TRADE-OFF BETWEEN LIFE CYCLE COST AND GREENHOUSE GAS EMISSION IN CONSTRUCTION PROJECTS

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Sustainability challenges brought forth the need to develop and implement the life cycle perspective of a process in construction industry. In this paper two aspects of life cycle will be discussed: life cycle cost analysis (LCCA) and life cycle assessment (LCA). In a project, LCCA provides a decision support in selecting a suitable alternative to executing a work package based on its financial benefits while in LCA, decision is based on the environmental impact. An attempt is made here to develop a trade-off model integrating the LCCA with LCA so that the financial benefits and sustainability in construction projects are understood simultaneously. The performance of the model is checked on a zero energy 2-storey residential building which demonstrates the trade-off between the LCC and LCA in terms of Greenhouse Gas (GHG) emission in CO_2 equivalent. A genetic algorithm (GA) optimization model is used to establish a trade-off between LCC and GHG emission. The results show that the slab, exterior finish, stem wall, and footing construction produce around 60 % of LCC and GHG emission. The proposed model may help the stakeholders to study the long-term analysis of construction projects not limited to construction phase alone.

Keywords: life cycle, greenhouse gas, sustainability, genetic algorithm, trade-off

INTRODUCTION

The contribution of the construction industry to the global economy is about one-tenth of world's total GDP (PwC, 2015). The growth of construction industry leads to further consumption of resources at a higher rate. The construction industry is dependent on the environment for most of the primary and essential resources. Also, construction activities are known to bear a clear impact on the environment due to the use of excessive consumption of the resource. Thus, the construction industry is not only a significant contributor to the economic growth; it also affects environmental aspects. The residential and commercial buildings contribute 7.9% of total anthropogenic Greenhouse Gas (GHG) emission in terms of CO2 (Parry *et al*., 2007). A construction activity contributes one-third of the GHG emission throughout its repair, maintenance, and operational phase (UNEP, 2009).Therefore it is imperative to make it an important aspect of planning stage so that early mitigation can be done.

Life cycle assessment (LCA) is an indispensable part of sustainability concept. According to ISO 15686, Part 5, to establish a robust sustainable construction, life cycle cost

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analysis (LCCA) should be included with the LCA. But in several studies, LCA is done neglecting the economic aspect, leading to little interest of construction professional towards environment impact analysis. It is, therefore, essential that at the time of life cycle assessment (LCA), the economic consequences of an alternative mode of execution must be taken into consideration so that the decision of optimal execution alternative can be made with respect to the entire life span of a construction project. However, financial characteristics of the decisions are not considered in most of the developed LCA methodology. Even the ISO 14040:2006 standard for LCA practice has not mentioned the incorporation of cost analysis with LCA. The main focus is on the integration of reduction of environment impact and LCC of erection activities. The study shows how LCA and LCCA together can be used as a tool in decision-making for construction sustainability.

LCCA and LCA despite being relatively similar in names, have major differences in term of methodology, origin, and problem statement. They provide solutions to two different problems. LCA deals with the environmental performance of a project which is determined by integrating all major inter-connected processes, all-important resource, and consumption flow, regardless of their impact on the construction activity. LCCA compares the cost-effectiveness of alternatives from the perspective of an economic decision maker. These differences in their purpose reflect in their scope and methodology.

The significant aspects of LCCA should be included in LCA so that a relationship can be established between environmental and cost consequences, thereby providing the most cost-effective means to lessen the environmental impact (Norris, 2000). Therefore, the goal of this work is to develop an optimization model to give a set of optimal alternatives of an activity's execution mode from the project life cycle prospect. To achieve this, a literature review has been done on the existing studies of LCA, LCCA and on their integration. By understanding the existing limitations, an optimization model is developed to fulfill the proposed objective.

LITERATURE REVIEW

Literature study shows that the past study is done in three different groups namely LCA, LCCA, and integrated model considering life cycle. Major work based on the life cycle is done on LCA of construction. Though the concept of LCCA is older than LCA, due to lack of practice and standards, it is yet to be explored in the construction industry (Arditi and Messiah, 1996). Some studies in the past have tried to integrate LCA and LCCA to deal with the environment and economic aspect in the same dimension.

Life Cycle Assessment

Life cycle assessment (LCA) approach assesses environment impact considering the entire life cycle of a product. The LCA method analyses a large amount of inventory data to estimate environment impact of construction or assembly process. LCA essentially consists of four steps - goal and scope definition, inventory analysis, impact assessment, and interpretation. The input data required to analyse LCA is provided by life cycle inventory (LCI) as quantified environmental information. The data needed for the LCA are construction data, usage data, and demolition data (Norris, 2001). Some of the studies assumed in the construction phase have negligible environment impact (Junnila and Horvath, 2003) while others have considered this phase to be a compelling factor influencing the environment (Hendrickson and Horvath, 2000).

Life Cycle Cost Analysis

It is important to consider life cycle costs when evaluating the construction alternatives of civil infrastructure. Asiedu and Gu (1998) reported that most of the LCC (around 70 to 80 % of a process) is committed at the time of design phase without considering any LCCA (Arditi and Messiha, 1999). Even though the concept of LCCA was recognised a century ago but the thorough application started only two to three decades back. The main obstruction in LCCA is that it is time intensive, costly, computationally exhaustive, less standardized and there is unavailability of a coherent methodology to evaluate LCC (Novick, 1993). The researcher also asserts that collection and execution of available data for LCCA is important for a construction project. The data required for the LCCA are cost data, quality data, physical data, performance data, and occupancy data (Schade, 2009). In spite of the aforementioned drawbacks, LCCA is gaining recognition in construction industry due to its indubitable benefits towards life cycle of a project. It is a tool which can give insight to the decision maker on the options which will be more financially rewarding at the time of planning stage itself (Gluch and Baumann, 2003).

Integrated Model Considering Life Cycle

It is seen that LCA and LCCA are fundamentally different in their methods of evaluation. LCA and LCCA performed quite well and gave satisfactory results when considered separately by decision makers (Settanni, 2008). When merged together, the differences in framework lead to inconsistent and obscure results (Heijungs *et al*., 2012). Some studies identified this challenge and tried to find an optimal solution by aligning them together. Studies related to the integration of LCCA and LCA are established in highway pavement design, optimal HVAC system for building and choice of economical construction material which also bears least environmental impact (Zhang *et al*., 2008; Heijungs *et al*., 2012).

Despite voids in the study of the integration of LCA and LCCA, numerous initiatives to effectively harmonize them have been taken in the past. Zhang *et al*., (2008) provided a pavement overlay system to indicate sustainability by integrating LCCA and LCA. The researchers divided LCA in six modules starting from material acquisition to the product end of life and LCCA into two costs namely the agency cost which includes construction and maintenance cost and social cost comprising of user and environment cost. Kendall *et al*., (2008) also developed an integrated LCA and LCCA model for choosing the better alternative for a concrete bridge deck from two promising options: conventional mechanical steel joint and engineered cementitious composites (ECC) link slab design. The study found that ECC offers more monetary benefits and reduced environmental impacts as compared to the conventional design.

A research project CILECCTA developed a life cycle cost and assessment model based on probabilistic approach with the aim of bringing together economic cost and environmental implications of a construction project (Vennström *et al*., 2010). The model developed different matrices combined in an eco-portfolio diagram for an integrated LCCA and LCA discipline which compares cost and environmental effect by assigning relative weights. A probabilistic model is used by defining the possible value of the rate of change and is converged within a certain range for further utilization in calculations. With this approach, the researchers also try to resolve the issue of uncertainty in life cycle analysis (Fawcett *et al*., 2012).

Fesanghary *et al*., (2011) developed an integrated model for LCCA and LCA based on harmonic search (HS) algorithm to minimize LCC and GHG emission of building envelope. The envelope is defined by a number of factors like the geometry of the building, weather status, HVAC system, lighting and inhabitants' schedule. The initial value for decision variable (envelope material) is assigned by HS, and an optimal envelope is found through simulation results. A multi-objective optimization model is developed by using non-dominating sorting genetic algorithm (NSGA) to analyse life-cycle costs and environmental impacts by Cerri *et al*., (2012). The researchers compared the developed model with two other optimization models and found better results with NSGA.

OBJECTIVE AND RESEARCH METHODOLOGY

The objective of this paper is to develop a trade-off model that is able to provide the best alternatives of the cost and environmental aspect at the time of planning stage of a construction project. A GA-based optimization model is developed which is able to choose the optimal set of alternatives for the construction activities. GA has been widely used to evaluate optimal solution for similar problems due to ease of implementation and for finding comparatively better solution (Cerri *et al*., 2012). The essential terminologies used in the GA are population - set of all possible solutions for the given problem; chromosomes - one possible solution to the given problem; gene - one element position of a chromosome. An example of a representation of chromosome for the study is shown in Figure 1.

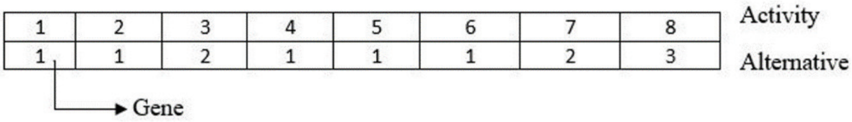

Figure 1: Representation of chromosome

The methodology used for the developed model is shown in Figure 2. There a number of alternatives are identified to execute the construction activity. The equipment and material used in each of the alternatives are listed, and the corresponding life cycle cost and the GHG emission for the same alternative are calculated for all activities.

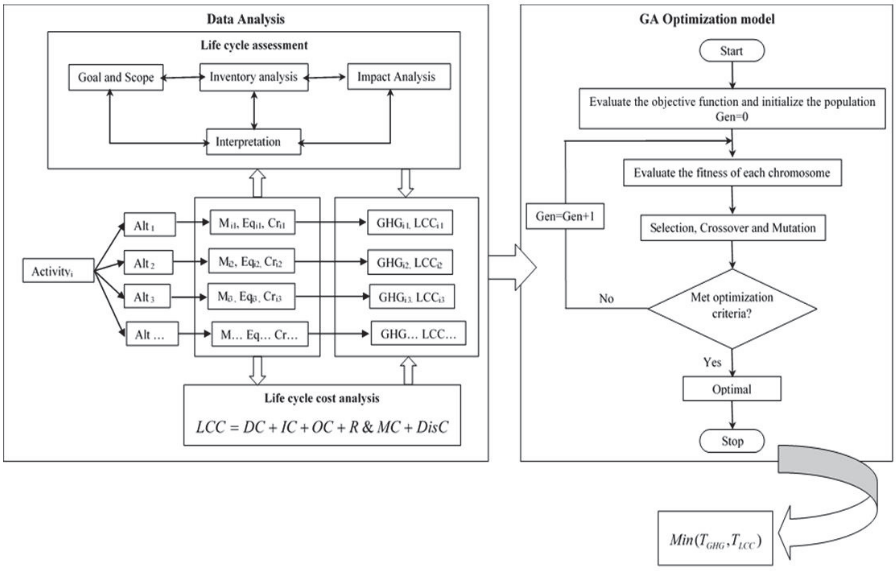

Figure 2: Flowchart of proposed model

The GA initializes the population by assigning one alternative each for all activities randomly and thus obtains initial solutions (initial population) of the total project life cycle cost and GHG emissions. Subsequently, the program considers another population based on selection, crossover, and mutation process to find another set of solutions. Each child solution (next population) is obtained by comparing the parents' solution (previous population). Based on their fitness value, the child population is generated. In this manner, the GA sets new values for decision variables based on the obtained results, and another iteration is performed to evaluate the new set of solution. This process is continued until a pre-specified maximum number of iterations (i.e., 100) or any other stopping criterion for the GA is reached. To validate the precision and utilities of optimization model a case study is taken from the literature.

Bi-objective Optimization for LCCA and LCA

In this paper, the goal of the study is optimization of LCCA and GHG emission as a bi-objective optimization problem. To develop the optimization model, genetic algorithm is used based on Darwin's theory of evolution proposed by John Holland in 1975.

Genetic Algorithm (GA)

The GA uses principles of selection, crossover, and mutation to generate optimal solutions. Selection is the process that determines which solutions from the population are to be preserved based on fitness values. Commonly used selection operators are tournament selection, roulette wheel selection, proportionate selection, etc. Crossover process is used to create new population from the existing population in mating pool. Mutation is a small and random change in the existing chromosome's gene to get a new solution.

The purpose of mutation is to maintain diversity within the population. In the presented model, tournament selection process is used followed by simulated binary crossover (SBX) and polynomial mutation process. Elite preservation is also used to attain the best optimal solution. Elite preservation is a process in which population is allowed to carry over the best solution for the current generation to the next generation so that the good solution is not diminished in the process. The GA parameters are considered as follows: Population size 20*P; P=11 (number of variables which in this case is equal to the number of activities); generation = 100; crossover probability = 0.9; mutation probability = 2/P (Deb, 2003).

The objective function and decision variable are as follows:

$$Objective\ Function = Min\,(T_{GHG}, T_{LCC}) \tag{1}$$

Subjected to:

$$T_{GHG} = \sum_{i=1}^{n} GHG_i \tag{2}$$

$GHG = CO_2$ equivalent produced by greenhouse gases (CO_2, CH_4, N_2O) emission from material and equipment used in corresponding activities.

$$T_{LCC} = \sum_{i=1}^{n} LCC_i \tag{3}$$

$$\mathrm{LCC} = \mathrm{DC} + \mathrm{IC} + \mathrm{OC} + \mathrm{R\,\&\,MC} + \mathrm{DisC} \tag{4}$$

Where, T_{GHG} is the total GHG emission; T_{LCC} is the total life cycle cost of project; LCC_i is LCC of activity i and GHG_i is GHG emission of activity i. DC represents direct cost;

IC - indirect cost, OC - operational cost (OC=0); R&MC - repair and maintenance cost (included in the available activity data); DisC- disposal cost (not included in the study).

MODEL IMPLEMENTATION

To evaluate the effectiveness of the proposed model a case study has been chosen from literature. The algorithm for the proposed model is coded in MATLAB R2015b.

Case Study

The case study of a two storey zero net energy building is considered from literature (Ozcan-Deniz *et al*., 2011) to demonstrate the utility of the proposed optimization model. The study considers 11 activities, each activity possessing more than one execution alternatives as shown in Table 1. For example, activity 1 can be performed in two ways with cost implications of US$5039.7 and US$4924.9 respectively. The corresponding GHG emission is listed beside each alternative in Table 1 to provide input to the optimization model.

The LCC data is modified from the real cost data. The operational cost for energy consumption is taken as zero for this building as it is a zero net energy building as mentioned earlier. Repair and maintenance cost is added for individual alternatives in only those activities which require future maintenance. Some other costs included in life cycle costing such as the cost of disposal, recycling, etc. are not considered due to the lack of data.

Table 1: Activity data and execution alternatives

Activity	Alternative 1		Alternative 2		Alternative 3		Alternative 4	
	LCC	GHG	LCC	GHG	LCC	GHG	LCC	GHG
Site work	5039.7	1728.9	4924.9	2938.4				
Excavation	360.7	317.7	297.1	399.3				
Footing	84232.7	9541.2	90392.3	9715.5				
Stem wall	80056.1	9647.7	86174.9	9822				
Slab	14636.1	15790.3	16758.6	15964.7				
Exterior wall	40497.1	9152.5	69064.4	35518.3	131206.9	35518.3		
Interior wall	76650.8	6228.3	95415.5	6246.2	51623.2	15056.4	58480.2	15062.4
Flooring	66598.4	236	62465.2	544.3	50238.9	3030.7		
Exterior finish	159486.5	4219.2	250999.8	61163.9				
Interior finish	4006.8	256	1746.6	256				
Roof	119558.2	12871.7	71966.1	6747.3				

Where LCC is in term of (US$) and GHG in term of (kg CO_2 eq.).

The repair and maintenance cost (R&MC) is considered for activities 6, 7, 8, 9, and 11. To demonstrate the calculation of R&MC, flooring construction is taken with bamboo flooring as its first alternative. The data required for the calculations are the life of the material, maintenance period, the life of the building and floor area.

$$T_{R\&MC} = \left(\frac{life\,of\ structure}{life\,of\ material} - 1 \right) \times Cost + \frac{R\ \&\ MC \times life\,of\ structure}{R\ \&\ M\ period} \qquad (5)$$

Where, $T_{R\&MC}$ is total repair and maintenance cost of activity; life of structure = 50 years, life of material = 25 years, Cost = US$28,341.60 floor area = 2940sq. ft., R&M period = 2 years, R&MC =0.1349 per sq. ft. (Ozcan-Deniz *et al*., 2011; Moussatche and Languell, 2001)

So, R&MC = US$38,256.75 and Total LCC = US$66,598.35

RESULTS AND DISCUSSION

To check the effectiveness of the developed model, a previous problem is analysed and comparative results were found (Ozcan-Deniz *et al*., 2011). Based on the input as explained earlier, the GA program generates the result as shown in Table 2. The obtained optimal solutions are further scrutinised activity wise to provide further insight to the decision maker. Each project and their owners come with different requirements and priorities. To address this, results are discussed under three common priorities which can be preferred in any project. The first one giving the highest priority (weight=1) to cost and zero priority to the environment impact, second giving the highest priority (weight =1) to the environment impact and zero priority to cost and lastly giving equal priorities to both the objectives (weights for the two objectives=0.5). The three optimal solutions based on these three favourable conditions are:

Table 2: Optimal solution

S. No.	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	T_{LCC} (US$)	T_{GHG} (kg CO_2 eq.)
1	2	2	1	1	1	1	3	3	1	2	2	520,560.6	67,950.8
2	1	1	1	1	1	1	1	1	1	2	2	537,098.5	63,865.0
3	1	1	1	1	1	1	1	3	1	2	2	520,739.0	66,659.7

(i) For the first case, the optimal solution considers alternative 1 for activities 3 to 6 and 9; alternative 2 for activities 1, 2, 10 and 11; and alternative 3 for activities 7 and 8. The corresponding optimal solution is US$520,560.6 for LCC and 67,950.8 kg CO_2 eq. for GHG emission.

(ii) For the second case, the optimal solution considers alternative 1 for activities 1to 9 and alternative 2 for activities 10 and 11. The corresponding optimal solution is US$537,098.5 or LCC and 63,865.0 kg CO_2 eq. for GHG emission.

(iii) For the third case, the optimal solution is obtained by the GA model assuming equal relative weight to LCC and GHG emission; the solution considers alternative 1 for activities 1 to 7 and 9; alternative 2 for activities 10 and 11 and alternative 3 for activity 8. The corresponding optimal solution is US$520,739.0 for LCC and 66,659.7 kg CO_2 eq. for GHG emission.

The LCC and GHG values are plotted on activity basis for all the three cases (See Figures 3(a), 3(b) and 4) so that the variation can be seen across the activities.

The results are summarised to distinguish the activities with high GHG emission from the low ones. Similarly, the activities with high LCC can be distinguished from the low ones. These will be useful for planning future alternatives for a given activity.

The optimal solution shows that about one-fourth (24 %) of the total GHG emission is contributed by slab construction which makes it the most prominent activity to be considered with respect to the GHG emission followed by stem wall (16%) and footing (15%). The cost of the exterior finish is maximum with 18 % share in the total LCC. This is followed by footing (16%) and stem wall (15%). These three constitute the top three high-cost activities.

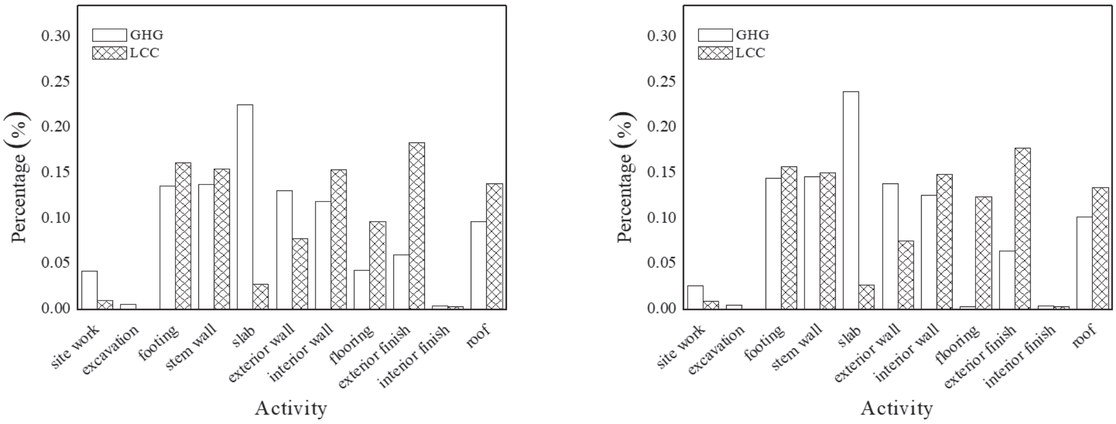

Figure 3: Activity LCC and GHG emission in percentage (a) for min LCC (b) for min GHG

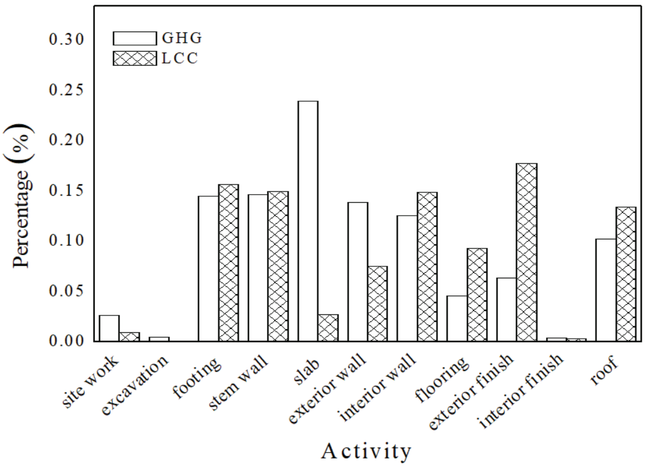

Figure 4: Activity LCC and GHG emission in percentage (Optimal solution considering equal weight to LCC and GHG emission)

CONCLUSIONS

In the construction industry, a number of intrinsic characteristics directly or indirectly affect the environment. On the other hand in the today's competitive market, the cost is an essential factor for any practitioner to survive in the industry. This study gives an insight on how the environment and economic aspects of a construction project can be harmonised. To address this issue, an optimization model is developed to integrate life cycle cost and environment impact of the construction industry. A GA program is developed to analyse the trade-off between LCC and GHG emission. The developed model has been demonstrated by a case study with 11 activities having different alternatives for two objectives (i) minimization of LCC and (ii) minimization of GHG emission. The result shows that the slab, stem wall, and footing construction generate large junk (around 55 %) of total GHG emission. Similarly, exterior finish, footing, and stem wall constitute around half (50 %) of the total LCC. So it is advisable to look forward to better alternatives for those activities which accelerate the cost and GHG emissions, thus minimizing the project LCC and GHG emissions. Further research is needed to analyse the life cycle cost by taking data on disposal and recycle cost into account so that a clear view can be developed before taking the decision.

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