Computational Model for Financial and Environmental Assessment of Purpose Built Offices towards Low Carbon Buildings in Malaysia

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***Abstract*— Construction projects have major impacts on the environment and are considered as one of the major consumes of naturally occurring and synthesized resources. Changing its conventional practices to incorporate environmental performance as part of its decision making process is a gradually slow process. The management of carbon emission from construction projects is an important competitive advantage in businesses especially towards achieving low carbon buildings. The study was initiated to address the issues and aims at designing a methodology to enhance the competitive advantage. 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 methodology is new in the Malaysian construction industry, 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 in the early project planning and design stages. The model was tested statistically to confirm the accuracy of the generated results. It provides an assessment model for managing carbon emission based on evaluation of environmental and financial performances. The model was applied to an existing office building and the findings suggest that it is suitable and practical as a tool towards achieving low carbon buildings in Malaysia**

Keywords— optimization; purposed built offices; low-carbon buildings

I. Introduction

The Malaysian construction sector plays a significant role in country's development as it has a significant contribution to the GDP and influences the development of social and economic aspects of infrastructures and buildings. 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 amount of greenhouse gases (GHG) emission in the United States [1]. The construction of buildings projects has a major impact on the environment and it is considered one of the major consumers of naturally occurring and synthesized resources. Despite the recognition that environmental issues are important to the survival of the construction industry, its activities are major contributors of environmental issues. In addition, changing its conventional practices to incorporate environmental performance as part of its decision making process is gradually slow process in developed and developing countries. However, with in-creased awareness and knowledge of these impacts, efforts are being made to avoid these adverse effects and to work towards impact mitigation.

Among these are sustainable building materials selection and carbon emissions reduction regulations. These are the most crucial steps and important issues in building design decision-making process. To mitigate the impact throughout the life cycle of buildings, the construction industry and the related activities are the pressing issues faced by all the stakeholders to promote sustainable buildings [2]. 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 [3].

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 [4].The formatter will need to create these components, incorporating the applicable criteria that follow. This study bridges the gap between environmental management and project management within the construction industry context by application of ISO14040 LCA framework. It provides an assessment model for managing carbon emission based on evaluation of environmental and financial performances.

II. BACKGROUND

A. Building Constructions & Climate Change

Regardless of whether people argue that global warming is triggered by natural phenomena or by humans or both it is one particular of the most controversial subjects in the scientific world nowadays, and the relationship between GHGs and global temperature has been acknowledge in science since the 19th century. It is showed that the relationship be-tween sea level, global temperature and CO_2 concentrations in the atmosphere is existed over the last 400 million years. Without doubt, the climate change effects on human and natural ecosystems have already existed. Despite current efforts on the part of Malaysian government to curb emissions, Malaysia are ranks one of the top 30 countries in the world that have the largest amount of carbon emission [5].

In fact, more than one third of total energy use and GHGs emissions come from Building construction both in developed and developing countries. Environmental issues are not only linked to technological or economic activities but also associated with cultural and behavioral aspects as well. In terms of economic and technological activities, which are the direct cause of environmentally destructive behavior, individual beliefs and societal norms guide the development of these activities [6-7]. The building construction consumes a great quantity of energy. For instance, in the European Union, buildings through their life cycle consume approximately 50% of the total energy demand and contribute almost about 50% of the carbon emissions to the environment [7].

B. Construction & Environmental Issues

The construction activities are considered as a major contributor to environmental pollution [8-12], and the impact of construction industry produces undesirable remnants [13]. The amount of GHG emissions released in 2004 is found to be increased by 70% compared to those of 1970 [14]. This increase which is caused by human activities is causing a significant year to year changes in the amount of CO_2 emission and also it is considered as a fundamental factor in current global issues such as rising of earth temperature, rising of the water level in the seas and oceans, disruption of rainfall, shortage or loss of food sources, reducing of fresh water availability, increasing the intensity and frequency of floods, depletion of the stratospheric ozone layer, late freezing and earlier break-up of ice on rivers and lakes, lengthening of growing seasons, shifts in plants and animal ranges, increasing the probability and extreme climatic events such as hurricanes, droughts, wildfires and other natural disasters.

The most important effect from the concentration of CO_2 emission is the rise in earth temperature, be-cause its impact is the primary reasons for all climate change issues Thus, is it important to control the level of GHG emissions in order to maintain the earth temperature at acceptable level as reported by the Intergovernmental Panel on Climate Change (IPCC-2007, fourth assessment report) and also to reduce these emissions at 50 to 85% by 2050 [15]. A finding of recent studies classifies construction as one of the top three industrial sectors in terms of contribution to GHG emissions in the United States [16]. This sector is responsible for release of more than one third of all GHG and consumption of 40% of the global energy [17]. Furthermore, the applications for cooling, refrigeration, and insulation materials make construction responsible of releasing significant amounts of non-CO_2 GHG emissions such as Halocarbons, CFCs, and HCFCs, and Hydro-Fluorocarbons (HFCs) [18].

Since the construction industry takes such a role in environmental degradation, controlling and reducing GHGs emissions have become an imminent task to be managed. The prime minister of Malaysia announced in Copenhagen in 2009 that Malaysia is adopting an indicator of voluntary reduction of up to 40% in terms of emissions intensity of Gross Domestic Product (GDP) by the year 2020 compared to 2005 levels. This announcement is now challenging the financial performance of different economic sectors in Malaysia because they should consider the impact of their investments on the environment. This announcement comes as a response to two facts re-ported by United Nations Development Program (UNDP) in 2007/2008; Malaysia has classified as number 26 in a top 30 CO_2 emitters in the world and the Malaysia's emission growth rate in the period from 1990 to 2004 is the highest in the world [19].

C. 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 [20]. Therefore, to solve conflicts between objectives, optimization methods are used to find the best or optimal solutions with respect to predetermined objectives of a project [21]. Evolutionary Algorithms (EAs) are the most widespread artificial tools that simulate the human brain in solving problems of multi-objectives optimization. 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, GA 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 CO_2 emission from construction materials would help in providing wide range of assessment solutions [22].

The quantification of CO_2 emission of building materials would help in identifying major sources of materials contributing to CO_2 emission. The use of case study is to test the assessment model developed in this research. The carbon emission per GFA ($kgCO_{2e}/m^2$) was used as the functional unit for carbon emission of office buildings.

III. METHODOLOGY

To assess construction cost and environmental performance, the CO_2 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_2 emission 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 58,126m^2. 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 aluminum 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 CO_2 emission released from building materials is calculated based on Input-Out LCA method. The CO_2 emission released from materials production and transportation during construction processes are calculated using a process based LCA. Fig. 1 shows the flowchart of optimization model. The model has 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 performs 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.

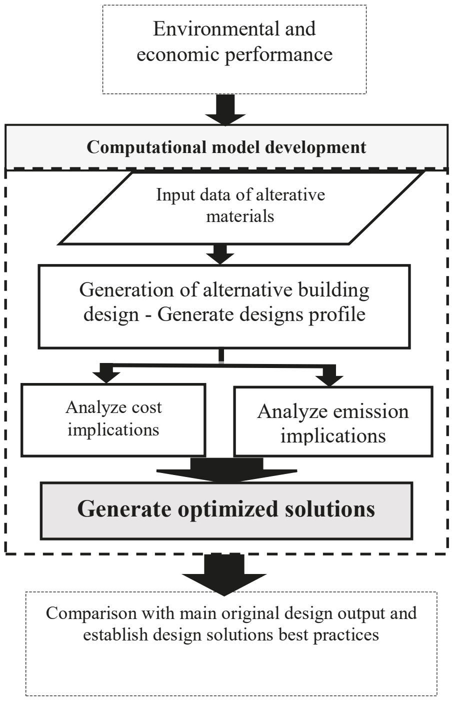

Fig. 1: Flowchart of model development

Cost estimation is one of the most important steps in a project management. Cost estimate establishes the base line of the project cost at different stages of development of the project. A cost estimate at a given stage of project development represents a prediction provided by the cost engineer or estimator on the basis of available data. Therefore, the construction material prices in the present study are obtained from cost database web site (JKR online Rates) Jabatan Kerja Raya and CIDB because they concern mainly within the Malaysian construction industry. The database includes latest prices for most of construction materials with regular daily updates. Other source of pricing including updating some of the case studies materials prices through consultation of professional registered quantity surveyor (QS).

The total cost of material is the summation of the products of the quantities multiplied by the corresponding unit costs. The prices include total material cost (raw cost) and additional fee (lapping and wastage cost, labor cost and profit). The prices were differing from one place to another, however, for the case study, the materials prices were estimated and calculated on average basis for pricing. In addition, sensitivity analysis was used to investigate the effect of the uncertainty on material prices for the evaluation results because prices may fluctuate according to market demand and its stability.

IV. Analysis and Discussion

A. *Carbon-Based Evaluation*

Fig. 2 to Fig. 5 represents the results of the optimization process that generated from the developed computational model. For these findings, the maximum number of iterations 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 carbon 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 evaluation of buildings materials indicated that the developed computational model provides better alternative solutions. The optimum construction cost and carbon emission values are represented by Pareto-optimal solutions (red curve), which indicate that all proposed solutions have lower construction cost and carbon emission as compared to the original design. The alternative proposed design solutions are generated from carful combination of building materials. Furthermore, the results were processed based on carbon emission minimization. However, some generated design solutions have lower carbon emission but higher cost compared to original design. Therefore, the solutions presented in these figures are grouped within the boundary of the original design.

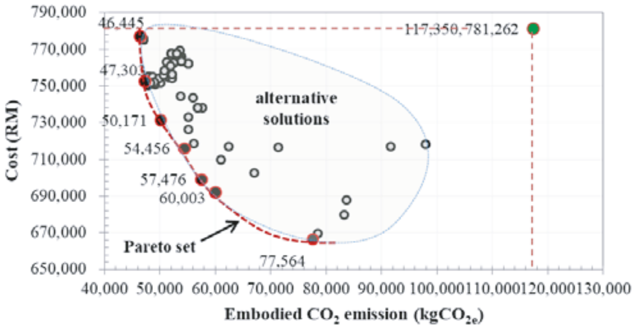

Fig. 2. Optimal CO_{2e}-based solutions of the case study (50 iterations)

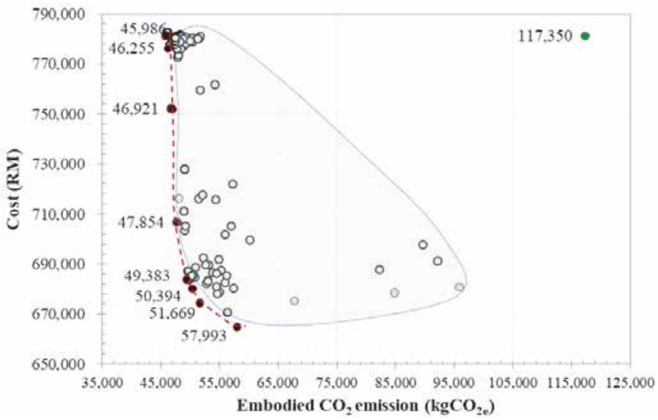

Fig. 3: Optimal CO_{2e}-based solutions of the case study (100 iterations)

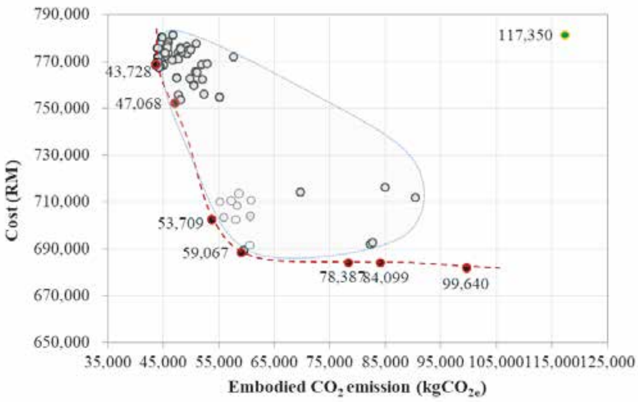

Fig. 4. Optimal CO_{2e}-based solutions of the case study (150 iterations)

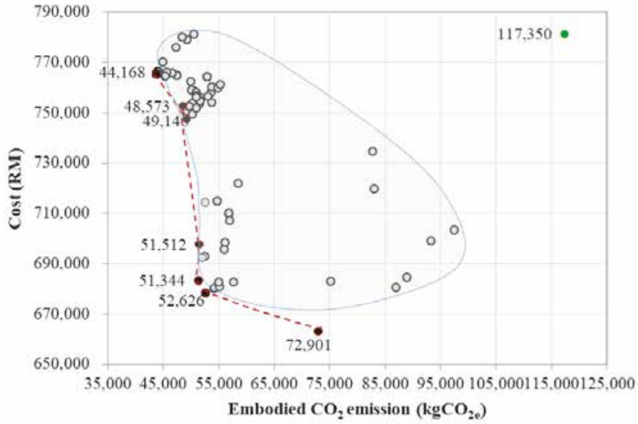

Fig. 5. Optimal CO_{2e}-based solutions of the case study (250 iterations)

Some design solutions have the minimum construction cost with the largest carbon 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 carbon emission. 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 carbon emission and instruction of the designer and client's requirements.

B. *Cost-Based Evaluation*

Fig. 6 to Fig. 10 represents the results of the optimization process that generated from the developed computational model. For these findings, only 50, 100, 150, 200, 250 and the maximum number of iteration is 300 iterations were considered. Hence, no further iterations were required since increasing the number of iterations would not affect the trend of the generated results.

Similarly with carbon-based evaluation, the optimum construction cost and carbon emission values represent that all proposed solutions have less construction cost and carbon emission when compared with the original one (carbon emissions and cost from the case study). Furthermore, the results were processed based on minimization of construction cost. However, some generated design solutions have higher cost and lower carbon emission compared to original design.

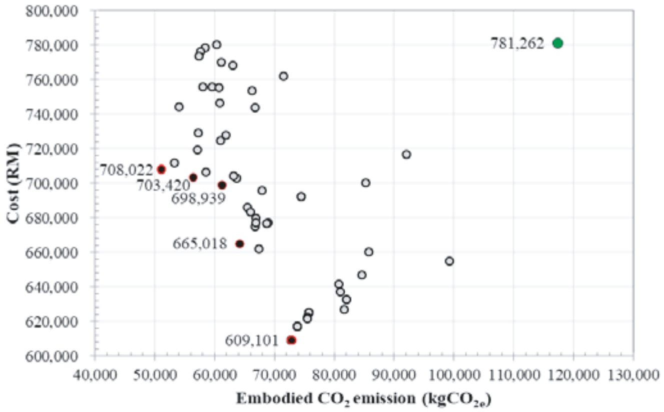

Fig. 6. Optimal cost-based solutions of the case study (50 iterations)

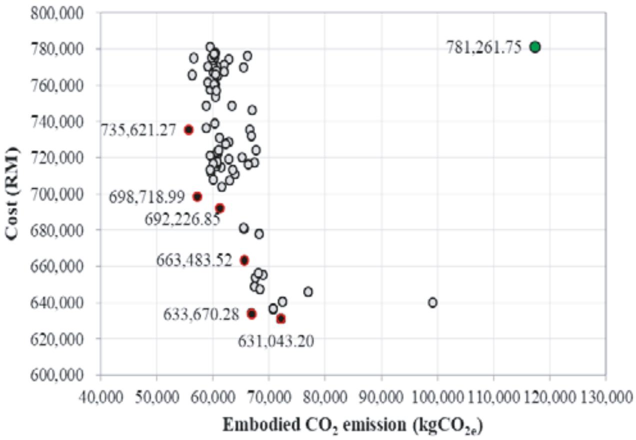

Fig. 7. Optimal cost-based solutions of the case study (100 iterations)

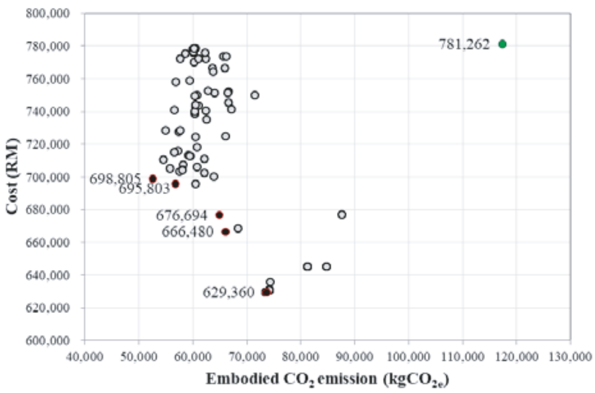

Fig. 8. Optimal cost-based solutions of the case study (150 iterations)

The pool of optimum solutions or the Pareto set is found by gathering the best design solutions of different number of iterations in one table. It can be observed that, the generated results have adequate reduction in terms of construction cost with a reduction percentage for more than 22% when compared with the original design.

Although these results have minimum cost but a great reduction of carbon emission is also achieved from the proposed solutions. Some of the proposed designs have carbon emission reduction percentage of more than 50% when compared with the original design. Therefore, the developed model has the advantages of achieving optimal results solutions when it is utilized for both construction cost (cost-based) and carbon emission (CO_2-based) minimizations for construction projects.

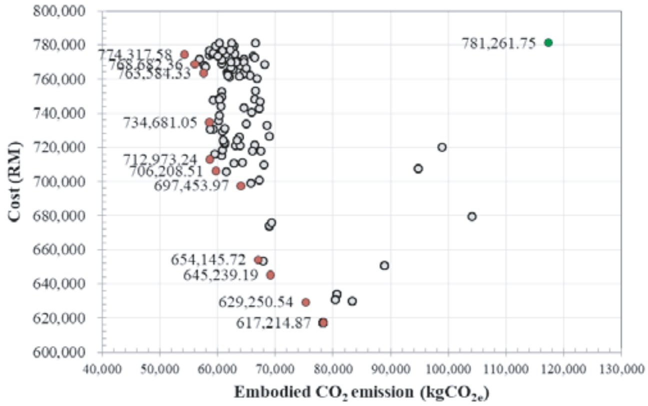

Fig. 9. Optimal cost-based solutions of the case study (200 iterations)

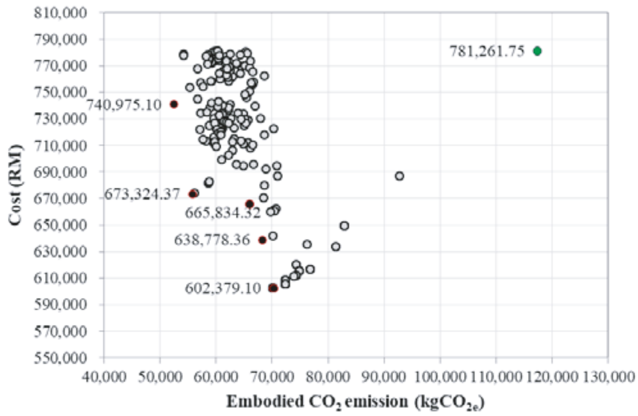

Fig. 10. Optimal cost-based solutions of the case study (300 iterations)

C. Cost Escalation of Construction Materials

Building cost increases usually occur as a result of market forces, and reflect increases in the cost of materials. The material prices were predicted to increase by 20% in order to determine the effectiveness of the model in evaluating optimized solution options for the case study in such situation. Conveniently, the evaluation of buildings materials indicated that the developed computational model still provides better alternative design solutions. Similarly, Fig. 11 to Fig. 12 are carbon-based evaluations for 50 and 200 iterations, which generated from the developed computational model with 120% prices escalation. The optimum construction cost and carbon emission values represent that all proposed solutions have less construction cost and carbon emission. Furthermore, the results were processed based on minimization of construction cost. It can be observed that, the generated results have adequate reduction in terms of construction cost and carbon emission when the construction material prices increased by 20%.

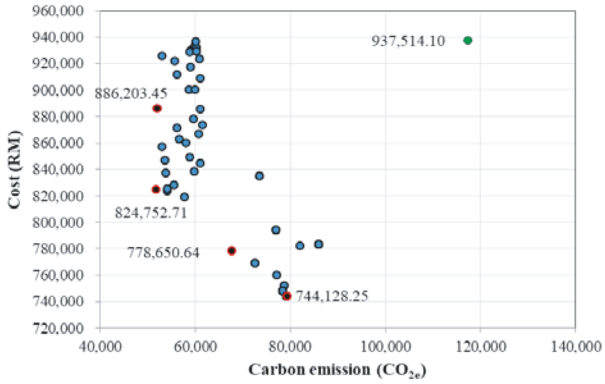

Fig. 11. Optimal cost-based solutions @120% for 50 iterations

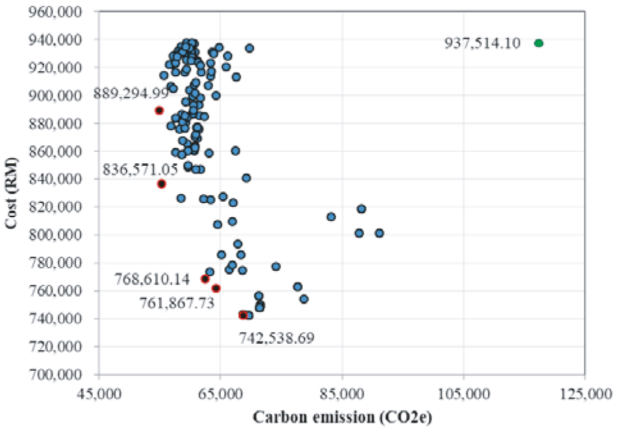

Fig. 12. Optimal cost-based solutions @120% for 200 iterations

V. 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. The proposed model can effectively assist decisions makers to select the trade-off solution between construction cost reduction and environmental impact mitigation.

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