Life Cycle Assessment of a Green Building Material – A Review

P. S. S. Vamsi[1], Nandamuri SivaRaja[1] and B. Sarath Chandra kumar [2]

[1]Student, Department of Civil Engineering, K. L. University, Guntur, A.P, India.

[2]Assistant Professor, Department of Civil Engineering, K. L. University, Guntur, A.P, India.

Abstract

In the past, the green building movement has taken a prescriptive approach to choosing building materials. This approach assumes that certain prescribed practices such as the use of local materials or products with recycled content are better for the environment regardless of the product's manufacturing process or disposal. Fortunately, it is being replaced by the scientific evaluation of actual impacts through life cycle assessment (LCA).

LCA is an internationally recognized method for measuring the environmental impacts of materials, assemblies or whole buildings over their entire lives from extraction or harvest of raw materials through manufacturing, transportation, installation, use, maintenance and disposal or recycling. When integrated into green building codes, standards and rating systems, LCA encourages design professionals to compare different building designs based on their environmental impacts and make informed choices about the materials they use.

Key Words: Green Building Materials, **life cycle assessment.**

Corresponding Author: P. S. S. Vamsi

Introduction

Buildings significantly alter the environment. Building construction consumes 40% of the raw stone, gravel, and sand used globally each year, and 25% of the raw timber. Buildings also account for 40% of the energy and 16% of the water used annually worldwide. In the United States, about as much construction and demolition waste is produced as municipal garbage. Unhealthy indoor air is found in 30% of new and renovated buildings worldwide [1]. Negative environmental impacts arise from these activities.

For example, raw material extraction can lead to resource depletion and biological diversity losses. Building product manufacture and transport consumes energy, generating emissions linked to global warming, acid rain, and smog. Landfill problems may arise from waste generation. Poor indoor air quality may lower worker productivity and adversely affect human health

Life Cycle Assessment (LCA) is a method for the analysis and assessment of potential environmental impacts along the life cycle of a good or a service. It is applicable on products, processes or firms, to document their environmental performance, to identify potentials for environmental improvements, to compare alternative options as well as to substantiate eco labeling criteria. In many cases, the outcome of an LCA is used in firms to order changes in the product or process design or in suppliers. However, the same static system model suitable for descriptive purposes such as environmental reporting is often used for planning purposes such as product or process development. The data taken as a basis for such analyses often represent average technology mixes (such as the annual electricity mix in a certain country), for which the emission factors and requirements are determined based on, e.g., annual averages. This may lead to a system model contradictory to the original goal of the LCA, namely to support decisions. This may in its turn result in wrong indications or in suboptimal solutions [1].

Increasing awareness of environmental issues and environmental impacts from design, construction, operation, and demolition of buildings, coupled with pressures from various stakeholders such as government regulators, legislative bodies, environmental activist groups, the insurance and banking industries (driven by risk concerns), and courts have led to what has come to be known as “the green building movement.” Through this movement, the construction industry has sought to reduce its energy and environmental impacts [2]. This movement gained substantial momentum with the development of marketable green certification systems such as the Leadership in Energy and Environmental Design (LEED) rating systems, developed by the United States Green Building Council [3]. The LEED rating systems provide guidance for implementing sustainable design and constructionstrategies and award green building certification for having utilized such strategies.

Green building certification systems like LEED and others have been successful as awareness-generating and marketing tools, and supporters have claimed environmental, social, and economic benefits from them. However, several researchers question the validity of environmental benefit claims from green certified buildings and criticize the LEED system for not taking a scientific and life-cycle perspective in assessing environmental impacts and in the evaluation of alternative designs and practices [4-6]. Analysis of an LEED-certified office building from a lifecycle perspective and found significant variations in the overall environmental benefits represented by various LEED credits [5]. They criticized certain LEED credits for having negative effects on the environment and proposed a new scoring system for LEED credits and the material and resources (MR) and energy and atmosphere (EA) categories in LEED credits for an institutional building from the energy and solid waste impacts standpoint and argued that the LEED system "does not provide a consistent, organized structure for achievement of environmental goals" from a life-cycle perspective, and theyrecommended incorporating life-cycle assessment (LCA) for further development of the LEED system [2, 6].

A number of other researchers have also recommended using life-cycle assessment methods for evaluating and promoting sustainable construction in general, in addition to the green certification of buildings [2].

LCA methods have been used for environmental evaluation of product development processes in other industries for a long time, although application to the building construction sector is fairly recent. Because LCA takes a comprehensive, systemic approach to environmental evaluation, interest is increasing in incorporating LCA methods into building construction decision making for selection of environmentally preferable products, as well as for evaluation and optimization of construction processes. In addition, a growing body of literature is developing, employing LCA methods in performance evaluation of buildings, their design, and construction practices. However, this LCA literature is fairly fragmented and spread over several national and international publications. There has been a need to compile and categorize such diverse literature to assist the building construction industry and associated researchers to understand the state of the art in construction- related LCA research and to provide direction for future development [2].

Why LCA?

LCA is a measurement tool, a way to measure the environmental performance of products over their life cycle, from "cradle" (where the raw materials are extracted) to "grave" (where the product is finally disposed of). The outcome of an LCA study is called the "ecoprofile," the compiled measurements of indicators of environmental issues such as climate change, toxicity, fossil fuel depletion, and water resource depletion. An LCA of a building will tell you how much climate change was caused by the building from the point where minerals were mined to the point where the building waste is landfilled [7]. It will do the same for about a dozen other environmental issues, including toxicity, acid rain, and resource depletion.

As it turns out, lots of people care about having more environmentally friendly products. Even if you aren't one of them, your clients probably are. For building product manufacturers, if you can prove that your product is greener, you will have more market to sell it in. Similarly, Building Teams that use environmentally friendly products may find greater client acceptance. Market research has shown over and over that at least 80% of people will prefer the environmentally friendly product if it does not cost more, and 10-20% will actually pay more for a greener product. The explosion of the LEED program of the U.S. Green Building Council reinforces the point [7].

LCA is the only science-based and credible tool that is actually designed to measure the environmental impacts of a product. Because it looks at all the important environmental issues and evaluates the entire product life cycle, an LCA uncovers the whole environmental story. That way, if a product has more impacts during manufacture but saves impacts during use, you can see if it is a better environmental choice. A good example of this is insulation. The more insulation you use, the less energy you use to heat or cool a building. It is true that by adding insulation you are adding manufacturing impacts, but the environmental benefits of insulation are so large that the more insulation you add (even with additional environmental impacts in the manufacturing stage) the fewer environmental impacts you get overall (because of the benefits in the use phase), for a net positive environmental outcome. As it turns out, adding insulation decreases the costs of operating the building, too.

One of the interesting things about LCA studies is that they can test our assumptions about what is really "green." For example, think about recycling as a way to decrease environmental impacts. We know that recycling preserves natural resources, so making recyclable products and using recycled products is a good thing, right?

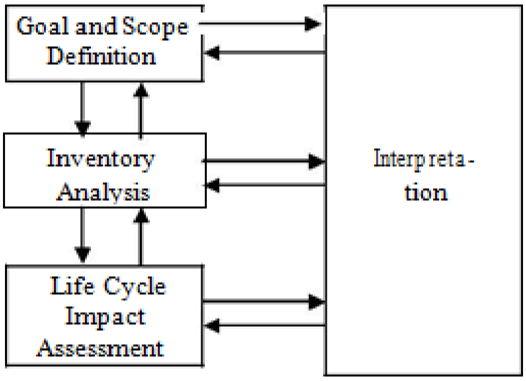

Fig – 1: LCA framework based on ISO 14040 [2].

Many life cycle assessments have been done on the topic of recycling and it turns out that recycling is only environmentally beneficial if it can be done close to the source of the waste stream. If you have to ship materials hundreds of miles away to a recycling facility, you probably are causing more environmental damage due to burning fossil fuels for transportation than you would if you just disposed of them in a landfill. You are using up one natural resource (petroleum) to save another. In the context of buildings, this means that onsite recycling of building wastes is a good thing and offsite recycling should be scrutinized carefully, especially for large volume materials such as waste concrete. You are trading off petroleum losses for concrete conservation. When we think about the impending depletion of oil versus the prevalence of gravel and the other components of concrete, it should give us pause.

LCA Applications in Building Construction A review of building construction-related literature from the last 10–15 years suggests a rising interest in incorporating LCA in construction decision making, within the United States and, more so, in Europe and Asia. We classify this literature into four categories: LCA applications for construction products selection; LCA applications for construction systems and process evaluation; LCA tools and databases related to the construction industry; and LCA methodological developments related to the construction industry. See Table 1 for a list of studies in each category. Sustainability and Life-Cycle Assessment Whereas many have debated the definition of sustainability, the authors use the definition of sustainable development presented by the World Commission on

Environment and Development (1987): “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

This definition illustrates the dynamic and multidimensional aspects of sustainability. The National Research Council (NRC 1999) further articulates this definition, stating that sustainability comprises economic, environmental, and social dimensions. Note that sustainability changes over time. What is seen as sustainable in one set of circumstances may not be sustainable in another set of circumstances. For instance, in a booming economy, different decisions may seem sustainable than in a more depressed economy. Sustainability also varies geographically. Environmentally friendly practices in Washington, for example, may be very different from environmentally friendly practices in Arizona. Finally, culture has an impact on sustainability. Social equity is accepted as a tenet of sustainability because this reinforces the ability of future generations to meet their own needs. However, the vehicles for social equity vary across economies, governments, geographies, and so forth. An infrastructure LCA is not synonymous with a sustainability assessment, but LCA provides critical information on environmental, economic, and social impacts of infrastructure projects and how to minimize those impacts. The sustainability assessment should use integrated indicators (i.e., indicators that capture the broad range of infrastructure goals), perform a consistent analysis of the targets to be achieved, and use transdisciplinary approaches that acknowledge the multiple stakeholders for the infrastructure service. The LCA does not address all these challenges, but it can provide valuable insight for some and be complemented with additional analyses to achieve a broader sustainability assessment

Life-Cycle Cost Method for New Construction Materials

The new-material life-cycle cost method has three important characteristics. First, it is a "project-based" approach; that is, the method computes the life-cycle costs of typical structures such as highway overpasses. Second, the method allows the designer to choose any construction material that satisfies the project's performance requirements. For example, to build a two-lane, two-span overpass, the project planner can specify that each material satisfies a set of minimum performance capabilities, including that the overpass built from it (1) be able to carry AASHTO HS20 loads; (2) not deflect between spans more than a prescribed limit; and (3) last a prescribed minimum number of years. None of the performance requirements assumes or precludes the use of a particular material. The third important characteristic of the method is that it includes a cost classification scheme which allows the bridge planner to compare the intrinsic life-cycle cost advantages and disadvantages of a new material to those of conventional materials [8].

Although the new-material life-cycle cost method can be applied in numerous types of analyses [9] it is primarily a tool for comparing new construction materials such as high-performance concrete to conventional materials such as normal-strength reinforced concrete. The life-cycle cost method's steps for comparing and choosing a cost-effective construction material are as follows:

1. Define the project objective and performance-based requirements.
2. Identify the material alternatives that achieve the project objective and satisfy the performance requirements.
3. Establish the basic assumptions for the analysis that apply to all project material alternatives.
4. Identify, classify, and estimate all costs over the life-cycle of the structure.
5. Compute the life-cycle cost of each alternative.
6. Perform sensitivity analyses.
7. Compare the alternatives' life-cycle costs.
8. Consider other project effects.
9. Select the best alternative.

In the first step, the project planner defines the specific project, say, the construction of a two-lane overpass. The step specifically caters to comparing new materials and conventional materials on an equal footing (that is, the project is an "overpass," not a "concrete overpass"). Current engineering practice inhibits the use of new materials because designs are often based on codes which prescribe specific construction materials. Step 1 allows the project planner to set minimum project performance requirements such as load-carrying capacity and span deflection. In Step 2, the planner can then select alternative materials that satisfy Step l's requirements. In Step 3, the planner estimates those project parameters that are common to all material alternatives such as the estimated traffic flow on and under the bridge, the value of drivers' time when they are delayed by construction work, and the rate at which future costs are discounted to the present. The focus is on project attributes that are not tied to a specific material.LCA Applications for Construction Products Selection [8].

Following in the footsteps of traditional LCA product evaluation applications, several studies have focused on the environmental evaluation of building materials.

BEES Methodology

The BEES methodology takes a multidimensional, life-cycle approach. That is, it considers multiple environmental and economic impacts over the entire life of the building product. A multidimensional, life-cycle approach is necessary for a comprehensive, balanced analysis. It is relatively straightforward to select products based on minimum life-cycle economic impacts because building products are bought and sold in the marketplace. But how do we include life-cycle environmental impacts in our purchase decisions? Environmental impacts such as global warming, water pollution and resource depletion are for the most part economic externalities. That is, their costs are not reflected in the market prices of the products that generated the impacts. Moreover, even if there were a mandate today to include environmental ‘‘costs’’ in market prices, it would be nearly impossible to do so due to difficulties in assessing these impacts in economic terms. How do you put a price on clean air and clean water? What is the value of human life? Economists have debated these questions for decades, and consensus does not appear likely. Although environmental performance cannot be measured on a monetary scale, it can be quantified using the evolving, multidisciplinary approach known as environmental life-cycle assessment. The BEES methodology measures environmental performance using a life-cycle assessment (LCA) approach, following guidance in the ISO 14000 series of environmental management standards. Economic performance is separately measured using the ASTM standard life-cycle costing approach (‘‘Standard’’ 1993). These two performance measures are then synthesized into an overall performance measure using the ASTM standard for multiattribute decision analysis (‘‘Standard’’ 1995). For the entire BEES analysis, building products are defined and classified according to UNIFORMAT II, the ASTM standard classification for building elements (‘‘Standard’’ 1996). All underlying data and computational algorithms are reported and documented [9].

Impact Assessment

The impact assessment step of LCA quantifies the potential contribution of a product's inventory flows to a range of environmental impacts. There are several LCA impact assessment approaches. The primary approach used in the BEES impact assessments is the classification/characterization approach, because it enjoys some general consensus among LCA practitioners and scientists [11].

The classification/characterization approach to impact assessment was developed within the Society for Environmental Toxicology and Chemistry. It involves a two-step process as follows [12-14]:

• Classification of inventory flows that contribute to specific environmental impacts. For example, greenhouse gases such as carbon dioxide, methane, and nitrous oxide are classified as contributing to global warming.

• Characterization of the potential contribution of each classified inventory flow to the corresponding environmental impact. This results in a set of indexes, one for each impact, which is obtained by weighting each classified inventory flow by its relative contribution to the impact.

Conclusion

The rising interest in using LCA in construction decision making is evident from the amount of ongoing research in this area. Consideration of sustainability aspects in construction decision making is likely to continue in the future, in view of increasing concerns about the environment in society. LCA can provide a useful decision framework for incorporating such sustainability concerns into construction and can potentially improve current green building assessment methods. Many construction materials are being developed that are technically equal or superior to conventional materials. By using LCA framework and with the help of BEES software every engineer will get the most eco friendly as well as economical Green Building Material.

Reference

[1]. Roodman, D. M., and Lenssen, N. (1995). ‘‘A building revolution: How ecology and health concerns are transforming construction.’’ Worldwatch Paper 124, Worldwatch Institute, Washington, D.C.

[2]. Amanjeet Singh, George Berghorn, Satish Joshi, and Matt Syal, (March 2011). “Review of Life-Cycle Assessment Applications in Building Construction” Journal of Architectural Engineering, ASCE.

[3]. United States Green Building Council (USGBC). (2008). “LEED rating systems.” United States Green Building Council, Washington, DC.

[4]. Bowyer, J. (2007). “Green building programs—Are they really green?” For. Prod. J., 57(9), 6–17.

[5]. Humbert, S., Abeck, H., Bali, N., and Horvath, A. (2007). “Leadership in energy and environmental design (LEED)-A critical evaluation by LCA and recommendations for improvement.” Int. J. Life Cycle Assess., 12 (Special Issue 1), 46–57.

[6]. Scheuer, C. W., and Keoleian, G. A. (2002). “Evaluation of LEED using life cycle assessment methods.” Rep. No. NIST GCR 02-836, prepared for National Institute of Standards and Technology, Gaithersburg, MD.

[7]. Life Cycle Assessment and Sustainability, November 2005, A Supplement to Building Design & Construction.

[8]. Mark A. Ehlen, December, 1997, "Life-Cycle Costs of New Construction Materials". Journal Of Infrastructure Systems, ASCE, ISSN 1076-0342.

[9]. Ruegg, R. T., and Marshall, H. E. (1990). Building economics: theory and practice. Chapman & Hall, Ltd., New York, N.Y.

[10]. Lippiatt, B. C. (1999). “Selecting cost effective green building products: BEES approach.” J. Constr. Eng. Manage., 125(6), 448–455.

[11]. Lippiatt, B. C. (1998a). BEES 1.0: Building for environmental and economic sustainability. Technical manual and user guide, NISTIR 6144, NIST, Gaithersburg, Md.

[12]. DeSmet, B., et al., eds. (1992). Life cycle assessment. Society for Environmental Toxicology and Chemistry-Europe, Brussels, Belgium.

[13]. Consoli, F., et al., eds. (1993). Guidelines for life cycle assessment: A ''Code of practice.'' Society for Environmental Toxicology and Chemistry, Pensacola, Fla.

[14]. Fava, J., et al., eds. (1993). A conceptual framework for life cycle impact assessment. Society for Environmental Toxicology and Chemistry, Pensacola, Fla.