International Journal of Engineering & Technology, 7 (3.7) (2018) 43-46

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Construction Cost and Carbon Emission Computational Model for Office Buildings in Malaysia

Mustafa M. A. Klufallah[a]*, Idris Othman[b], Muhd Fadhil Nuruddin[c], Mohd Faris Khamidi[d]

[abc] *Department of Civil & Environmental Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 32610 Seri Iskandar, Perak, Malaysia.*
[d] *Department of Built Environment, University of Reading Malaysia, Menara Kotaraya, 80000, Johor Bahru, Johor, Malaysia*

Abstract

A novel embodied carbon emission and construction cost computational optimization model has been developed based on evolutionary Genetic Algorithm (GA) for purpose built offices in the Malaysian construction industry. The GA evaluation was lack of implementation in addressing financial and environmental performances for construction projects in Malaysia. Therefore, the office project was evaluated through the adoption of ISO 14040 framework and evolutionary GA. The model was designed to provide alternative optimal design solutions for office buildings, which can be used at the early project planning and design stages. The assessment of embodied emissions was limited to pre-construction phase with “cradle to site” boundary. The model was tested statically to confirm the accuracy of the generated results. It provides an assessment model for managing carbon emission based on evaluation of environmental and financial performancesand it was validated by an application to an office building and the findings obtained suggest that the it would be suitable for use in practice.

Keywords: *Carbon emission, Construction, Computational Model, Optimization*

1. Introduction

Enviromental Impact Assessement

The Malaysian construction sector plays a significant role to face the challenge as it has a significant contribution to the GDP and influences the development of social and economic aspects of infrastructures and buildings. During the past three years, the share has become more stable. The commercial and residential building sectors account for 39% of carbon emission in the United States per year. In addition, construction is one of the top three industrial sectors that contribute the highest of GHG emission in the United States (Truitt, 2008).
The recent approaches of Environmental Impact Assessment (EIA) are qualitative, only about two percent have been focusing on quantitative methods for environmental impact management from the available database which concerned with environmental management of building projects (Gangolells et al., 2009). Therefore, studies on LCA through quantitative methods are required.
LCA it is a process to evaluate the environmental impact, process, or activity throughout the quantification of energy and materials used and wastes released to environment and assessing energy impact and materials with its associated emissions and evaluating opportunities for environmental improvements (Hong et al., 2009).

Optimization of Construction Projects

The management of any project depends on predefined objectives which required the use of techniques and tools to achieve the project’s objectives and to assess and improve its performances. In addition, the processes of management are classified into initiation, planning, execution, control and closing processes. Conflicts may occur in some objectives which prevent achieving other objectives (Yulan et al., 2007). Therefore, to solve conflicts between objectives, optimization methods are used to find best or optimal solutions with respect to predetermined objectives of a project (Murty, 2009).

Evolutionary Algorithms

Evolutionary Algorithms (EAs) are the most widespread artificial tools that simulate the human brain in solving problems of multi-objectives optimization (Ko & Cheng, 2007). An EAs start with population initialization which depends on random selection, then calculation and evaluation of the fitness functions of population based on objective functions. The most common EAs used for optimizing the objectives of construction project management are GA, ACO and PSO respectively.

Application of an Artificial Intelligence Algorithms (AIA) in previous studies for decision making process in construction can be classified into three categories. The first category is decision related to design evaluation and planning, which include; Linear and non-linear algorithms (Goicoechea, 1982), GA (Zheng, Ng, & Kumaraswamy, 2004) and Simulated Annealing Algorithm. The second category is decisions that concern with resources allocation during construction phase, which include; GA and ACO optimization. In the third category, decisions that are affected by design evaluation and resources allocation such as tasks coordination in construction project, which include; Enumerative Branch-And-Cut algorithm (EBAC). The determination of CO2 emission from construction materials would help in providing wide range of assessment solutions.

The quantification of CO2 emission of building materials would help in identifying major sources of materials contributing to CO2 emission. The use of case study is to test the assessment model developed in this research.The carbon emission per GFA (kgCO2e/ m2) was used as the functional unit for carbon emission of office buildings.

Methodology of Research

To assess construction cost and environmental performance, the CO2 emission computational model was developed by using MATLAB software. The parameters of the Genetic Algorithm have been set. The percentage of fittest populations kept and the mutation rate are 50% and 25% respectively. The size of population is considered as recommended by GA toolbox of MATLAB as 16 multiplied by the number of variables which are 20 in this case study; 320 populations are considered in each iteration.

The model has two objective functions which are cost and CO_2 emission functions. This model helps in computing the absolute values of cost and CO_2 emission from construction materials. The input stage for model development was based on different materials options from the original material design of the case study. A high rise conventional office building in Malaysia was selected as a case study in the procedure of developing construction cost and CO_2e computational model. The office building is located in the capital city Kuala Lumpur, Malaysia.

The building structural design has a reinforced concrete superstructure with GFA approximately of 58,126m2. In accordance with the model development stages, the floor plan of the project was broken down into six subsections, namely, ceiling, internal and external walls, internal floor, columns and façade. The materials options for ceiling are; fibrous plaster board, gypsum board, laminated gypsum, mineral fibre board, cement board, calcium silicate board and aluminium tiles panel. Moreover, for internal floor are; tiles, vinyl, epoxy, wood tiles.

The materials options for internal walls are; tiles, paper wall covering, marble and granite slabs and paint. For external walls are; paint and cladding systems. In addition, the resource options for columns are; tiles, paper wall, marble and granite slabs and paint and cladding system. While for façade of the building the resource options for curtain wall system are; clear tempered Tined low-e glass and single glazed tempered class.

The CO2 emission released from building materials is calculated based on Input-Out LCA method. The CO2 emission released from materials production and transportation during construction processes are calculated using a process based LCA. Figure 1 shows the flowchart of optimization model.

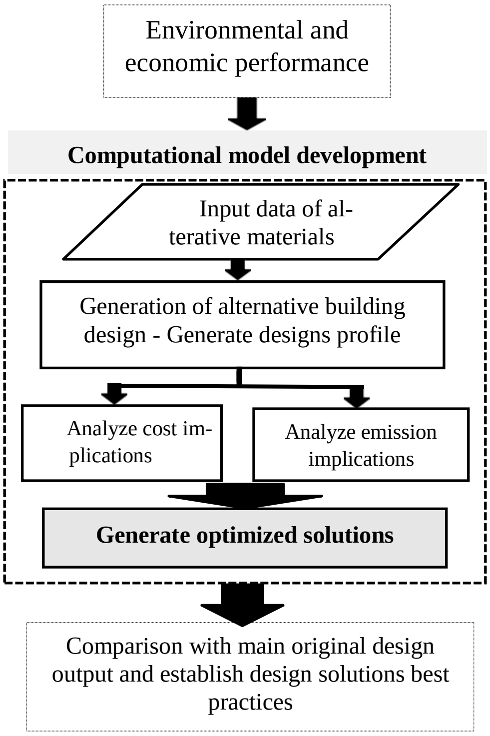

Figure 1. Flowchart of model development.

The model have two stages which are modification of design and evaluation stages which are compatible with the guides of ISO14001. The first stage generates database for the sections of building material. This stage will enable formulation of all potential project proposals in form of chromosomes. The chromosome is composed of a set of genes, each gene represents one of the work breakdown structure of the project.

The evaluation stage (second stage) generates different plans for construction of the project and determines the optimal design solutions (Pareto set) of proposals (chromosomes). The generation process depends on the crossover and mutation processes. The evaluation stage performing the changing process by genetic approach to evaluate and improve each of the construction cost and CO_2 emission. In additions, there are 511 material options (variables) for each chromosome to be evaluated.

Analysis and Discussion

Construction Cost and CO_2-Based Evaluation

Figure 2 and Figure 3 represent the results of the optimization process that were generated from the developed computational model. The maximum number of iterations for CO_2-based evaluation is 250 and no further iterations were required since increasing the number of iterations would not affect the trend of the generated results. The embodied CO_2 emission released from the original main building materials for the case study (green point) is 117,350 $kgCO_{2e}$ and its total construction cost is RM 781,262.00. the optimum construction cost and CO_2 emission values represented by Pareto- optimal solutions (red curve) which means that all proposed solutions have less construction cost and CO_2 emission when compared with the original one (CO_2 emissions and cost from the case study).

The alternative proposed design solutions are generated from carful combination of building materials. Furthermore, the results were processed based on CO_2 emission minimization.
Some design solutions have the minimum construction cost with the largest CO_2 emission reduction percentage for more than 50% when compared with the original design. While other generated results are more balanced design solutions and having excellent

minimization performance in both construction cost and CO_2 emission.

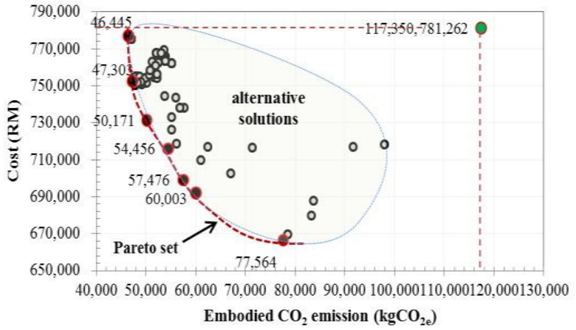

Figure 2. Optimal CO_{2e}-based solutions of the case study (50 iterations).

From these results the decision makers in construction project would select the final trade-off optimal proposed design solutions set in terms of environment protections and their own preference taking into account the construction cost and CO_2 emissions, and instruction of the designer and client's equirements.

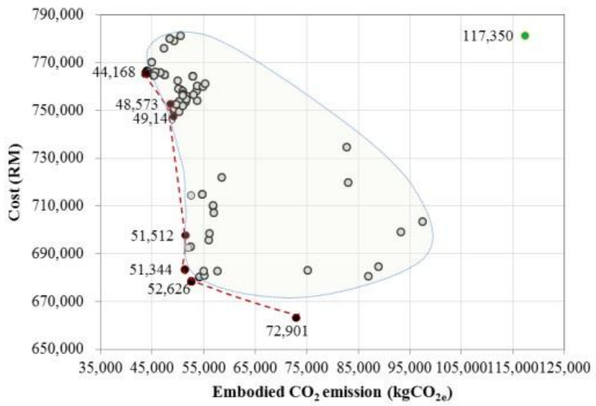

Figure 3. Optimal CO_{2e}-based solutions of the case study (250 iterations)

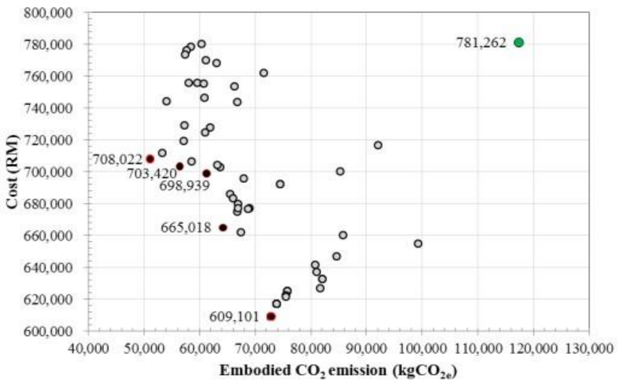

Figure 4. Optimal Cost-based solutions of the case study (50 iterations).

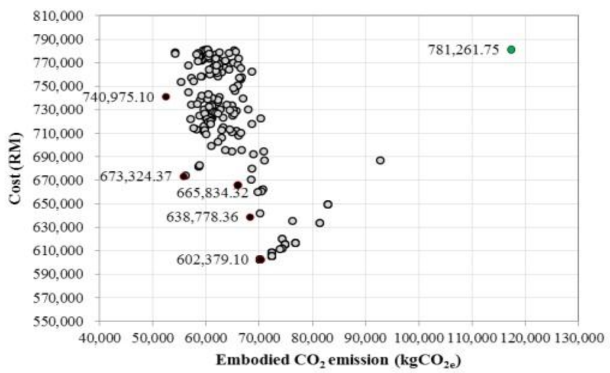

Figure 5. Optimal Cost-based solutions of the case study (300 iterations).

The generated results in Figure 4 and Figure 5 (cost-Based optimization) have adequate reduction in terms of construction cost with a reduction percentage for more than 22% when compared with the original design. Some of the proposed designs have CO_2 emissions reduction percentage of more than 50% when compared with the original design.

Table 1 is Pareto set for cost-based evaluation and it was used to determine the trade-off between construction cost and CO_2 emission based on 300 iterations. Point A have 5.16% cost reduction with a larger CO_2 emission reduction for about 55.25%, point B have 13.82% cost and 52.41% for CO_2 reduction, while point C and D have 14.77% and 18.24% for cost reductions, 43.75% and 41.83% for CO_2 emission reduction respectively. Point E is considered optimum in terms of construction cost and CO_2 emission with 22.90% cost reduction and 40.12% reduction in CO_2 emission.

Table 1. Reduction of construction cost and CO_{2e} emission

	Points	Total construction cost (RM)	Cost reduction (%)	Total CO_2 emissions ($KgCO_{2e}$)	CO_2 reductions (%)
Design solutions	A	740,975.10	**5.16**	52,471.67	**55.29**
	B	673,324.37	**13.82**	55,847.25	**52.41**
	C	665,834.32	**14.77**	66,006.70	**43.75**
	D	638,778.36	**18.24**	68,259.49	**41.83**
	E	602,379.10	**22.90**	70,269.88	**40.12**
Original design		**781,262.75**	-	**117,350.00**	-

	Points	Total construction cost (RM)	Cost reduction (%)	Total CO_2 emissions ($KgCO_{2e}$)	CO_2 reductions (%)
Design solutions	A	740,975.10	5.16	52,471.67	55.29
	B	673,324.37	13.82	55,847.25	52.41
	C	665,834.32	14.77	66,006.70	43.75
	D	638,778.36	18.24	68,259.49	41.83
	E	602,379.10	22.90	70,269.88	40.12
Original design		781,262.75	-	117,350.00	-

2. Conclusion

The developed model aims at managing financial and environmental performances form construction projects. It provides alternative optimal design solutions for construction project which can be used at early design stage of construction. All the alternative optimal design solutions generated from the model have less total construction cost and total CO_2 emission levels when compared with the original one from the case study. It indicates that the model is valid and can be used for practice. The capability of the model in generating better results is considered good since the obtained result in this research satisfy the required objective functions at minimizing construction cost and CO_2 emission. From the generated design solutions, the construction professionals would refer to the materials options list and identify what is acceptable to be selected and used for construction project based on the client's requirements. This is because maybe some of the generated combinations from the model may not satisfy the designer or the client requirements.

The proposed model can effectively assist decisions makers to select the trade-off solution between construction cost reduction and environmental impact mitigation. Also the model can bridge the gap between the developed prediction model and observed values from the office buildings in Malaysia.

Acknowledgements

Authors would like to show gratitude to Universiti Teknologi PETRONAS (UTP) for providing excellent facilities and fund.

References

[1] Gangolells, Marta, Casals, Miquel, Gassó, Santiago, Forcada, Núria, Roca,Xavier, & Fuertes, Alba. (2009). A methodology for predicting the severity of environmental impacts related to the construction process of residential buildings. Building and Environment, 44(3), 558-571.

[2] Goicoechea, A, Hansen DR, and Duckstein L, . (1982). Multiobjective Analysis With Engineering and Business Applications. USA: John Wiley & Sons Inc.

[3] Hong, J., Hong, J., Otaki, M., & Jolliet, O. (2009). Environmental and economic life cycle assessment for sewage sludge treatment processes in Japan. Waste Manag, 29(2), 696-703.

[4] Ko, Chien-Ho, & Cheng, Min-Yuan. (2007). Dynamic prediction of project success using artificial intelligence. Journal of construction engineering and management, 133(4), 316-324.

[5] Murty, Katta G. (2009). Optimization for Decision Making: Springer.

[6] Truitt, P. (2008). Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States. Washington, DC: US Environmental Protection Agency, 1.

[7] Yulan, Jin, Zuhua, Jiang, & Wenrui, Hou. (2007). Multi-objective integrated optimization research on preventive maintenance planning and production scheduling for a single machine. The International Journal of Advanced Manufacturing Technology, 39(9-10), 954-964.

[8] Zheng, Daisy XM, Ng, S Thomas, & Kumaraswamy, Mohan M. (2004). Applying a genetic algorithm-based multiobjective approach for time-cost optimization. Journal of Construction Engineering and Management, 130(2), 168-176.