Classification of reinforced concrete single story and double story house using eco-efficiency index approach

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Abstract. In the current construction industry, the selection of structural design was important in order to ensure the design were satisfied in term of economic, environment and social as for the purpose to fulfill need of sustainable development. Eco-efficiency has been introduced to be used for the decision-making method in selection of the best design that fulfill requirement of sustainability. This study was develop to integrate analysis of eco-efficiency index for reinforced concrete structural elements by considering economical score and environmental score as a main approach. The classification of the design case for single story and double story house took place from low level to high level of eco-efficiency design level based on its eco-efficiency index. Result shows single story house was classified from medium low to medium high eco-efficiency design level for all 10 cases while for double story house was classified from low to high eco-efficiency design level.

1. Introduction
Construction industry has been identifying as non-environmental friendly activities [1]. Malaysia’s government has encouraged players in construction industry for adopting the sustainable development concept in order to establish safe and green environment. This concept will be realized with the high knowledge on the sustainable practices among the developer who was responsible in initiating the project [2]. Therefore, it was found that the GBI system does not take into consideration of the structural design as green building index criteria for the evaluation [3]. This is because, in GBI system, the production of sustainable design was affecting by the selection of sustainable building material [4]. On other hand, structural design has play an important role in construction stage where ineffective design will lead to the production of high material’s volume due to over-designed [5]. Eco-efficiency is an indicator that is tied to economic activities and ecology, it serves as a useful instrument for sustainability analysis. Eco-Efficiency is based on concept to create property or services while using less resources compared to normal amount use but it creates less waste and pollution. Due to significant environmental and economic benefits associated with reduced energy consumption in green building, energy efficiency is considered a key driver for the green building movement. Development of new system in designing building that fulfill requirement of sustainable development has been emphasizing to promote green system to save the environment. This study was developed to provide...
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2. **Eco-efficiency index classification of reinforced concrete structure**

Figure 1 shows the design classification flow chart of the reinforced concrete structure. The process shows below including determination of cost and equivalent carbon emission of reinforced concrete structure, determination of economical score and environmental score, determination of eco-efficiency index and classification of the design. Furthermore, fly ash and blast furnace slag were used as an alternative material in reinforced concrete to provide eco-efficiency design. Two type of building was selected in this study that are single story house and double story house where optimization of design cases produces different set of design cases up to 10 number of sets.

![Design classification flow chart](image)

**Figure 1.** Design classification flow chart

Material volume was determined for concrete and steel reinforcement. Both material was count in weight unit (kg) to determine the total amount of cost and equivalent carbon emission. The analysis in this study was focused on structural elements of the building which were foundation, slab, beam and column. Two different calculations was done for original reinforced concrete and alternative reinforced concrete. In this study, fly ash and blast furnace slag were used as an alternative material to measure alternative cost and equivalent carbon emission.

Calculation of the structural elements cost is based on total amount of material cost (Cost,m) and structural work cost (Cost,c). While for alternative cost was determined by its total alternative material cost (Cost,am) and also structural work cost (Cost,c). The total equivalent carbon emission was determined by multiplying the total weight of material (concrete and steel) with the coefficient of equivalent carbon emission of reinforced concrete (EF<sub>RC</sub>) per kilogram. This consideration was made due to reinforced concrete as a composite structure that combines concrete and steel. Furthermore, the analysis was lead to determine the economical score and environmental score. Economical score is the parameter to determine the economical impact of the structural system in term of cost. Environmental score is the parameter to determine environmental impact of the structural system in term of equivalent carbon emission of the elements.
The classification of the impact due to economical and environmental score was determined the structural system was design to be eco-efficiency or not. The positive value will shows there is positive impact towards environment while negative values will shows harmful to the environment. To design eco-efficiency structural system, both criteria should produce positive values in order to ensure there is positive impact to the environment. Determination of eco-efficiency was made to determine the design classification of the structural system into five (5) different level of eco-efficiency as shown in Table 1.

Table 1. Eco-efficiency level classification

| Value               | Eco-efficiency Level |
|---------------------|----------------------|
| 0 to 0.9899         | Low                  |
| 0.9899 to 1.2728    | Medium Low           |
| 1.2728 to 1.5556    | Moderate             |
| 1.5556 to 1.8385    | Medium High          |
| 1.8385 and above    | High                 |

3. Results and discussion

Analysis of the structural system was done in considering the design parameters to determine the eco-efficiency level of each cases. Results and discussion of this study focused on economical and environmental factors that influence the design and classification of the structural system.

3.1 Economical score comparison

Figure 2 shows the overall results of economical score of reinforced concrete single and double story residential house. Considerations of the material cost and structural work cost were defining the overall analysis of economical score. In overall view of the results, it was found that the design produced positive impact due to positive values except for Case 3 and Case 5 of double story residential house. The positive score reflect as the propose case is suitable for eco-efficiency design in term of economical impact. By controlling the characteristic strength of concrete in the design, it may control the economical score of the building. The evaluation was made between original cost of reinforced concrete structure and alternative reinforced concrete structure that controlled by the material use in the system.
Furthermore, it was found that in single story reinforced concrete house, the economical score between each design case was identified almost same due to the amount of material used for different design case 1 to 10 is very small based on taking off recorded. The analysis shows that the increasing of 5MPa concrete characteristic strength in structural elements cause the reduction of cost about 1 to 11 percent for both type of concrete. Furthermore, the reduction of 10MPa in concrete characteristic strength not less than 30MPa was recorded increasing of the structural work cost about 1.5 percent. Based on this study, it was found that the optimum characteristic strength of concrete that fulfill requirement of sustainable design in term of cost is 25MPa for slab and 30MPa for beam, column and foundation. This result is also fulfilling the structural performance of the building and produce balance reinforced concrete design.

By using alternative material that has zero cost or lower cost than Ordinary Portland Cement will produce positive economical score. High ratio will produce as the replacement of the material is increasing without affected the structural performance of the building. Increasing of the replacement material percentage should follow the specific standard determine by Inventory Carbon Emission Document Version 2.0 [8].

3.2 Environmental score comparison

Figure 3. Environmental score comparison of single and double story house.

Figure 3 shows the environmental score comparison of single and double story residential house. The environmental score was reflected the impact of the carbon emission to the environment. Case 5 with slab (20MPa), beam (30MPa), column (30MPa) and foundation (30MPa) was found as the highest economical score ratio and it show less impact to the environment. High concentration of carbon in material will increased the environmental impact and may cause pollution to the environment. Based on the analysis, it was found that the performance of the structural system for single and double story residential house for each design is same. In overall, the designs propose produce positive impact to the environment with different level of efficiency.

Analysis of the results also found that the characteristic strength of concrete, \( f_{ck} \) used in structural element can affect the section of structural elements being proposed where higher value of concrete strength, it may produced an optimum design of the structural elements. Concrete with high carbon content will increase the total amount of equivalent carbon emission and reduced the economical score ratio of the structural elements. Moreover, replacement of Portland cement with alternative material such as fly ash will only contribute on the performance of concrete where it help the improvement of concrete in terms of workability, durability and long terms of compressive strength [9]. The
The implementation of alternative material in concrete was found to affect the impact to the economical score because it may differ the result in terms of total carbon emission. Waste material is suitable to be used as a replacement material and sustainable in terms of recycling the materials but it was found not sustainable in terms of total equivalent carbon emission because of the concentration of carbon in the compound is high.

3.3 Classification of eco-efficiency design

Table 2 shows the overall analysis results of eco-efficiency index level of single story and double story house. In overall analysis of single story houses, it was found that most of the design classified as moderate and medium low due to low ratio of economical score and environmental score. Case 5 was identified as the optimum design because it produced low amount of equivalent carbon emission compare with other cases. In double story houses, it was identified Case 4 and Case 9 produced an optimum design and this combination is suitable to be used as characteristic strength of concrete parameters in reinforced concrete design. It can be concluding that, optimization of characteristic strength of concrete is important in order to produce eco-efficiency design of reinforced concrete structure because it may control amount of concrete and steel reinforcement of the structural elements. Furthermore, by using green material as an alternative concrete it may reflect on low content of carbon emission of the structural elements.

In overall, it was found that single story house classified in a range of medium low to medium high of eco-efficiency level of the reinforced concrete structural design. But, for double story house it was found that the classification of eco-efficiency level was identified in a range of low to high level of eco-efficiency. In single story house, the floor area was smaller than double story house that lead to small range of eco-efficiency level. Other than that, the eco-efficiency level of the building can be increased by using 30 percent alternative material as cement replacement material in reinforced concrete due to low content of equivalent carbon emission. As a result, it may increase reduction of equivalent carbon emission of the structural element 11 percent.

The classification of the design case was lead for the design engineer to produce level of efficiency for the structural elements of the building. Furthermore, this efficiency will provide reduction of equivalent carbon emission of the building compare to Ordinary Portland Cement reinforced concrete. It fulfills requirement of low-carbon design in sustainable development design criteria of building. Besides that, this approach is suitable to be applying for Green Building Index (GBI) in criteria 6 under innovation criteria because it was providing new concept of design that is required in green building criteria.

Table 2. Classification of eco-efficiency index level of single story and double story house

| Case | Single Story | Double Story |
|------|--------------|--------------|
|      | ENV_s | ECO_s | ECO_eff | Classification | ENV_s | ECO_s | ECO_eff | Classification |
| 1    | 0.0094 | 0.0092 | 0.0132 | Moderate | 0.0096 | 0.0091 | 0.0157 | Medium High |
| 2    | 0.0114 | 0.0095 | 0.0147 | Moderate | 0.0110 | 0.0014 | 0.0104 | Medium Low |
| 3    | 0.0129 | 0.0090 | 0.0155 | Moderate | 0.0143 | -0.0133 | 0.0008 | Low |
| 4    | 0.0111 | 0.0094 | 0.0145 | Moderate | 0.0105 | 0.0145 | 0.0210 | High |
| 5    | 0.0132 | 0.0094 | 0.0160 | Medium High | 0.0117 | -0.0024 | 0.0078 | Low |
| 6    | 0.0070 | 0.0094 | 0.0115 | Medium Low | 0.0072 | 0.0004 | 0.0064 | Low |
| 7    | 0.0051 | 0.0091 | 0.0101 | Medium Low | 0.0053 | 0.0058 | 0.0093 | Low |
| 8    | 0.0078 | 0.0090 | 0.0119 | Medium Low | 0.0084 | 0.0047 | 0.0110 | Medium Low |
| 9    | 0.0080 | 0.0092 | 0.0122 | Medium Low | 0.0084 | 0.0188 | 0.0229 | High |
| 10   | 0.0098 | 0.0092 | 0.0134 | Moderate | 0.0104 | 0.0090 | 0.0163 | Medium High |
There is a lot significant of sustainable design towards environment, economy and social community because it may provide us living within environmental limit that is important to stabilize and reduce carbon emission produce. Meanwhile, sustainable development important to economic aspect to reduce future economic, environmental and social cost. By using less natural resources material in construction for sure it can reduce the overall cost of the project and it also can strengthen economic competitiveness.

4. Conclusion
As for conclusion, classification of eco-efficiency reinforced concrete structural design of building was found positive in term of economical and environmental impact by using low coefficient of equivalent carbon emission and low cost alternative materials. Furthermore, this classification was giving indicator to the designer in developing sustainable structural design of building by providing suitable parameter such as characteristic strength of concrete, characteristic strength of steel, alternative material types and structural element dimension. By controlling that parameter, it will reflect the design result into different classification of eco-efficiency level. In overall, this study proves that eco-efficiency design of structural elements is possible to be implemented in construction industry suitable with the need of sustainable development policies.

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