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ECO-EFFICIENCY INDEX MODEL FOR REINFORCED CONCRETE STRUCTURAL DESIGN: MALAYSIA CASE STUDY

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ABSTRACT

In reinforced concrete design, the consideration of the characteristic strength of concrete is not theoretically determine and it is based on the experience of the designer with respect to some theoretical on the design background. Therefore, it may lead to produce ineffective design that produce high volume of material due to over-designed product. Highly cost designed will be produced due to this problem. Currently, align with the consistently in the environmental issues awareness, an impact assessment has been recognized as main key factor to encounter the problems. Therefore, it is necessary to proposed new solution that is simultaneously compliment the cost and environmental impact in the choosing the most sustainable design. This study proposed and integrated model for assessing cost and CO_2 emission that lead to produced eco-efficiency design of reinforced concrete structure for Malaysian construction practice. The eco-efficiency design is determine by two parameter which is economic score and environmental score that is based in Malaysian practice. Therefore, the proposed eco-efficiency design model will be adopted as the decision-making process method in selecting the best sustainable design for reinforced concrete structure.

Keywords: economic score, environmental score, eco-efficiency index.

INTRODUCTION

In Malaysia, reinforced concrete design was widely implement in designing a structure either building or infrastructure. Furthermore, British Standard and Eurocode were code of practices that adopted for the design purposes. In the designing process, selection of design parameter is important to ensure the efficiency of the design. Efficiency of the design should fulfill requirement of an economical design and low impact to the environment (Taehoon *et al*., 2012). An economical design is an element that needs to be considered as important criteria to choose the best construction method with optimum cost. The decision-making process needs to take place in order to access the economical impact of the structural system for long-term period. Despite of an economical factor that need to considered, further consideration on environmental factor need to take place in order to produce eco-efficiency design. An environmental factor is a consideration to reduce carbon dioxide emission from the structural material that is used as a construction material.

The increasing of carbon emission may cause the annual mean air temperature increasing in the city with 1 million people or more was about 1 to 3 degree Celsius. These phenomena will lead to create heat island and it may also increase the summertime peak energy demand, air conditioning costs, air pollution and greenhouse gasses (EPA, 2009). Therefore, action need to be taken now to reduce the carbon emission so that it will limit the maximum concentration or delay the point at which higher concentrations are realized (Edmunds *et al*., 2008).

In year 2012, the top three emitting countries or region that was accounted for 55 percent of total global carbon emission were China (29 percent), United States (16 percent) and European Union (11 percent). Other than that, there was increasing of carbon emission for India and Japan that were 7 percent and 6 percent. Meanwhile, Russian Federation was noted a 1 percent decreasing of carbon emission in 2012. The small increasing in emission for year 2012 about 1.1 percent shows of a slowdown in global carbon emission. Declining of carbon emission is possible if China achieves its own target of a maximum level of energy consumption by 2015 and its shift to gas with a natural gas share of 10 percent by 2020 (Olivier *et al*., 2013).

In Malaysia, construction industry was among highest carbon dioxide emission. Furthermore, that study was also stated that all the sectors that lies in this category should be given the most consideration due to high contribution on carbon dioxide emission that is above the average values. This study was also suggested that to practice environmental friendly products with less carbon dioxide emission to keep clean environment (Chik *et al*., 2013). 34 percent carbon emission was contribute by on site construction that refer to the method and material used for the construction. It was contribute one third of the total carbon emission in construction industry. Therefore, it will lead the designer to improve on construction method and design that may lead to reduce carbon emission production (Ko, 2010).

The common environmental impact categories used in LCA were global warming, photochemical oxidation, human toxicity, ozone depletion and acidification. (Crawford, 2011). It was determined that global warming has been identified as a main issue that cause environmental problems. The emission factor of CO_2 has been established and to consider all GHGs was impossible because lots of GHGs emitted from the raw materials in concrete production process. Furthermore, sustainability construction need to be imply that the needs

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of the present generation for the sake of future generation without wasting, polluting, damaging, destroying environment and without compromising the ability of future generation to meet their needs. In construction industry, sustainable development would involved there main criteria which are design for durable and functional service life of structure for the duration of their specified design life, use of waste materials, reduction of waste and recycling of waste and construction to cause the least harm to the environment (Swamny, 2004).

Nowadays, the construction industry is aiming to choose a design that is satisfied to compliment economical factors and environmental factors. Therefore, it is compulsory to develop a method that considers the economic and environmental impact simultaneously in order to select the best alternative design. Therefore, an eco-efficiency design is important to develop in order to satisfy the decision-making criteria in selection of sustainable reinforced concrete design that fulfill both criteria. Generally, eco-efficiency was defined as the product value per unit of environmental impact (Kobayashi *et al*., 2005). An alternative eco-efficiency design will genuinely help an engineer to choose the most economical design with low impact to the environment. Furthermore, the alternative design will improve the decision-making process of reinforced concrete design of structure (Taehoon *et al*., 2012). Other than that, current practice of reinforced concrete design that was implemented will lead to differ the element sizes because of changes in ready-mixed concrete strength (Taehoon *et al*., 2012). Therefore, this study was developed to propose alternative design by using different type of materials in order to choose best design.

Therefore, Figure-1 shows the framework that has been design to determine the eco-efficiency of the reinforced concrete structure. This framework is used to determine the eco-efficiency index based on economic score and environmental score. The consideration in economic score is based on construction cost which consists of material cost and construction work cost. For the environmental score, it is based on carbon emission amount that is produced by the material used in the constructions which are concrete, steel and alternative materials. This framework is become a model that strongly support the decision-making in choosing eco-efficiency design and it will be adopted by using the data resulted from the assessment.

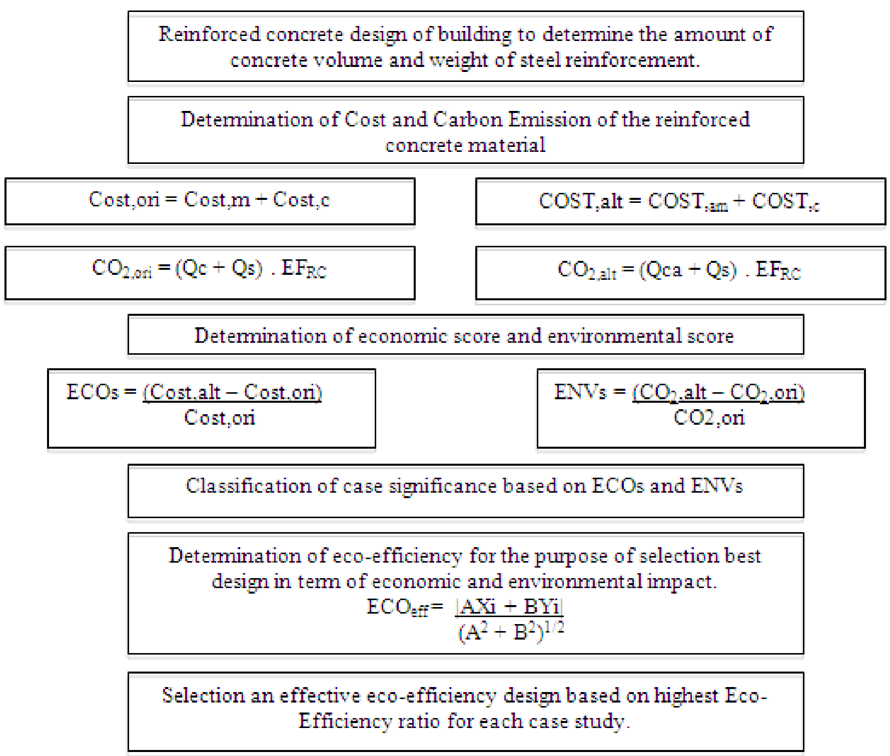

Figure-1. Framework of eco-efficiency of reinforced concrete design.

DETERMINATION OF ECONOMIC SCORE

Determination of economic score is the calculation of the reinforced concrete work cost that involved material cost and work cost. In Malaysia, the construction cost should be refer to Schedule of Rate (SOR) by Department of Work Malaysia (JKR20800). The SOR is differ based on amendment of the policy and also fluctuating of the material cost respect to the market concern. Equation 1 shows the calculation to determine the Economic Score (ECOs) of the reinforced concrete structure in this model that shows the reduction ratio of cost.

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$$ECOs = \frac{(Cost.alt - Cost.ori)}{Cost.ori} \quad (1)$$

The original cost (Cost,ori) is total cost for the material cost (Cost,m) of the normal concrete and the construction cost (Cost,c) that is used in the design as shown in Equation 2. The quantity of the material used is determine by the reinforced concrete design process of the structure. The quantity of the material should be separated in term of concrete grade and diameter of steel reinforcement.

$$Cost, ori = Cost, m + Cost, c \quad (2)$$

Determination of material cost (COST,m) is shown by Equation 3. The material cost is calculated by summation of concrete material cost and steel material cost. Equation 4 shows the formula in determining the concrete cost (COST,cm) by multiplying the quantity of concrete (Qci) in cubic meter (m^3) that is used for the construction with the unit price of concrete (Uci) in ringgit per cubic meter (RM/m^3). The concrete unit price is refer to JKR20800 standard for schedule of rate and it is not a fixed price due to fluctuating cost in market. Furthermore, the unit price price of concrete is different to different grade of concrete. The cost of steel (COST,sm) is determined by Equation 5 and it is multiplying product of quantity of steel (Qsh) in kilogram (kg) with unit price of steel (Ush) in ringgit per kilogram (RM/kg). The unit price of steel is also depending on the steel reinforcement diameter that is used in the design. Each diameter of steel reinforcement will give different unit price of that material.

$$COST_{,m} = COST_{,cm} + COST_{,sm} \quad (3)$$

Where;
Cost of concrete material: $COST_{,cm} = Qci \times Uci$ (4)

Qci = Quantity of concrete (i) (m^3)
Uci = Unit price of concrete (i) (RM/m^3)
i = *(20,25,30,35,40)*

Cost of steel material: $COST,sm = Qsh \times Ush$ (5)

Qsh = Quantity of steel (h) (kg)
Ush = Unit price of steel (h) (RM/kg)
h = *(8,10,12,16……)*

Determination of the construction cost (COST,c) is shown in Equation 6. The construction cost is a summation of concreting work (Cost,cw) and steel work (COST,sw). The general formula for cost of concrete work is determine by Equation 7 where it is summation of cocreting work for foundation (Cost,cf), concretion work for ground floor (COST,cg) and concreteion with for other floor (COST,cst). Therefore, Equation 8 shows the details of the calculation. The cost of steel work (COST,sw) is shown by Equation 9 where it is summation of steel work cost for each type of steel reinforcement used in the construction which is depending on the steel reinforcement diameter. Furthermore, Equation 10 shows the details formula of the steel work in order to determine the total cost of steel work.

$$COST_{,c} = COST_{,cw} + COST_{,sw} \quad (6)$$

Where;
Cost of concrete work:

$$COST_{,cw} = COST_{,cf} + COST_{,cg} + COST_{,cst} \quad (7)$$
$$= (Qci \times Wci)_{cf} + (Qci \times Wci)_{cg} + (Qci \times Wci)_{cst} \quad (8)$$

Qci = Quantity of concrete (i) (m^3)
Wci = Cost of concrete work (i) (RM/m^3)
i = *(20,25,30,35,40)*

Cost of steel work:

$$COST,sw = COST_{,6} + COST_{,8} + COST_{,10} + COST_{,12} \quad (9)$$

$$= (Qsh \times Wsh)_6 + (Qsh \times Wsh)_8 + (Qsh \times Wsh)_{10} + (Qsh \times Wsh)_{12} \quad (10)$$

Qsh = Quantity of steel (h) (kg)
Wsh = Cost of steel work (h) (RM/kg)
h = *(8,10,12,16……)*

The calculation of the material cost and construction work cost need to be sum up with different grade of concrete and different diameter of steel reinforcement. It is because different grade of concrete and steel diameter will give different unit price of material and unit price of work. The total original cost calculation for this study is determine by following the current practice in Malaysia construction industry.

The alternative cost (Cost,alt) is the total cost of the material used which is including alternative material in the concrete. The general formula for alternative cost is shown in Equation 11. The alternatie cost is summation of the alternative material cost (COST,am) and the construction work cost (COST,c).

$$COST,alt = COST_{,am} + COST_{,c} \quad (11)$$

The alternative material cost (COST,am) is a summation of concrete cost (COST,c), new material cost (COST,nm) and steel cost (COST,s) as shown in Equation 12. Equation 13 shows the details calculation of alternative material cost. The calculation of alternative material cost is needs to consider the new material amount that is used as a construction material. Therefore, the unit price of the new material that is added in the concrete design should be refer to the current market prices. Besides that, the current standard by the government should be refer in order to avoid descripencies of the construction cost.

$$COST,am = COST,c + COST,n + COST,s \quad (12)$$

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Where;

Alternative material cost:

COST,am = (Qci x Uci)+(Qna x Una)+(Qsh x Ush) (13)

Qci = Quantity of concrete (i) (m^3)
Uci = Unit price of concrete (i) (RM/m^3) *i = (20,25,30…..)*
Qna = Quantity of alternative material (a) (kg)
Una = Unit price of alternative material (a) (RM/kg)
Qsh = Quantity of steel (h) (kg)
Ush = Unit price of steel (h) (RM/kg)
H = (8,10,12,16...)

The alternative material that is identified to be used in the design is refer to the Iventory of Carbon and Energy Document Version 2.0. Furthermore, the percentage of the alternative material is also referred to the same document. The construction cost for the alternative cost is referred to be same as original cost due to the construction method is same. The alternative material is mixed together with the concrete mixed as part of the process in preparing the concrete.

DETERMINATION OF ENVIRONMENTAL SCORE

A critical evaluation of the world scenario on global warming, carbon emission and construction industry historical revolution was emphasize the complexity of the issues but close relationship between three seemingly unrelated issues which are insatiable infrastructure needs of a rapidly growing and urbanizing world coupled with the desire for a better quality of life of nations suffering from a lack of availability and accessibility, need to achieve a balance between economic development and protection of environment, and crisis in the area of materials and durability.

Therefore, the evaluation of the environmental condition need to take place in order to ensure the environmental protection will give a better future of the earth. The evaluation of the environmental condition is based on the carbon emission that is produced by the human activities because it was contributed the largest amount of carbon emission in the world. Therefore, Equation 14 shows the general formula of environmental score (ENV,s) that shows the reduction carbon emission volume of the normal structural design and alternative structural design.

$$ENV, s = \frac{CO_{2,alt} - CO_{2,ori}}{CO_{2,ori}} \quad (14)$$

Where;
$CO_{2,alt}$ = Alternative carbon dioxide emission for the alternative design
$CO_{2,ori}$ = Original carbon dioxide emission for normal concrete design

The original carbon dioxide emission ($CO_{2,ori}$) is determine by Equation 15 which is the product of material quantity with emission factor of reinforced concrete. The material quantity is summation of quantity of concrete (i) in kilogram (kg) and quantity of steel (h) in kilogram (kg). The quantity of concrete in cubic meter need to be divided with a constant (2406.53) in order to convert the quanty in kilogram.

$$CO_{2,ori} = (Qci + Qsh) \cdot EF_{RC} \quad (15)$$

Where;
Qci = quantity of concrete (i) (kg)
Qsh = quantity of steel in (h) (kg)
EF_{RC} = emission factor of reinforced concrete ($kgCO_2/kg$)

The emission factor of reinforced concrete (EF_{RC}) is a total coefficient of carbon emission of concrete and steel that is produce in the process. The emission factor of concrete (EFc) is refer to ICE Document Version 2.0 and the values is depending on the concrete grade design. Furthermore, the emission factor of steel (EFs) that need to referred ICE Document Version 2.0 is per 100 kilogram emission. Therefore, the emission factor of steel need to multiply with the amount of steel weight (kg) per concrete volume (m^3).

The alternative carbon dioxide emission (CO2, alt) is determine by Equation 16 which is the product of alternative material quantity with emission factor of reinforced concrete. The material quantity is summation of quantity of normal concrete (i) with alternative material in kilogram (kg) and quantity of steel (h) in kilogram (kg).

$$CO_{2,alt} = (Qca + Qsh) \cdot EF_{RC} \quad (16)$$

Where;
Qca = quantity of alternative concrete (a) (m^3)
Qsh = quantity of steel (h) (kg)
EF_{RC} = emission factor of alternative reinforced concrete ($kgCO_2/kg$)

The emission factor of alternative reinforced concrete (EF_{RC}) is shown in Equation 17 which is the total emission factor of alternative concrete (EFac) in and emission factor of steel (EFs) in kilogram carbon dioxide per kilogram of material (kgCO2/kg). The emission factor is referred to ICE Document Version 2.0 (Hammond and Jones, 2011).

$$EF_{RC} = EFac + EFs \quad (17)$$

Where;

EFac = emission factor of alternative concrete (a) (kgCO2/kg)
EFs = steel coefficient per 100kg (refer to ICE Document V2.0) x (steel weight (kg)/concrete volume (m^3))

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Eco-efficiency index

Two –dimensional plane has been adopted to assess the eco-efficiency portfolio for manufacturing and chemical industries (Saling *et al*., 2002; Huppes and Ishikawa, 2005; Kobayashi *et al*., 2005; Rudenauer *et al*., 2005). A relationship of economic values and environmental impact was plotted in x and y axis where the eco-efficiency was presented by the location of a two-dimensional plane. But, this concept does not clearly proposed the values in evaluation criteria. With that, the assessment of cost and environmental values for different design will be proposed in this study. The numerical results from the proposed framework will be applied as an index in development of the decision-making process.

An assumption has been made as the method in selection of most sustainable design in considering the economic and environmental scores that concluded "the total cost of constructing a building was identical to the value of the total amount of CO_2 emitted in constructing a building." Therefore, hypothesis can be made with 1 percent reduction of CO_2 emission was proportional with the 1 percent reduction in the cost. The choosing approach may cause a problem where the decision-maker may not grant identical values to the two items. The reason is because the process is depending on the decision-maker where various type of parameters consideration may be accorded to the cost and CO_2 emission. This study is carried out to answer the question on the construction cost and carbon emission of different alternative materials used in the design. Therefore, the most sustainable structural design alternative can be selected based on environmental score and economical score values.

The results can be categorized into four different possible cases as shown in Table-1. The table shows the categories of the design that was determine by the values of economic score or environmental score. The positive values will results positive impact toward the respective parameter either economic or environment. The positive economic score will show the most effective optimum cost of the construction that was calculated by using the developed equation. Furthermore, the positive value of environmental score shows the low impact on the environment because the material use in the construction or design will produce small amount of carbon dioxide emission.

Table-1. Significance of the case (Taehoon *et al*., 2012).

Economic score	Environmental score	Signification
+	+	The alternative is always better than the original design in terms of economic and environmental impact.
+	-	The alternative is better than the original design in terms of economic impact, but is worse than the original design in terms of environmental impact.
-	+	The alternative is worse than the original design in terms of economic impact, but is better than the original design in terms of environmental impact.
-	-	The alternative is always worse than the original design in terms of economic and environmental impact.

Further evaluation is being made by determine the eco-efficiency index (ECOeff). Eco-efficiency index is the method to determine sustainable design of reinforced concrete structure based on the economic score and environmental score. Taehoon *et al*., (2012) is adopted in this study to determine the best design because it is also use the same parameter on economic score and environmental score. Therefore, the ecoefficiency index is determine by Equation 18. The index is calculated to shows the efficiency of the design based on the economic score ration end environmental score ratio that has been calculated.

$$ECOeff = \frac{|AXi + BYi|}{(A^2 + B^2)^{1/2}} \tag{18}$$

Where;

X_i = economic score for each structural-design alternative

Y_i = environmental score for each structural-design alternative.

A = weight of the economic score

B = weight of environmental score

Furthermore, specific weights were marked for the cost and CO_2 emission to ensure the decision-maker will make acceptable assumption for the design criteria so that it will fulfill the requirement of sustainable design. Besides that, if two variables are independent, the weights

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can be applied directly to the two variables (Wang *et al*., 2010). Thus, the method by which the decision makers such as users, owners or clients can directly input the weights to two scores was used in this study. The slope of the IE-line can be change and it is depending on the weights applied to two scores. As for example, considering that the economic and environmental scores are identical, the IE-line will have a slope of -1. If the weight of environmental scores is doubled, the slope of the IE-line changes to -2, as shown in Equation 19.

$$AX + BY > 0 \quad (19)$$

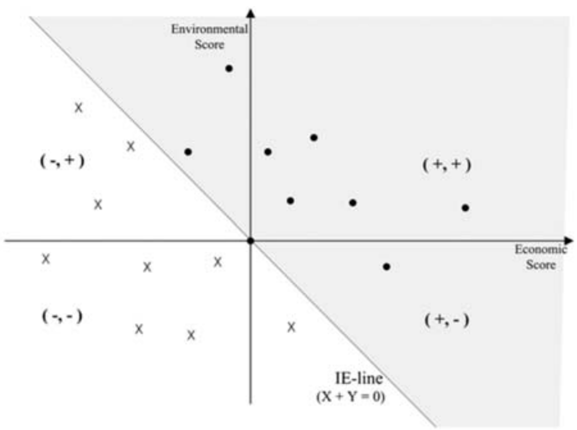

Figure-2. Results of different design alternatives, depicted in a two-dimensional plane. (Taehoon *et al*., 2012).

DISCUSSIONS

The methodology is determine to develop the decision making model for selection of effective design in reinforced concrete structure that is respect to economical impact and environmental impact. In economical score calculation, the designer should consider few factors in order to avoid miscellaneous of the calculation. The standard price of the material and construction work should be refer to the current standard of rate by Department of Work Malaysia. Furthermore, the development of the formula should be understand as a standard formula to determine economic score that show the ratio between original cost and alternative cost. The transportation cost of the material is not included in this study because of it is inclusive as a material cost. In the alternative cost calculation, the alternative material amount should be define by calculating the replacement material percentage in order to avoid misinterpretation of the calculation.

In calculation of the environmental score, the amount of carbon dioxide need to be determine as a parameter to show the ratio values between an original carbon dioxide emission and alternative carbon dioxde emission. The calculation of carbon emission is based on Inventory of Carbon and Energy Document Version 2.0 because it is widely used as a reference for carbon emission and energy coefficient that is produced by the construction materials. Furthermore, the carbon emission coefficient of reinforced concrete cannot be separated because the reinforced concrete structure is a composite structure that combined two materials which are concrete and steel. Therefore, the designer should carefully determine the parameter that used in the design so that it will not cause a problem to determine the efficiency of the design.

The eco-efficiency index is developed to determine the best design. Higher value of eco-efficiency index will produce most economical design with low impact on the environment which produces low carbon dioxide emission. The values for economic weight and environmental weight should be consistent either 1 or 2 based on the case situation. To verify the applicability of the proposed Eco-efficiency Index calculation, practical application need to carry out based on the method that has ben developed. The analysis results finally will be presented by Eco-efficiency Index are expressed in numerical values. Thus, it can be adopted as clear indicators for the decision-making process to choose the best design of reinforced concrete structure.

In this study, an integrated model for analyzing the cost and CO_2 emission that is capable of supporting the decision- making process in selecting the most economical and eco-efficiency design in designing reinforced concrete structure was proposed. The Eco-efficiency Index Model that analyzed the cost and CO_2 emission of different reinforced concrete design was framed into three phases which are analysis of the construction cost and CO_2 emission of the design alternatives, calculation of the economic and environmental scores which signify the cost and CO_2 emission reduction ratios respectively based on the previous assessment and selection of the best design alternative based on these two scores.

CONCLUSIONS

Determination of best designed nowadays should be extend to a new criteria that is including on economical factor and environmental factor. It is because, by introducing this two new factor in the decision making of design process will help the designer to improve their design parameter to avoid over design of the structural elements. Therefore, in this study the Eco-efficiency Index Model is developed to propose the best reinforced concrete design that fulfill the requirement of optimum cost of the materials with respect to protect the environment by using low carbon dioxide emission materials. With this model, it will help the designer to choose suitable concrete grade with suitable alternative material that promote sustainable or green design of reinforced concrete structure. Positive values of economic score and environmental score will lead to produce the best design of reinforced concrete structure that promote high intensity of green design. Furthermore, the final decision should be made by eco-efficiency index that shows the ratio of the economic score and environmental score. Higher efficiency will shows most optimum cost of the materials and lowest carbon dioxide emission produce by its construction materials. To produce higher eco-efficiency index the material that is used in the design should have a lower score and the material used will produce lowest emission of carbon dioxide. Therefore, selection of the material is important to ensure that it will produce most eco-efficiency design of reinforced concrete structure. The implementation of this model is suitable for any reinforced concrete structure that proposed to be designed as a green building or sustainable structure. Furthermore, this model is genuinely develop to ensure that the design will not cause over-designed and avoid an appropriate grade of concrete and steel reinforcement diameter. There is no limitation of the structural sizes because of the model can be used for any structural size. Other than that, this model is developed to determine the eco-efficiency for reinforced concrete structure only. With this model, the objective to produce eco-structure will become a reality.

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