

Carbon Footprints Calculator for Construction Industry with Case-based Reasoning

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Abstract. This project aims to calculate carbon emission level for construction activity in Malaysia by developing a carbon footprint calculator to determine the amount of carbon emission per square feet of a building in unit of tonne. The carbon emission level can be reduced through better selection and combination of construction materials. The case-based reasoning functionality embedded in the system provides user options to review past similar projects and reuse the solution for the new project to be constructed.

Keywords—component; carbon footprint calculator; embodied carbon; construction

1. Introduction

Carbon footprint is the total amount of Greenhouse Gases (GHG) emissions caused directly and indirectly by a person, organization, event or product [1]. The primary GHG in the atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone [2]. The most significant GHG is the carbon dioxide (CO₂), which accounting for over 50% of the Greenhouse effect [3].

Malaysia is ranked 30th in the world for countries that has the largest amount of carbon emission [4]. Construction industry alone contributes 24% of the country's total carbon dioxide [5]. CO₂ is released throughout the various stages in construction. This project focuses on the CO₂ emission released by materials of the building which is also known as embodied carbon.

Several efforts taken by individuals and organizations to increase awareness of this issue have not remained unnoticed. Former Vice President of America, Al Gore's documentary entitled the 'An Inconvenient Truth' which highlighted global warming issues and human's destruction towards mother earth has gained public attention and instilled a sense of awareness in individuals towards preserving the earth [22]. With a more concerned society that is eager to support this cause, some tools are now available to help calculate carbon emission at household or organizational level. The most popular and widely used is the Carbon Calculator.

This project aims to develop a Carbon Footprint Calculator and a database system that can record, calculate and summarize various projects' Carbon Footprint. The calculator is equipped with Case- Based Reasoning functionalities that can retrieve the most similar projects, reuse the project's solution (selection of material), revise the proposed solution and retain the new solution as part of the database.

This project focused on developing a software for the construction industry within Malaysia only. The embodied carbon values used in this project are not localized. The values are taken from the Inventory of Carbon and Energy (ICE) [6], which is a research conducted by two researchers from Bath University, UK to determine the carbon, energy and density of construction materials within the scope of UK and Europe.

2. Literature Review

2.1. Carbon Footprint Increase in Malaysia

There was a 38% increase in the unit number of housing stock during 2001 to 2007 and it has become a trend to use concrete which has a high percentage of embodied carbon as a structural material [7]. The author in [8] states that 10% of embodied carbon can be reduced if low impact materials are used as substitutes. However, materials must be compared on a functional unit basis [6]. That is, two materials can only be compared for a set of purpose and in this case, the purpose is construction of a whole building.

2.2. Energy Consumption, Carbon Emission and Embodied Carbon

Three categories of energy consumption in relation to buildings and construction materials are energy in use, embodied energy and inherent energy [9]. Energy in use refers to the energy required by occupants of a building such as water heating and lighting. Embodied energy of a building is the total energy required to construct the final product (material) which includes activities such as acquiring raw materials, process and manufacture, transporting to site and assembling. The last category is inherent energy, which is the release of chemical energy contained within a material through combustion or chemical processing. All the mentioned activities consume energy and in return emit carbon.

Hammond and Jones in [6] state that it is a common practice to specify embodied energy or carbon as 'Cradle to Gate' (from acquiring raw material until leaves the factory) because the boundary condition is the most commonly specified as compared to 'Cradle to Grave' (from acquiring raw materials until perishes) which lack complete consensus on the boundary conditions.

2.3. Carbon Footprint Calculator

Carbon Footprint Calculator is a website that allows users to enter information about their lifestyle application, such as what type of car they drive, the size of home they live in, and how often they travel by plane [10]. This information is then used to give people a rough estimate of carbon footprint by summing up the average amount of carbon dioxide (or carbon dioxide equivalents when including other greenhouse gases) produced and recorded in a particular activity.

There are few existing Carbon Footprint calculators for the construction industry available online or can be downloaded in the form of spreadsheet. The programme spreadsheet calculators can be downloaded from [11] and [12]. These calculators however poses some flaw as they lack user-friendliness, too complicated to use, the type of material available are slightly different from the local scope and absence of analysis functionalities. There is also an online calculator named CarbonCalculated [13]. This calculator however is for personal use and requires a fee for multiple users. Most of the materials in the Malaysian construction industry are measured in m^3 thus this poses some difficulty as the unit used in the website are in tonne and kg.

2.4. Case-Based Reasoning

Case based Reasoning (CBR) was inspired due to domain experts' inability to externalize their knowledge into a set of rules to solve the problem domain [14]. Case Based Reasoning is a continuous cycle which involves 4 crucial steps such as in [15]:

1. RETRIEVE (find similar problems)
2. REUSE (reuse proposed solution)
3. REVISE (adapt and repair proposed solution)
4. RETAIN (integrate in case base)

There are various retrieval technique used in CBR namely Nearest Neighbor Retrieval and Inductive Retrieval.

a) *Nearest Neighbor Retrieval*

Nearest Neighbor Retrieval retrieves the most similar cases using weighted sum distance function. This concept is applied in CBR through distance calculation of the cases' various features. Degree of similarity is between 0 and 1, 1 being identical. Therefore, similarity of each feature is 1 subtracted by the distance. The formula based on [16] is as follows:

$$\text{similarity}(\text{Case}_I, \text{Case}_R) = \frac{\sum_{i=1}^n w_i \times \text{sim}(f_i^I, f_i^R)}{\sum_{i=1}^n w_i} \quad (1)$$

Based on (1) w_i is the importance weight of a feature, sim is the similarity function of features, and f_i^I and f_i^R are the values for feature i in the input and retrieved cases respectively.

b) Inductive Retrieval

This retrieval technique decides which features do extremely well in differentiating cases and generates a decision tree structure to organize the cases in memory [17]. In deciding the most likely outcome, this technique will traverse the decision tree constructed earlier based on past cases using features of the new case.

2.5. Related Work

CBR-Works is a similarity calculation tool or software that is used widely in various applications [15]. Based on this tool, features are further categorized as unordered symbols, ordered symbols, numbered, intervals, strings and taxonomy.

c) CBR in Construction

A CBR prototype was developed in [18] using the CBR- Works tool mentioned previously. The application which operates within the CBR-Works addresses waste of building material in the domain of construction management. The tool allows users to define the types of each attribute which will be used in the similarity calculation later on. Cases in the form of data sheet are fed into the system to form the case base.

Rezgui et al [19], describe the implementation of CBR in COMMIT which is an on going project that aims at providing information management support in the context of distributed collaborative construction engineering. The project aims to solve the problem of determining process specification in construction projects. This is due to the fact that implemented processes are commonly different than what is specified or intended as it is prone to changes.

d) CBR in Education

There is a CBR-learning tool known as SAM (for structures and materials) developed in [20]. This tool can provide assistance to users in the identifying relevant design cases and the modification of a case for the new design problem. In SAM, designs are represented as cases and CBR is represented as a design process. New design problems are provided as the criteria in searching for a design solution. Student's interaction with SAM allows them to direct their own learning in the context of a design problem in architectural science.

3. Methodology

This project adopts the prototyping methodology system development life cycle and is divided into 4 distinct phases. This methodology starts with the planning phase and continues to iterate from phase 2 until phase 4 which are the analysis, design and implementation phase until the prototype is ready for use. Key Project Activities is shown in Fig. 1.

Phase 1: Identify Need for Carbon Footprint Calculator and It's Long Term Benefit.

Phase 2: Review Current Existing System, Identify Suitable Method of Calculation, Formulas and CBR Technique.

Phase 3: Draw Diagrams, Design Interface and Storyboard and develop prototype.

Phase 4: Develop Database, Create Interface, and Integrate Interface with Database and Testing.

Figure 1. Project Activities

4. Results & Discussion

4.1. Carbon Emission Calculation

The formula for calculating each material's carbon emission, derived from [6] is defined as the quantity of x material measured in m^3 needs to be converted into its equivalent kg value and multiplied by the Embodied Carbon - $Kg CO_2/kg$ per x material. The embodied carbon values are retrieved from the inventory in [6]. The formula is as follows:

$$CO_2Emissions\ x(kg) = Quantity\ x * Density\ x * Embodied\ Carbon\ x\ Kg\ CO_2/Kg \quad (2)$$

The final desired output is carbon per meter square feet in tonne as comparisons between buildings can only be made in terms of carbon emitted per square feet of the buildings. To calculate this, the total amount of carbon emission for a particular project or building is divided by the total build up area of the building. The total build up area of a building is equivalent to area by number of story. The formula to calculate this is as describe in (3):

$$tCO_2 / m^2\ ft = \frac{\sum CO_2\ Emissions}{TotalBuildupArea} * 0.001 \quad (3)$$

4.2. Case- Based Reasoning Retrieval (Calculating Similarity)

As this project follows the Nearest Neighbour Technique, the weighted sum distance function is used to calculate similarity between cases. The overall similarity calculation is based on the technique proposed in [16]. Different feature types however have different calculation method. The following formulas describe the distance function for numeric features (4) and symbolic features (5) as derived from [15].

$$d_f(p,c) = |p - c| / (max\ diff) \quad (4)$$

$$d_f(p,c) = 0\ if\ p = c\ otherwise; = 1\ or\ dis \quad (5)$$

Based on (4) and (5), d is distance between the new and old case, f is the features for comparison, p is the problem or new case, c is old case, $max\ diff$ is the maximum difference of a particular feature and dis is the prefixed distance between values of a feature . Each feature's similarity is calculated based in the (6) where sim is similarity. After each individual feature's similarity have been calculated, then it proceeds with the weighted sum distance function as described earlier.

$$sim_f(p,c) = 1 - d \quad (6)$$

The features of the project's system cases that are used in representing and retrieving cases are tabulated out in Table I below:

TABLE I. CLASSIFICATION OF FEATURES IN CBR

Feature	Example	Category
Type	School, Office, Hospital	Taxonomy
Rise	High, Medium, Low	Ordered Symbol
Storey	1-8	Numeric
Area	1000 – 10000	Numeric
CO2/m2	0-1	Numeric

Taxonomy is conducted on 'type' feature with the help of a civil engineering expert and the result is as listed in Table II. Similarity values of each type within the same category are valued 0.7 with the exception of Religious Category which the expert placed a value of 0.5 due to some obvious dissimilarity in their usage and function.

TABLE II. TAXONOMY OF TYPE FEATURE

Category	Feature			
Commercial	Office	Shop Mall	Shop Lots	Supermarket
Residential High	Hotel	Apartment	Dormitory	Condominium
Residential Low	School	University	College	

Category	Feature		
Industrial	Factory	Power Plant	
Religious	Church	Mosque	Temple

The expert has also identified the similarity values between each category of the taxonomy. The feature listed under a particular category will inherit the similarity values of its parent. Table III lists the similarity values between the different categories.

TABLE III. SIMILARITY BETWEEN CATEGORIES

Feature	Example	Category
Commercial	Residential High	0.5
	Residential Low	0.5
	Educational	0.5
	Industrial	0.3
	Religious	0.2
Residential High	Residential Low	0.7
	Educational	0.5
	Industrial	0.3
	Religious	0.2
Residential Low	Educational	0.5
	Industrial	0.3
	Religious	0.2
Educational	Industrial	0.3
	Religious	0.2
Industrial	Religious	0.1

4.3. Case- Based Reasoning Model

The CBR model of the system is illustrated in Fig.2. This model shows the interaction between the system, database (case-base) and users. The CBR cycle starts off with users identifying the feature value of the new case to be compared with the case base. The system then retrieves the most similar cases for the users to select from. After selection, users reuse the case and revise through the Carbon Footprint Calculator. The system then retains the new case with its revised solution.

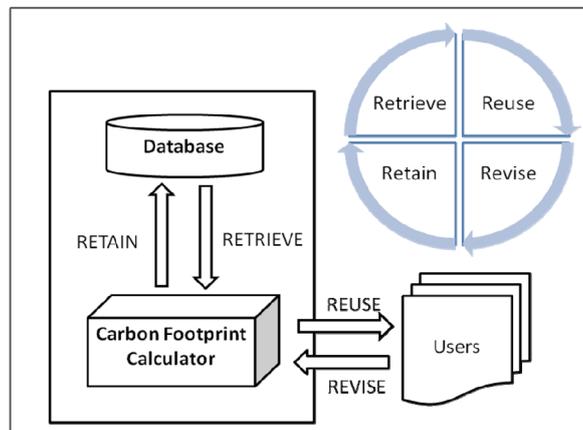


Figure 3. Case- Based Reasoning Model

4.4. System Interface

The following figures are some of the forms of the system. Fig. 3 is the ‘Contract Form’ which store the details of a project. Fig. 4 is ‘Input Form’ where the purpose, quantity, width, length, type and rate of a particular sub-material is recorded. The ‘Summary Form’ in Fig. 5 summarizes all the carbon emission based on each major material and lastly, the case-based reasoning form in Fig.6

SITE ORGANIZATION

Architect:

Project Manager:

Asst. Project Manager:

Consultant:

Contractor:

Quantity Surveyor:

TYPE

Type of Construction:

Storey:

Rise:

Width: X Length:

Area:

SIMULATION

SUMMARY

SITE ORGANIZATION

Contract No:

Contract Details:

Location:

Date:

Approved By:

FILLING INFO

Reference No:

Filling Location:

Figure 4. Contract Form

SUPERSTRUCTURE | **SUBSTRUCTURE** | **ARCHITECTURE** | **SUMMARY**

summary | cement | concrete | steel | timber | glazing

Purpose	Submaterial	Width	Height	Thickness	Unit	Quantity	Rate
Sides of column	Glue Laminated timber	1.00	5.00	1.00	kg	1	1.00
Sides of stiffener	General Timber	2.00	1.00	1.00	m3	1	6.00
Sides and soffit of suspended beam	General Timber	3.00	1.00	1.00	m3	1	238.39
To soffit/ floor slab	Glue Laminated timber	2.00	2.00	2.00	kg	1	45.60
Fascia Board	Plywood	1.00	1.00	2.00	kg	50	23.40

Figure 5. Input Form

SUPERSTRUCTURE | **SUBSTRUCTURE** | **ARCHITECTURE** | **SUMMARY**

MATERIAL	QUANTITY	RATE	CO2
cement	91	\$10,825.66	18947.47
concrete	132	\$83,110.09	0.44
glazing	2	\$2.00	14.82
plastic	24	\$544.28	60.72
steel	7	\$597.02	49.59
tile	2468	\$60,442.50	43666.49
timber	55	\$4,916.88	1438.25

CO2/m2:

Figure 6. Summary Form

Project Criteria

Type:

Rise:

Storey:

Area:

CO2/m2:

Similarity Analysis

Type	Rise	Storey	Area	CO2/m2	Similarity
Semi-D	High	5	6378	0.456	0.92228
Linked House	Low	7	5616	0.712	0.79292
Linked House	High	6	3108	0.691	0.79324
Linked House	High	5	3200	0.682	0.89954

Figure 7. CBR Form

4.5. Result And System Testing

e) CO_2/m^2

The system was tested using data of a Corner Double Storey House and an Intermediate Double Storey House. The average tCO_2/m^2 for both projects is 0.71. This is considered relatively high when compared to the average house carbon emission in UK and USA which is 0.404 based on the study conducted in [21]. The

system's calculation accuracy is tested against manual calculation using spreadsheet and the results are identical.

f) Case- Based Reasoning Retrieval Output

The system's CBR function is tested against 4 cases (dummy data). The result of the testing is described in Table IV. The system is tested for accuracy by setting the attribute values of the new case's (Case x) values exactly the same as Case 1 in the database. The system's calculation is accurate as it produced an accuracy of 1 for Case 1.

TABLE IV. SIMILARITY BETWEEN CATEGORIES

Features	Case x	Case 1	Case 2	Case 3	Case 4
Type	Semi-D	Semi-D	Linked -House	Linked-House	Bungalow
Rise	High	High	Low	Medium	Medium
Storey	3	3	1	2	1
Area	6578	6578	5616	5106	8280
CO ² /m ²	0.456	0.456	0.712	0.691	0.682
Similarity		1	0.703	0.725	0.692

5. Conclusion

The Carbon Footprint Calculator is able to calculate the carbon emission for materials used by construction firm. With the assistance and guidance from the Carbon Footprint Calculator, construction firms can now calculate the carbon emission of their activities. With this information, firms can make a better and more informed decision in material selection to reduce the carbon emission level.

The result of functional testing for case-based reasoning functionalities proves that it can calculate the similarity between old and new cases. This would also help building construction firms to reuse past project's material combination solution and make necessary revision based on the needs of the current project.

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