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The Use of Life Cycle Techniques in the Assessment of Sustainability

Selin Gundes*

Department of Architecture, Mimar Sinan Fine Arts University, Meclis-i Mebusan Cad. No:24 Findikli, Istanbul, Turkey

Abstract

After a period characterized by a strong emphasis on the environmental and physical aspects of construction processes, researchers are speeding up efforts to combine environmental performance with economic data. The driver of this movement has been the challenge of establishing a balance between the three main pillars of sustainable construction; namely the social, economic and environmental dimensions. Life Cycle Costing (LCC) has long been recognized as an important technique for the evaluation of the total cost of ownership from cradle to grave and it has frequently been used in decision making processes in construction. Life Cycle Analysis (LCA) on the other hand, measures the environmental performance; in other words the consumption of natural inputs and emissions to nature by production processes. However, the difficulties faced in the implementation and integration of life cycle methods raise concerns over the ability to meet all objectives of sustainability including the social dimension. Practical difficulties encountered in the collocation of existing tools, their structural differences, theoretical concerns, efforts to alleviate these problems and the extent to which LCC and LCA techniques may fulfil the requirements of sustainable construction are discussed. The study is expected to enhance our understanding of life cycle sustainability assessment concept and the extent to which existing tools can be integrated.

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* Tel.:+90-212-2521600
E-mail address: sgundes@libero.it

1. Introduction

Construction industry is one of the major consumers of energy and natural resources. According to UNEP SBCI (2009), buildings consume approximately 40% of global energy and consequently are responsible for one third of annual gas emissions in the world. The term 'sustainability' entered into construction industry in mid-1990's upon

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greater awareness on the impact of the industry on our planet. Although first attempts to include sustainability in building production focused solely on environmental factors, through time, economic and social pillars of sustainability have also been incorporated in the assessment of buildings.

One of the main tools utilized to include economic factors in the assessment of sustainability is the Life Cycle Costing (LCC) methodology. LCC is used to compare alternative design strategies based on initial, maintenance and operational costs incurred over a specified period of time. Despite the fact that investment efficiency is the main goal of LCC, efforts to use this technique in environmental decision making have attracted the attention of many researchers. As a result, several research projects have been initiated to incorporate LCC in environmental decision making. However the adoption of such holistic approaches has been limited in the building sector due to the challenges associated with the inability to include environmental costs in LCC calculations (Gluch & Baumann, 2004). Therefore, it can be stated that LCC basically provides the most cost effective solution, not necessarily the most environmental friendly option.

Life Cycle Analysis (LCA) on the other hand is another widely recognized decision making support tool that is considered for solely evaluating the environmental load. LCA aims to evaluate the potential environmental impacts of a product or a process during the entire life cycle. Similar to LCC, LCA studies for buildings may be concerned with the whole building or its constituent parts such as materials or components. Most of the studies undertaken in building LCA literature falls into the latter category.

The identification and assessment of social aspects in life cycle calculations are often reported to be challenging due to the diverse nature, the variety of stakeholder groups effected by them and the tendency for a greater change in time compared to environmental aspects (Griesshammer et al., 2006). Therefore, few studies have focused on a comprehensive assessment of buildings that combine social aspects with environmental and economic data. However, this is an important deficiency in the building research arena, as the term "sustainability" stands on three pillars and all aspects should be considered concurrently in decision making in order to reach meaningful results.
Based on this shortcoming, the two main objectives identified for this study are;

- to undertake a review of the use of economic, environmental and social life cycle studies for construction and
- to explore the difficulties faced in the unification of three pillars of sustainability in life cycle sustainability studies.

2. LCC

LCC aims to evaluate the cost effectiveness of alternative design strategies by considering the potential initial and operational costs that will be incurred over a specified period of time. Only values that can be expressed in monetary terms are taken into account in LCC calculations; thus intangible impacts such as comfort and environmental load are neglected.

The use of LCC calculations in construction projects started to become more important with the increased awareness on the significance of operational and maintenance costs of buildings and the growing "value for money" trend. According to Flanagan (2005), the operational and maintenance costs of an office building in 25 years will be threefold over its initial costs. Sustainability aspects and the rise of the project finance model has furthermore caused LCC techniques to come to the front. However still, problems associated with the lack of standardized data on cost, performance and uncertainty in the prediction of future costs exist.

The LCC process is governed by the ISO 15686 standards (ISO 15686-5, 2008). However, the methodologies used for LCC in construction are several. Therefore in 2006, the European Commission appointed Davis Langdon Management Consulting to develop a common methodology for construction projects. The final report was published in 2007 (Davis Langdon, 2007) and the proposed methodology is intended to be compatible with ISO 15686, part 5. The first two steps in the report are to identify the main purpose and scope of LCC study according to the expected outcomes. The third step includes the identification of the extent to which sustainability and specifically environmental analysis relates to LCC. The identification of an appropriate study period is the next step in the report. Factors such as the design life, economic interest and projected refurbishment/remodeling periods are deemed important in the selection of an appropriate period. Davis Langdon (2007) furthermore points out that the analysis period and the discount rate used are closely related and should be selected very carefully as these decisions directly have an important impact on the outcome of the LCC analysis. The purpose of the discounting process undertaken at this step is to compare costs occurring at different points in time by discounting future costs to present time using appropriate discount factors. The selection of the discount rate that will be used in LCC calculations are of great importance as for example a low discount rate will cause a favorable option to be rejected and vice versa. The effects of inflation are also taken into account in a LCC analysis. Inflation is either ignored by the use of real discount rates (when inflation applies equally to items in the analysis) or it is allowed by the use of nominal discount rates (when the items in the analysis are assumed to inflate at different rates, e.g. higher rate in energy prices compared to other items).

At steps 5 and 6, the need to support LCC study by a risk analysis and key parameters including functionality, physical characteristics, intangibles, quality and constraints are identified. Step 7 is concerned with the detailed identification of options. Step 8 is of crucial importance as the all costs relevant to the LCC study are identified at this stage. Once the key parameters are controlled, the LCC analysis is performed. The process continues with optional steps such as risk/uncertainty and sensitivity analysis. The last two steps are associated with the interpretation and reporting of the outcomes.

As far as the cost indicators are concerned, it can be stated that LCC calculations involve several different components incurred at various phases of a building's life cycle: project, utility and maintenance costs. Project costs that are included in LCC techniques include 'hard' or construction costs and soft costs such as design and permit fees. Utility costs are associated with the operational phase of the building and depend on the use of water, energy and sewer services. Maintenance costs on the other hand, depend on the strategies adopted: the routine preventive maintenance, reactive or planned maintenance. In theory, reactive maintenance - which is undertaken after problems occur - is minimized if a strict preventive maintenance plan is put into action. Planned maintenance is involved with the replacement of building subsystems. If the useful life of a subsystem is short and it has to be replaced say at every 5 years, then the replacement costs of the subsystem should be included in LCC calculations for the 5th, 10th, 15th,... years.

In construction projects, LCC calculations may be undertaken at the whole building or component level. However, they are widely used for addressing design problems on the selection of the solution with lowest life cycle costs. Apart from the fore mentioned discounting, inflation and escalation factors; the prediction of building life expectancy plays a major role in LCC. Ashworth (2004) argues that the uncertainties on the life expectancy of buildings is caused by the obsolescence factor rather than deterioration. While the latter is a function of time and use and therefore could be controlled by the selection of appropriate materials and components, obsolescence is very difficult to control as factors such as fashion, technological development and innovation in design and use are highly uncertain (Ashworth, 2004). For example, buildings in locations where land prices are high will have to be demolished before the end of their useful life in order to make way to newer and more profitable developments. Therefore, although the total cost consumed by resources in LCC calculations should to some extent reflect the environmental and social burden of building systems, economic life of a building does not fully reflect its whole life cycle. The study period in LCA on the other hand covers the whole environmental life cycle. Next section introduces the LCA concept.

3. LCA

The International Organization for Standardization (ISO) standard 14040 is the internationally recognized standard for LCA. ISO defines life cycle assessment (LCA) as the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040, 2006). In other words, LCA aims to evaluate the environmental load of products and processes created during the entire life cycle including the extraction and processing of raw materials, manufacturing, transportation, use maintenance, recycling and disposal.

The LCA methodology described by ISO includes four steps: goal and scope definition, inventory analysis, impact assessment and interpretation. In the first step, the reasons for undertaking the LCA study under question, the groups that the results of the analysis will be communicated, data requirements, assumptions and limitations are identified. The second phase called the life cycle inventory analysis is described as the creation of an inventory of flows from and to the nature in the entire life cycle of a system. Flows from the nature or the inputs in this definition may include water, energy and raw materials. Flows to the nature on the other hand consists of the releases to water, air and to land. At the end of this phase, a list consisting resource flows to and releases or emissions from the system under question is formed. The data on this list depends on the resource types and amounts used in production, the mode of transportation and distances, the way the product will be used and its disposal. However, the availability of resource requirements in specific regions and the technologies used up in production are highly variable determinants of this phase. Therefore, it can be stated that inventory analysis data changes from country to country and even from region to region.

The impact assessment undertaken in the third step is perhaps the most challenging phase of a LCA study as the significance of environmental impacts based on the list created in the inventory analysis is evaluated at this stage. The multi-step procedure starts with the identification of impact categories such as climate change, land use, acidification, toxicity and ozone depletion. The results from the previous phase are then assigned to the impact categories (e.g. CO2 emissions from the system are assigned to the climate change category). At this point, the characterization of indicators are required in order to compare the results expressed in different units within each impact category. For this reason, inventory data are multiplied by internationally accepted characterization or conversion factors in order to obtain impact indicators. An example over characterization provided by United States Environmental Protection Agency (2006) is as follows ".... For example, all greenhouse gases can be expressed in terms of CO2 equivalents by multiplying the relevant LCI (life cycle inventory) results by a CO2 characterization factor and then combining the resulting impact indicators to provide an overall indicator of global warming".

Once the data within impact categories are unified, the next challenge is to compare the different results for various options. For this reason, it is necessary to divide indicator values by a selected reference value. The process is called normalization and several methods have been proposed for the identification of reference values. The impact assessment phase concludes with the weighting step where weights are assigned for different impact categories according to their perceived importance. Finally, the results are analyzed, conclusions are reported, the limitations are discussed and recommendations are provided in the interpretation phase of LCA.

The use of LCA in the construction sector dates back to the beginning of 1990's (Ortiz et al., 2009, Khasreen et al., 2009). According to Khasreen (2009), LCA applications in the building sector has become a distinct and complex area within LCA. The author provides four main reasons for this phenomenon. Firstly, the long lifetime of buildings complicates the prediction of life cycle from cradle to grave. Secondly, interference on both form and function of buildings during the life span is a common practice. Thus calculation of lifetime environmental impacts more complex and accuracy of results become questionable. Third, unlike most other complex products, the majority of environmental burden of buildings occur in the use phase. Therefore, design and material selection play a very important role in the minimization of environmental burden in the use phase. Finally the high number of stakeholders involved and the lack of standardization practice in design further complicates the issue. ENVEST (BRE), ATHENA, and BEES (US EPA) are examples of widely recognized LCA based tools that aim to assess the life cycle environmental impacts of buildings and materials.

4. Holistic Approach to the Assessment of Sustainability

From the previous discussions it can be observed that although LCC and LCA both address life cycle thinking, they are distinct in purpose, scope and methodology. Therefore, combining or integrating the existing tools is the first step towards a more comprehensive sustainability assessment. Norris (2001b) provides three reasons for the importance of linking economic analysis and environmental assessment. First, without a thorough consideration of economic factors, the relevancy of the use of LCA for decision making remains limited as the resources required for production will always be scarce. Second, a sole economic analysis may omit several ‘hidden’ cost and revenue components which only become evident with an entire life cycle perspective. Third, important relationships and trade-offs between economic and environmental performances of alternative products or scenarios cannot be fully taken into account when the methods are used separately.

Albeit the need for an integrated model is clear, several concerns come into prominence in combining LCC with LCA type methodologies. The integration of the two methods is complicated due to the differences in purpose, terminology, framework and calculation rules (Norris, 2001a; Heijungs et al., 2013). These are briefly explained below.

- Flows and their units.

The purpose of the two methods are completely different, so are the flows addressed (e.g. resources and pollutants in LCA and monetary flows in LCC). Thus, the results provided by LCC and LCA methodologies are expressed in different units. While LCC provide results based on monetary terms, the resulting flows in LCA calculations are expressed in physical quantities such as mass, energy and volume (Norris, 2001a; Hoogmartens et al., 2014). Therefore, the first question relates to how results with different units can be combined into a single form.

- Data requirements.

There are also significant differences between the inputs in the calculation of these two methods. While LCA requires data for the environmental impacts for all upstream processes, LCC calculations use the price as the main determinant of upstream costs (Hoogmartens et al., 2014). The data requirements of LCA is in particular enormous for construction. Thus, efforts to produce region specific databases are continuing in various countries.

- Life cycles addressed.

LCC accounts for the economic lifetime of a project which does not fully reflect the whole life cycle of a built product. This is because LCC methodology uses the perspective of economic decision makers. Consequently only those costs to the decision maker is considered and thus some flows which have no consequences for the decision maker are ignored (Norris, 2001b). LCA and its variants however, take into account the resource flows along the whole life cycle of the product as it is based on a broader perspective.

- Timing of flows.

While discounting the cash flows to present value is an important step in LCC calculations, timing of flows in LCA calculations is ignored.

Since today, there have been several different perspectives on combining LCA with LCC. While some researchers advocated the use of Environmental LCC where environmental costs are expressed in monetary units and used as a cost input in LCC analysis (e.g. see Hunkeler et al., 2008 and Reich, 2005), others claimed that a full integration of the two methods was not possible and thus preferred to analyze the two indicators separately. Built on earlier work, Klöpffer (2008) derived the following formula in response to the need for combining LCA, LCC and social life cycle analysis (SLCA).

$$\text{Life Cycle Sustainability Analysis (LCSA)} = \text{LCC+LCA+SLCA} \quad (1)$$

As it can be seen from formula 1, apart from LCC and LCA, the LCSA calculations also include the SLCA. The social dimension in the evaluation of product or process sustainability refers to the impacts on stakeholders. Studies on SLCA are relatively new and thus a number of challenges are observed in methodology such as the selection of social criteria to be used and the need for region specific data (Finkbeiner et al., 2010). Several researchers have attempted to investigate whether and how social factors can be included in LCA calculations for product systems. However Zamagni (2012) outlines challenges in particular with SLCA and states that more studies are needed to improve calculations.

The problems with LCSA are not limited to peculiar difficulties observed in conducting separate LCC, LCA and SLCA calculations. An overarching assessment obtained from different life cycle tools with very different purposes involve trade-offs among three dimensions of sustainability. Therefore, interpretation and communication of LCSA results are rather challenging. Researchers have proposed various multi criterial approaches and ratios for interpretation. For example, Life Cycle Sustainability Dashboard (LCSD) proposed by Traverso & Finkbeiner (2009) evaluates alternatives based on scores and colors. Life Cycle Sustainability Triangle (LCST) is another graphical representation tool (see Finkbeiner et al., 2010). LCST uses visual means to identify preferability of alternative options based on selected combination of weighting factors. Nevertheless, there are new efforts underway to establish a robust methodological framework for presenting and communicating the results from LCSA calculations.

Although there is still no widely agreed approach for conducting integrated assessments in construction, there have been several important initiatives in the last decade. The ever increasing need for "a common LCC methodology at European level, incorporating the overall sustainability performance of building and construction" (Task Group 4, 2003) triggered the development of new tools peculiar to the sector. Consequently in 2006, UK consultancy Davis Langdon was appointed to develop a common methodology for LCC incorporating the overall sustainability performance in building and construction (Davis Langdon, 2007). However, the proposed methodology does not aim to fully integrate LCC with LCA, instead it attempts to use LCC to assess the economic impacts of design alternatives identified on the basis of sustainability assessments.

More recently, European research project CILECCTA has introduced the Life Cycle Costing and Assessment (LCC+A) model that aims to integrate economic and environmental assessments of construction projects. The CILECCTA model combines different metrics through a two-dimensional plot with one dimension for cost and the other for environmental impact (Vennström et al., 2010, Fawcett et al., 2012). The range of outcomes are expressed in patches rather than classical dots as the model identifies probabilistic boundaries for data about the future. In other words, the model aims to address the uncertainty in predicting future economic and environmental variables. In this way, design alternatives can be compared systematically without the need to merge them into a single measure (Fawcett et al., 2012).

5. Conclusions

There is no doubt that building sector plays an important role in sustainable development of nations. To date, a variety of life cycle focused techniques with different purposes are presented for assessing the different dimensions of sustainability. However, the need for a clear, systematic and standard methodology for integrating the economic, environmental and social impact assessments still remains unfulfilled. This challenge has increasingly attracted the attention of many researchers in the last decade. Consequently, several approaches have been proposed for a variety of sectors. However, the new techniques are still evolving and thus further efforts should focus on the problems faced in the development of a standardized approach. The availability of regional data is one of the primary concerns. Although a significant progress is evident in the establishment of national databases, there is still a long way to go in broadening the availability of data. Second, the interpretation and communication of results from sustainability assessments remains unresolved. In this regard, more published examples of applications of the new and existing tools are needed. Overall, the promotion of multidisciplinary research appear to be essential for bringing together different areas of expertise needed in sustainability assessments.

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