**Journal of Computer Science Research**
http://ojs.bilpublishing.com/index.php/jcsr

ARTICLE

# ECO-Case Based Reasoning Tool for Environmental Product Design

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ARTICLE INFO

*Article history*
Received: 20 May 2019
Accepted: 26 June 2019
Published Online: 30 July 2019

*Keywords:*
CBR
Case Based Reasoning Tool
Eco-product design
Eco-design
Product sustainability
Environmental impact

ABSTRACT

Case Based Reasoning (CBR) is one of the artificial intelligent methodologies that is widely used in problem solving by reusing the most similar previous experiences stored in the library. A framework of ECO-CBR for Life Cycle Assessment data collection has been used and the process was carried out using SolidWorks program. The practicality of the tool has been validated using case study, which then provides solution. The output enable researchers to determine forecast error and forecast accuracy, by valuing the calculation from Total Carbon Footprint, Energy Consumption, Air Acidification, and Water Eutrophication. ECO-CBR is able to assist designers in product design. Due to the limitation of environmental impact consideration in product sustainability, there is a demand to propose a tool that can assist designers to reduce environmental impact of product design at early stage. The model works as an essential guideline to lessen repeated mistakes in the product development process and help designers measure the risks before concluding ideal decisions. Minor errors that occur through the study showed that ECO-CBR is reliable to be implemented in order to find a better solution.

## 1. Introduction

Case-Based Reasoning (CBR) is an artificial intelligent (AI) methodology, specifically used in problem solving based on previous experiences. It consists of four processes, which are retrieve, reuse, revise and retain [1]. According to Aamodt and Plaza [2], the process of CBR method starts with defining the new problem description. In order to retrieve the cases from case-based library, a calculation is intended to find the highest similarity rate that has been carried out before. The retrieved case is reuse to provide a solution that fits the new problem. As the number of cases in the library increase, the CBR application becomes more reliable and efficient [3].

Every manufactured product will produce environmental impact [4]. Eco-design is an approach to ensure the product is smarter and safer throughout its life cycle. Formerly, product designers would emphasize features such as quality and functionality, but the fact consideration of eco-design strategies in product design is even more important in order to preserve the environment [5]. Therefore, eco-design strategies should be implemented in the early stage of product design to obtain better results in the final

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DOI: https://doi.org/10.30564/jcsr.v1i2.1146

stage of the production [5]. Applying and implementing sustainable practicing in any manufactured product especially from the early phase of the process may leads to not only environmental benefits but also bring profits to economic and social as well [6,7].

CBR application has been applied in various area such as medical and engineering [8,9]. It assists in product design area as well [10]. However, the CBR application in product design that focuses on eco-design strategies are limited as the following factors; abandonment of eco-design consideration among manufacturers due to the huge investment in time and resources, which are needed in collecting Life Cycle Assessment (LCA) data [11]. These factors make it less practical for the first level of product innovation. Due to the issue, some of LCA tools uses impact assessment database separately [12].

According to Hassan [13], eco-design consideration leads to product sustainability. The characteristics of sustainable product design included minimal material usage, improved material choices and design for ease of disassembly, product reuse, minimal energy consumption, producing zero hazardous wastes and usage of clean technologies [14].

Therefore, the purpose of this study is to provide a decision tool with a specific database that assists product designers to estimate the environmental impact at the early phase. The environmental impact solution provided at the early stage of product design is important as it helps designers to lessen the risk of incurring losses and support the green product development especially for small and medium manufacturers. It is beneficial for manufacturers as a guideline to improve the process of product development hence the products become more sustainable in the future.

## 2. Related Works

### 2.1 Eco-design Tool for Sustainable Product Design

Many tools have been introduced to ensure manufactured products have sustainable elements. According to Criel et al. [17], there were three basic types of eco-tool, which are qualitative, semi-quantitative and quantitative. While Hernandez Pardo et al. [18] had classified eco-tools to three types, which are analytical, guiding and information tools. Analytical is for a quantitative tool such as LCA. Guiding are tools for providing a piece of advice and idea generating for the designers, while information tools are use for generating information about material usage and substance produce during product development. A checklist is one of the examples of information tools. In vehicle design area, Poulikidou [19] classified the tools into six categories, which are checklist and indices, radar graph and schematic, matrix method, analytical method and software, and computer-based tools. While Ramani et al. [20] distinguished eco-design tools into three categories, which are checklist based, LCA based and Quality Function Deployment (QFD) based.

A checklist is a simple tool used to investigate the impact at the early stage of the design process [19-21]. Adam [22] used a checklist tool for electronic manufacturers and found it is useful for both technical and non-technical personnel. Whereas Wimmer [23] applied a checklist tool to highlight the product's weak point to be improved. Apart from that, Rocha [24] implemented eco-design checklist in a ceramic industry to figure out the environmental impact level. Even though a checklist offers simplicity, but it contains general information that causes confusion and wrong impression among the personnel [22]. Besides, a checklist provides subjectivity in the answer, which finally indicates to incomplete information and makes the investigation product eco-assessment become difficult [24].

In order to overcome the limitation of the checklist tool, there is an LCA based tool, which provides quantitative data instead of qualitative data. LCA tools that are widely used for eco-assessment are GaBi and SimaPro [25]. Else, WRATE and Ecoinvent Waste Disposal Inventory Tools v1.0 have been developed to address the issue of uncontrolled wastes [12]. While Eco-Bat 4.0, ECO MODULE and novaEQUER are tools based on LCA use for building construction [12,26]. One of the limitations facing by traditional LCA based tool is, it is not design oriented as it is developed to assess environmental impact from the perspective of product structure only; and not to access environmental cost connected with product function based on customer requirements [27]. With this regard, an integrated LCA with computer-aided design (CAD) has been introduced to overcome the limitation, for example, AutoCAD and SolidWorks software package. Another approach is three-dimensional computer-aided design (3D CAD) system, which the impact of packaging and transportation phases can be analyzed from the calculation of mass and volume for each part of the product [25].

### 2.2 CBR Approach in Product Design

In product manufacturing, time management is vital and need to be considered when they are producing a product. As a complex process, a wise time management can make an organization works more efficiently [28]. For that purpose, Stéphane and Marc [29] proposed a CBR tool for a chemical product to accelerate the process of designing until the packaging. Apart from that, Li and Xie [30], pro-

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posed a CBR application to speed up the creation of an innovative product. The researchers managed to overcome the difficulties of product families' customization in the context of one-of-kind-product (OKP) design through the implementation of CBR methodology. Wu and Chen [31] applied CBR methodology in an automotive area where the researchers believed that this approach able to accelerate new idea generated in the design concept.

Li-xia et al. [32] used CBR method to retrieve and reuse the existing design information for shoes to avoid designers to go through the process of market research all over again once new style came out into the market. Yang & Chen [33] conducted case studies of cell phone using TRIZ evolution pattern integrated with CBR to help designers formed a new concept of development efficiently. Bejarano et al. [34] proposed a Recursive-CBR by manipulating the existing industrial and CBR methodology standard. The process included the development of ontology to help the designers to define system requirements precisely and provided guideline for the steps of retrieved, reuse, revised and retained. From the perspective of eco-design, Romli, Prickett, et al. [35] had proposed an Integrated Eco-Design Decision Making (IEDM) framework which integrating eco-design quality function deployment (Eco-QFD) with ecological CBR tool. In this study, medical forceps with new material act as a product in research's case study to examine the environmental impact for the whole product's life cycle as well as the cost estimation of the solution provided. Table 1 shows the summary of CBR application in product design.

**Table 1.** Summary of CBR Application in Product Design

| Author | Case study | Eco-design | Sustainability factor | | |
|---|---|---|---|---|---|
| | | | *Economy* | *Social* | *Environmental* |
| **Wu and Chen** [31] | Automotive | × | × | × | × |
| **Stéphane and Marc** [29] | Chemical product | × | × | × | × |
| **Yang & Chen** [33] | Cell phone display | √ | √ | × | √ |
| **Li-xia *et al.*** [32] | Shoe design | × | × | × | × |
| **Li and Xie** [30] | Fruit chute | × | × | × | × |
| **Bejarano *et al.*** [34] | Aeronautics | × | × | × | × |
| **Romli, Prickett, *et al.*** [35] | Medical forceps | √ | √ | √ | √ |

## 3. Method and Materials

The framework was designed to support the development of ECO-CBR tool. Figure 1 shows the framework of ECO-CBR for LCA data collection, which constitutes the product functional requirement, material and manufacturing, transportation, end of life (EOL), carbon footprint, air acidification, energy consumption, and water eutrophication values.

SolidWorks has been used to carry out the process of calculation. For this study, the product's 3D model has been loaded into the software and a sustainability report was generated in .docx and .csv format. Refer to Figure 2 for the report generated by SolidWorks.

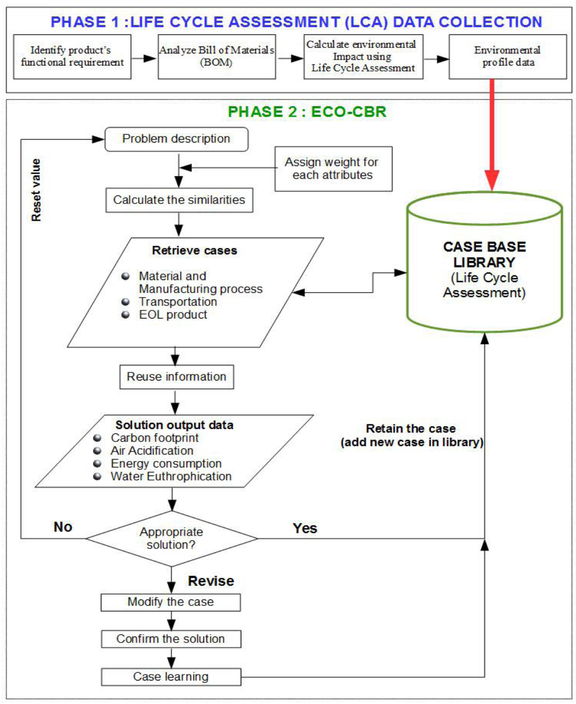


**Figure 1.** ECO-CBR Framework

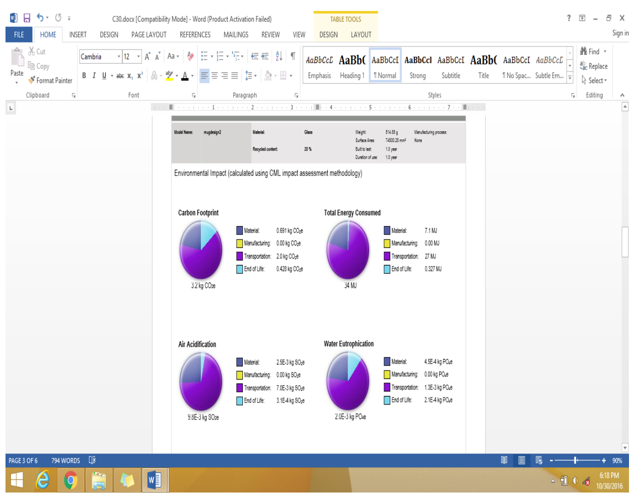

**Figure 2.** Sustainability report contains of carbon footprint, energy consumption, air acidification and water eutrophication pie chart

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All generated data was compiled to create a case-based library. The prototype of ECO-CBR tool has been developed as a web-based application using C# programming language for back end application while Microsoft SQL Server was used to store the case-based library.

The first step of the process is to enter problem description for the new product consisting of different attributes. Every attribute has been assigned with the weighting factor as an indicator level of importance. The CBR mechanism compared a new case with the existing cases in the library. Cases with the highest similarities were retrieved and used, thus to provide the estimate solution. It allowed designers to measure the level of carbon footprint, air acidification, energy consumption and water eutrophication produced in the product's life cycle.

## 4. Implementation

The purpose of this case study is to evaluate the practicality of the ECO-CBR tool. Drinking mug is the selected product for the case study. There are three groups of problem description need to be entered into the ECO-CBR tool: Material and Manufacturing process; Transportation; and End of Life (EOL) group. ECO-CBR provided the environmental impact solution consist of carbon footprint (kg CO2), energy consumption (MJ), air acidification (kg SO2) and water eutrophication (kg PO4).

Currently, there are 144 LCA profiles data for two dimension of drinking mug inside the case-based library. The two drinking mugs are namely as D1 and D2. In order to demonstrate the tool, new drinking mug dimension has been entered into the ECO-CBR tool.

**Table 2.** Existing Drinking Mug Functional Requirement

| Attributes | Drinking Mug (D1) | Drinking Mug (D2) |
|---|---|---|
| **Thickness (mm)** | 5.14 | 6.00 |
| **Height (mm)** | 125.35 | 110.00 |
| **Parameter (mm)** | 682.48 | 719.57 |
| **Volume ($mm^3$)** | 215875.13 | 209494.64 |
| **Surface area ($mm^2$)** | 85968.27 | 74500.25 |
| **Weight (gram)** -depends on material | PS HI = 233.15 Glass = 530.53 | PS HI : 226.25 Glass : 514.85 |

**Table 3.** New Drinking Mug Functional Requirement

| Attributes | New Drinking Mug |
|---|---|
| **Thickness (mm)** | 5.00 |
| **Height (mm)** | 110 |
| **Parameter (mm)** | 710.69 |
| **Volume ($mm^3$)** | 20,4882.05 |
| **Surface area ($mm^2$)** | 80,092.58 |

Table 2 is the functional requirement for D1 and D2 drinking mug. While Table 3 shows the functional requirement for new drinking mug design. New drinking mug weight was reduced by approximately 5% compared to D1. By reducing the drinking mug weight, it could contribute to the reduction of material use. Besides, low impact logistics has been chosen to transport the product. The application has two main tabs. The first one is to allow product designers to enter the values for new case description while the second tab will prompt the case retrieval with the highest similarity. There are another three main fields, perform specific task accordingly.

### 4.1 New Case – T1(A) Area

The process starts with describing a new case. Product designer entered new problem description at T1(A) area. The information of product functional requirements should be entered for reference. Conversely, the weight value was not required. Problem description has divided into three sections, which were Material and Manufacturing, Transportation and End of Life. Table 4 shows the information of new drinking mug design entered into the ECO-CBR tool.

**Table 4.** New Case Problem Description

| Attributes | Values | Weighting |
|---|---|---|
| ***Product Functional Requirement*** | | |
| **Thickness (mm)** | 5.00 | - |
| **Height (mm)** | 110 | - |
| **Surface Area ($mm^2$)** | 80,092.58 | - |
| **Volume ($mm^3$)** | 20,4882.05 | - |
| **Perimeter (mm)** | 710.69 | - |
| ***Manufacturing and Material*** | | |
| **Material Type** | PS HI | 5 |
| **Manufacturing Process** | Injection Molded | 5 |
| **Product weight (gram)** | 221.27 | 5 |
| ***Transportation*** | | |
| **Origin** | Malaysia | 4 |
| **Destination** | Malaysia | 4 |
| **Transportation type** | Train | 5 |
| **Distance (km)** | 380 | 5 |
| ***End of Life*** | | |
| **Recycle (%)** | 50 | 5 |
| **Incineration (%)** | 25 | 3 |
| **Landfill (%)** | 25 | 3 |

### 4.2 Weighting Factor – T1(B) area

Product designer has to assign weighting factor at T1(B) by entering the value 1 to 5. It signified the impor-

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tance level for each of the attributes. Referring to Table 4, value 1 is for less important while value 5 is signify as very important. It based on a common importance scale. The weighting value is essential for similarity calculation.

### 4.3 Case Retrieval – T2 area

The cases that retrieved from ECO-CBR case-based library were from three different groups: Material and Manufacturing, Transportation and End of Life. There were two types of equations used to calculate similarity: Local Similarity and Global Similarity. Local Similarity has been divided into two techniques, which were Non-Numerical Local Similarity and Numerical Local Similarity. Equation (1) and (2) are used to calculate similarity for text or symbol; and similarity for numerical data respectively. Equation (3) is defined as the average weight of the local similarities. The rate of global similarity is [0, 1]. 0 is the lowest rate while 1 is the highest similarity rate.

$$\begin{aligned} &IF\ NC == Lib_k \rightarrow Local\ Similarity\,(LS) = 1 \\ &Else \qquad\qquad \rightarrow Local\ Similarity\,(LS) = 0 \end{aligned} \qquad (1)$$

$$s = \frac{\min(NC, Lin_k)}{\max(NC, Lib_k)} \qquad (2)$$

$$IF\ (NC == 0\ \&\ Lib_k == 0)\ then\ Local\ Similarity\,(LS) = 1$$

$$GS = \frac{\sum_j w_{ij} * LS_{jk}}{\sum_i w_{ij}} \quad \forall i \qquad (3)$$

Where:
$i$ = group of feature;
$j$ = set of input feature;
$LS$ = local similarity for each feature;
$w_{ij}$ = weight per group

## 5. Results and Discussion

Eco-CBR tool will perform the searching by finding a case with the highest similarity rate. The case retrieved from ECO-CBR case library for three different groups: Material and Manufacturing, Transportation and End of Life.

Material and Manufacturing Process

| Case No | Material Type | Process | Product Weight(gram) | Global Similarity |
|---|---|---|---|---|
| C4 | PS HI | Injection Molded | 226.25 | 0.9927 |

**Figure 3.** Highest similarity case retrieval for Material and Manufacturing group

Figure 3 shows a case retrieval for Material and Manufacturing group. The result in the first row is the case with highest similarity rate. From the result, Case No. C4 is the most similar case with the new case entered. The global similarity rate is 0.9927.

Below is the calculation of the local and global similarity for Material and Manufacturing group.

$$NC_{material\ type}\,(PS\ HI) == Lib_{material\ type}\,(PS\ HI) \rightarrow LS = 1$$

$$NC_{process}\,(Injection\ Molded) == Lib_{process}\,(Injection\ Molded) \rightarrow LS = 1$$

$$LS_{product\ weight} = \frac{\min\,(NC(221.27), Lib(226.25))}{\max\,(NC(221.27), Lib(226.25))} = 0.9780$$

$$GS_{material\ and\ manufacturing} = \frac{(5*1)+(5*1)+(5*0.9779)}{5+5+5} = 0.9927$$

Transportion

| Case No | Origin | Destination | Transport Type | Distance (km) | Global Similarity |
|---|---|---|---|---|---|
| C67 | Malaysia | Malaysia | Train | 375 | 0.9924 |

**Figure 4.** Highest similarity case retrieval for Transportation group

As for the Transportation group, Figure 4 shows the list of cases. The case with 0.9923 global similarity rates derived from the ECO-CBR case library is from case C67.

$$NC_{origin}\,(Malaysia) == Lib_{origin}\,(Malaysia) \rightarrow LS = 1$$

$$NC_{destination}\,(Malaysia) == Lib_{destination}\,(Malaysia) \rightarrow LS = 1$$

$$NC_{transportation\,type}\,(Train) == Lib_{transportation\,type}\,(Train) \rightarrow LS = 1$$

$$LS_{\text{distance}} = \frac{\min\,(NC(380), Lib(375))}{\max\,(NC(380), Lib(375))} = 0.9868$$

$$GS_{\text{transportation}} = \frac{(4*1)+(4*1)+(5*1)+(5*0.9868)+(5*0.9780)}{4+4+5+5+5} = 0.9924$$

End of Life

| Case No | Recycled (%) | Incinerated (%) | Landfill (%) | Global Similarity |
|---|---|---|---|---|
| C5 | 50 | 25 | 25 | 0.9948 |

**Figure 5.** Highest similarity case retrieval for End of Life group

Figure 5 shows the case retrieved for End of Life (EOL) group. The highest similar case retrieved from ECO-CBR library is C5 with 0.9948 global similarity rates. The similarity calculation is as follow:

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$$NC_{material\,type}(PS\,HI) == Lib_{material\,type}(PS\,HI) \rightarrow LS = 1$$

$$LS_{recycle} = \frac{\min(NC(50), Lib(50))}{\max(NC(50), Lib(50))} = 1$$

$$LS_{incinerated} = \frac{\min(NC(25), Lib(25))}{\max(NC(25), Lib(25))} = 1$$

$$LS_{landfill} = \frac{\min(NC(25), Lib(25))}{\max(NC(25), Lib(25))} = 1$$

$$LS_{product\,weight} = \frac{\min(NC(221.27), Lib(226.25))}{\max(NC(221.27), Lib(226.25))} = 0.978$$

$$GS_{end\,of\,life} = \frac{(5*1)+(5*1)+(3*1)+(3*1)+(5*0.9780)}{5+5+3+3+5} = 0.9948$$

The environmental impact solution for LCA of new case drinking mug has been displayed as in Figure 6. It covers five phases of a life cycle: Material, Manufacturing, Use, End of Life and Transport. The total amount for Carbon Footprint, Energy Consumption, Air Acidification and Water Eutrophication are 1.136 kg, 22.26MJ, 0.0081 kg and 0.00048 kg.

Solution has been provided based on the combination of highest similarity case retrieval from a different group. Environmental impact during Material and Manufacturing phases was derived from case no C4. In this product use phase, the impact was 0.000 because drinking mug does not require energy to operate. For End of Life phase, environmental impact was derived from case no C67 while environmental impact for Transportation phase was derived from case no C5.

The valuation has been carried out using SolidWorks software package. The same problem description has been entered into the software. The impact total values proposed by ECO-CBR tool later then has been compared with the report provided by SolidWorks. The comparison between SolidWorks and ECO-CBR solution shown as in Table 5.

**Table 5.** Comparison between Eco-CBR Tool and SolidWorks

| Total environmental impact solution | SolidWorks | ECO-CBR tool | Forecast accuracy |
|---|---|---|---|
| Carbon Footprint (kg $CO_2$) | 1.11092 | 1.13587353 | 97.75 % |
| Energy Consumption (MJ) | 21.7698 | 22.2593269 | 97.75 % |
| Air Acidification (kg $SO_2$) | 0.00789897 | 0.0080760616 | 97.76 % |
| Water Eutrophication (kg $PO_4$) | 0.000473615 | 0.0004842417 | 97.75% |

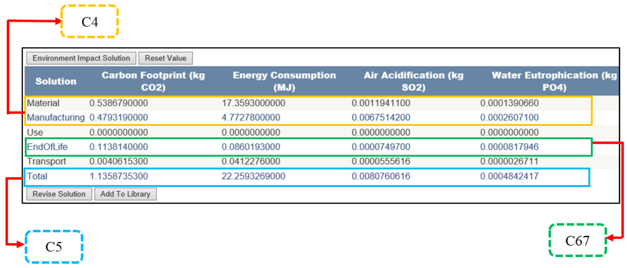


**Figure 6.** Environmental impact solution

In order to determine the forecast error and forecast accuracy, the value from Total Carbon Footprint, Energy Consumption, Air Acidification, and Water Eutrophication were used to perform the calculation. The actual value provided by SolidWorks and the forecast value was from ECO-CBR. Equation (4) and (5) are used to calculate forecast error; and forecast accuracy respectively.

$$Forecast\ error = ((|Actual - Forecast|)/Actual)*100 \quad (4)$$

$$Forecast\ accuracy = 100\% - Forecast\ error \quad (5)$$

The actual impact solution proposed by SolidWorks for carbon footprint, energy consumption, air acidification, and water eutrophication were 2.2462%, 2.2487%, 2.2420%, and 2.2466%; less than forecasted by ECO-CBR. Therefore, the percentage of accuracy for carbon footprint, energy consumption, and water eutrophication is 97.75%. While for air acidification, the percentage of accuracy is 97.76%. Accuracy with 90% and above proved that ECO-CBR tool is practical and reliable because the solution provided is close enough to the actual solution from SolidWorks.

This solution can be retained by instantly saved into the library. Retain process is to increase the number of cases inside the library. It will be reused to solve another new product problem in the future to make the process become more sustainable. However, designer also has an option to revise the solution before save it into the library by modifying the environmental impact proposed by ECO-CBR with the actual value from SolidWorks. It is purposely to improvise the solution by having the most accurate environmental impact from SolidWorks. This revised solution, which retained into the library called a case learning.

ECO-CBR tool assists designers to forecast the environmental impact at the early stage of product design. Based on the proposed solution, it helps the product designers to plan well the future of one particular product before the product manufactured. Indirectly it could help to solve the issues of improper waste management and pollution that come from products dumping.

One of the functions in ECO-CBR tool is to allow

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product designers to alter the product description in order to see the consequence impact. If the proposed solution deemed inappropriate, the solution can be revised to improve the accuracy result based on the evaluation. The revised solution called as case learning. The accurate result will be stored in the library and will be used in the future to solve any potential product design problems. This function has a potential to reduce the risk in repeating the same mistake done in previous activities. Eventually, the cases in the library will be increased and this feature is useful in addressing the problem of collecting LCA data, which is costly and time-consuming.

## 6. Conclusion

This paper proposed a framework to provide environmental impact solution in the early stage of product design. In ECO-CBR, past experiences in the sustainable product design process have been reused in order to solve new potential product design problems. Besides, the tool also has the capacity to evaluate product sustainability through its environmental impact assessment in the solution provided. The model works as an essential guideline to reduce repeated mistakes in the product development process and helps the designers to measure risks to make ideal decisions. Minor errors that occur through the study showed that ECO-CBR is reliable and this model is able to find a better solution.

## 7. Future Work and Recommendation

There are a few limitations in this study. ECO-CBR tool provided the environmental impact solutions throughout the entire product lifecycle. However the case study used in this research, required no energy consumption during the use phase. For future improvement, attributes in similarity calculation during the use phase need to be identified.

Moreover, the material used for the case study involved a single type of material. To enrich the tool functionality, it should be able to support a product produced from combination of different materials.

Additionally, the product tested in the case study is a simple product. Therefore, in order to see more consequence impacts in sustainability factor, the future tool should be able to cater a complex invention, which consists of product integration and assemble with complex parts of others products.

Finally, for commercialization purpose and upgrading the market value, the interface and visual of the tool should be improvised and a few functions should be added into the system; for example, a function for uploading LCA data into the database.

### Acknowledgement

The research reported in this study is conducted by the researchers at University Malaysia Pahang (UMP), it is funded by RDU190116 grant. The researchers would like to thank UMP for supporting this research.

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