative comes to meeting the project's overall goal. This process will be applied for a case study library building to determine the alternative that best meets the project's overall goal. The model's results and validity are discussed.

Keywords: Green design, Sustainability, Decision making, Optimization, Renewable energy, Lifecycle calculation.

1 INTRODUCTION

For many decision makers who desire to build a sustainable building that is also budget-friendly, there is tremendous difficulty in determining the degree to which a project has or will meet the goals set forth by the decision maker. While a decision maker has to consider a plethora of possible goals while trying to determine how well a project complete its goals, this paper looks at two major goals; the sustainability and costs/benefits associated with a sustainable project. Utilizing the Analytical Hierarchy Process, a hierarchy will be formed that includes the project's main goals or criteria (obtaining LEED credits, costs/benefits of building green, and designing a carbon neutral/Net-Zero building), its sub-criteria (collection of smaller goals, that when combined, make up the main criteria), and the project's alternatives (set of competing design alternatives). It is through the determination of how well each sub-criteria and criteria has met its goals, that the decision maker can determine which of the project's alternatives best meets their preferences and goals. Through the creation of a weighting system, the development of utility function calculations, and the development of a model to interpret the data, the decision maker can gain a good insight into how well each of the competing alternatives comes to meeting the project's goals. Consequentially, the decision maker can rank the project's alternatives and choose the one that best fits their goals or performance criteria.

1.1 Literature Review

The literature review was conducted for this research by reviewing the U.S. Green Building Council's LEED rating system and the costs and benefits associated with it. Additionally, this research looks at the concepts of net-zero buildings and carbon neutrality. Moreover, the review includes an investigation of the Analytical Hierarchy Process (AHP) and Multiple Attribute Utility Theorem (MAUT).

1.1.1 *Leadership in energy and environmental design – LEED*

The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program utilizes a system that awards credits based on whether or not a building achieves certain specified sustainability indicators. The category of interest in this research is LEED for Building Design & Construction due to the fact that it is the category used for New Construction (NC) projects.

Projects that have LEED accreditation generally are able to claim a range of benefits. Projects with LEED accreditation are expected to conserve resources (such as water and energy) to a certain degree in order to obtain their appropriate LEED credits. Kats (2003) lists how one could expect to pay less for utilities, operations & maintenance, increase worker productivity, etc., to generate savings over ten times the initial investment.

One of the major roadblocks for industry-wide implementation of LEED are the somewhat uncertain, incremental costs associated with getting LEED accreditation. The types of costs and their severities can differ depending on which cost element is being examined. One can expect around 2% increase in upfront construction costs for any building that is designed to be LEED certified, silver or gold (Kats 2003). High costs of LEED certification and an excessive bureaucracy are other areas where LEED has been criticized (Murphy 2009).

1.1.2 *Carbon neutral and Net-Zero design*

The second sustainability system that will be investigated for this paper is the concept of net-zero building/carbon neutral design. The terms carbon neutral and Net-Zero tend to be treated in a manner that considers their end goals to be the same; however, the definitions of these two concepts differ in a few respects. The difference between the two is that, "… a net-zero building produces as much energy (or more) than it uses in a year. A carbon neutral building on the other hand does not use any fossil fuels in its operation" (Archisage 2014).

1.1.3 *Multiple attribute utility theory*

In Multiple Attribute Utility Theory, the problem is broken down by separating the main goal from the criterions (second level hierarchy), separating the criterions from the sub-criterions (third level hierarchy). At the very bottom of the hierarchy are the project's alternatives. All of these elements together form the hierarchy structure associated with the complex problem (Pohekar and Ramachandran 2004).

According to Baird (1989), the term "utility" refers to the how well an evaluator likes a set of outcomes. The utility values have a range of values, which are defined by a lower bound, U_L, and an upper bound, U_H. The decision maker must also determine how they would like to handle risk. For this paper, it is assumed that the decision maker is risk neutral; therefore, the following equation will be used to determine a sub-criteria's degree of liking:

$$U(x) = [1/(U_H - U_L)]*x + -U_L /(U_H - U_L) \qquad (1)$$

The value for *x* in the above equation is the actual value for an attribute in a project. While UL and UH are minimum acceptable and desired values, the *x* value indicates what the actual value that is associated with the project.

1.1.4 *Analytical hierarchy process*

AHP decides whether or not a project has met its objective through the use of pairwise comparisons. These pairwise comparisons allow the user to weigh the attributes and criteria so that the model understands which of the attributes/criteria are vital for the project to succeed and which are not considered to be important.

AHP sometimes is classified as a MAUT approach. It involves an importance-ratio assessment procedure and uses a hierarchy to establish preferences and orderings. A linear model is then derived and used to rank alternatives (Dyer 1990).

2 SUSTAINABILITY ASSESSMENT CASE STUDY

In order for the model to be put into practice, the Eastside Branch Library located in Tallahassee, Florida was used as a case study. The architect designed the building with the intent that it would achieve LEED Gold accreditation. The 10,000 square foot library is currently in operation and is expected to be awarded a LEED Gold status.

The pairwise comparisons for this study were developed in part by the authors and in part by asking academia and non-academia with backgrounds in sustainability, construction, or buildings sciences to fill out the pairwise comparisons. The average of all of the results was taken to be the pairwise comparison for this project. While the authors decided to gather multiple opinions for the development of the project's pairwise comparisons for the sake of ensuring that several viewpoints were considered, one could feasibly only account for their own preferences when developing the pairwise comparisons for their own uses.

2.1 Alternative 1

2.1.1 *Criteria and sub-criteria pairwise comparisons*

The very first inputs into the model are those for the pairwise comparisons for the project's criteria. For this study, the goal with the highest level of importance has been identified as the building's ability to minimize costs and increase benefits. The building's Costs/Benefits goal is considered to be moderately more important than obtaining LEED credits and moderately more important than having the building reach its Net-Zero/Carbon Neutral goals. These pairwise comparisons were developed using Table 1 as developed by (Saaty 1980). The sub-criteria pairwise comparisons are similarly developed by the decision maker (much like the pairwise comparisons for the criteria) by comparing two different sub-criteria of a similar hierarchy with one another.

2.1.2 *Utility function generation*

The input in this section will form the utility functions that develop the decision making tool into one that combines the AHP elements (from the piecewise comparisons) with those of MAUT (from the utility functions) to create the decision making tool used in this paper.

2.1.3 *Sub-criteria utility functions*

Utilizing Eq. (1), the sub-criteria utility functions can be generated. Examples of user inputs for U_H, U_L and the actual/expected value are shown in Table 1. Using Eq. (1), the utility function equations and sub-criteria values are calculated.

Table 1. Utility Function Data Input for the Energy & Atmosphere Sub-Criteria.

Energy & Atmosphere (0-35 credits possible)	**Number of Credits**
Minimum Acceptable:	26
Desired Level:	35
Number of Credits Obtained:	33

Table 1's sub-criteria obtained a utility value of 0.78, which shows that the actual/expected value has come closer to meeting its desired goal of 35 credits than it has its minimum acceptable value of 26.

2.1.4 *Project utility value and criteria utility values*

After all of the inputs for the case study have been input into the system, the project's utility value and its criteria's' utility values can be determined from the previous inputs. Utilizing Eq. (2), the utility value for the Eastside Branch library can be determined.

$$u_i(y_1, y_2, \ldots, y_n) = w_1u_1(y_1) + w_2u_2(y_2) + \ldots + w_mu_m(y_m) \quad (2)$$

"Where u_iy_i = single attribute utility function for attribute *i* and ranges from 0.0 to 1.0, y_i range of values taken by attribute *i*; and corresponds to the relative importance of attribute *i*" (Ghanem 2007).

According to the model output shown in Table 2, the project received a utility value of 0.746. This utility value will be compared to those generated for Alternatives 2 and 3, which will be explored following this analysis of Alternative 1.

2.2 Alternative 2

The second alternative generated for this case study was one that would involve the removal of the library's rooftop solar panels. The idea of this is to investigate whether or not the removal of the solar panels would reduce the upfront price of the library enough to make up for its increases in utility bills, lost LEED credits, and its increased pollution generation.

As one can see from Table 2, there are major changes associated with removing the solar panels. The elimination of these panels causes a large drop in renewable energy on-site (to zero kWh) and an increase in the library's carbon footprint. These changes and the increase in the utility value for Energy consumption (due to the decrease in the investment cost associated with the solar panels) modified the project's utility value to 0.689.

2.3 Alternative 3

The third and final alternative examined by this paper is one which involves an increase in on-site renewable energy, an increase in off-site renewable energy purchased, and the purchase of carbon offsets. The aim of this alternative is to improve upon certain sustainable elements of the project (when compared with Alternative 1) and determine whether or not they are worth the increased investment.

The increases in on-site renewable energy lead to an overall reduction in energy consumption, thus lowering the monthly utility bills and increasing its respective "green" utility values; however this energy is more expensive, thus leading to increases in the cost of the energy purchased.

Table 2. Alternative 3's Utility Value and Criteria Utility Values.

	Alternative 1	**Alternative 2**	**Alternative 3**
Utility Value for this Project	**0.746**	**0.689**	**0.767**
Utility Function for Cost/Benefits	0.81	0.863	0.761
Utility Function for LEED Credits	0.706	0.553	0.706
Utility Function for Net-Zero/Carbon Neutral	0.575	0.262	0.886

2.4 Discussion

When examining the data from Table 2, one can see that the alternative that best aligns with the project's goals is Alternative 3 because it has the highest utility value (0.767). As such, the user should chose to design the building according to Alternative 3 given the preferences of the user. Alternative 1 showed to be very similar in utility value to Alternative 3 and could feasibly be chosen over Alternative 1 if any inputs are slightly changed. Additionally, this conclusion was formed with the pairwise inputs of the authors and other contributors and required assumptions in the development of the 2 other alternatives; therefore, it is not suggested that Alternative 3 is a better design than Alternative 1, just that with the given inputs it will be the preferred option.

3 CONCLUSION

The research succeeded in developing an AHP/MAUT model to integrate the concepts of LEED, net-zero/carbon neutrality, buildings costs/benefits, and the user's pairwise comparisons into a decision making tool. A decision making tool for building sustainability was generated to examine alternatives, and determine the alternative that best meets the owner's sustainability and cost goals as defined by the user's pairwise comparisons, U_L and U_H values. A case study, the Eastside Branch Library, was used to prove the validity of the model and to examine the model's ability to evaluate the user's preference of multiple competing building design alternatives and choose the alternative that best fits the overall goals of the project. Finally, an analysis of the case study and its alternatives was conducted. The first alternative, the library as it was actually constructed, was chosen as the best alternative.

The study ran into the following limitations while creating the model and calculating the case study utility values. The data for the case study was incomplete, partially due to accessibility of data and partially due to it not being finalized (e.g. complete LEED data wasn't available since the library is still undergoing LEED certification inspections). Due to this, for certain calculations data either were assumed from documents provided by the architect or developed based on pricing data that could be found online.

Future areas of research might include the addition of a sensitivity analysis tool would allow the user to better understand how changing some of the model's parameters will affect the overall output of the program. The decision maker may also wish to add or change certain project criteria, which would lead to the requirement of major changes to the model. Future work can utilize other criteria goals that better conform to the project or project alternatives being examined.

References

Archisage. "Carbon Neutral or Net Zero Design." Web log post. *Archisage*. N.p., 1 May 2011. Web. 15 Feb. 2014. <http://www.archisage.net/profiles/blogs/carbon-neutral-or-net-zero>.

Baird, Bruce F., *Managerial Decisions under Uncertainty: An Introduction to the Analysis of Decision Making*. New York: Wiley, 1989.

Dyer, J. S., Remarks on the Analytic Hierarchy Process, *Management Science* 36.3 (1990): 249-58. *JSTOR*. Web. 12 Feb. 2014.

Ghanem, Amine Abdallah, "Real-Time Construction Project Progress Tacking: A Hybrid Model for Wireless Technologies Selection, Assessment, and Implementation" (2007).Electronic Theses, Treatises and Dissertations. Paper 4339.

Murphy, Pat., LEEDing from Behind: The Rise and Fall of Green Building, *Community Solutions* 18 (May-June 2009): 1-11.

Pohekar, S. D., and M. Ramachandran, Application of Multi-criteria Decision Making to Sustainable Energy Planning—A Review, *Renewable and Sustainable Energy Reviews* 8.4 (2004): 365-81. *Science Direct*. Web. 13 Feb. 2004.

Saaty, Thomas L., *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. New York: McGraw-Hill International Book, 1980.