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Minimization of Embodied Carbon Footprint from Housing Sector of Malaysia

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The reduction in embodied carbon footprint is one of the major concerns in the construction industry. Among many other adopted techniques, the use of recycled materials is one of recommended method to lower the environmental effects of construction materials. However, the potential of recycled materials to offset the embodied carbon footprint from conventional Malaysian housing construction requires to be evaluated. The main focus of study was to perform a comparative analysis for minimization of embodied carbon footprint from the conventional materials used Malaysian housing industry by using recycled materials. A typical double story semi-detached house commonly constructed in Malaysian tropical climate was selected as case study. The model of the house was generated in a virtual environment using Building information modelling (BIM) process. The results highlighted that with incorporation of recycled materials within a range of 0 % to 100 %, the embodied carbon footprint offset potential varied up to 18 % as compared to conventional construction.

1. Introduction

In addition to the capture and disposal, the reduction of CO_2 emissions is one of the biggest challenges of future (Muazzam et al., 2013). The construction materials are one of the major sources of carbon footprint in execution phase of construction projects known as “embodied carbon footprint”. A handsome quantity of fossil fuels and energy is utilized to transform the ore form of the materials found in the natural environment to achieve the final shape to be used in any construction activity. Such transformation ultimately affects the environment in terms of embodied energy or embodied carbon footprint of these construction materials. The environmental effects of embodied carbon energy or footprint have been studied by many researchers. Different researchers have adopted various methodologies and solutions to lower down the effect of emissions. The use of alternate and recycled materials have been adopted and proposed by different researchers as one of the effective methods to lower the embodied carbon footprint. According to Yeheyis et al. (2013), recycling means separating, collecting, processing, marketing and ultimately using a material that would otherwise have been thrown away. Among multidisciplinary approaches, Asif et al. (2007) highlighted use of alternate construction materials. Thormark (2002) observed the recycling potential of materials in dwelling for reduction of environmental effects from construction. The use of recycled materials was adopted to offset the embodied carbon footprint from the conventional housing construction in Malaysian tropical climate in current study. The study aimed to evaluate the “embodied CO_2 offset” potential of recycled construction materials. A double storey semi-detached house was selected as a case study and developed in a virtual environment using Building information modelling (BIM) technology. Different percentage combination of recycled materials with the conventional construction materials were adopted to observe the trend in reduction of carbon footprint. The study highlighted that by replacing the convention construction materials with recycled materials in a double storey housing unit, an offset/reduction of 18 % in embodied carbon footprint was achieved.

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2. Literature Review

Recycled materials in construction have been a constant concern of the environmental studies for various researchers. Scheuer et al. (2003) assumed the recycling of materials like concrete, concrete masonry units, mortar, brick, granite, ceramics, all metals (steel ducts and pipes, structural steel, duct iron pipes, aluminium window frames), ceiling tiles in their study. Blengini and Di Carlo (2010) quantified the decrease in life cycle impacts of some materials by adopting the recycling potential as an effective tool. Similarly, Zabalza Bribián et al. (2009) reported that adoption of recycling is necessary to reduce the environmental burden associated with materials embodied in a building. Table 1 details the work of some other researchers using recycled materials to offset the CO_2 emissions in different parts of the world.

Table 1: Some previous studies adopting recycled materials for reduction of carbon footprint

Researchers	Findings
Thormark (2002)	Recycling potential range 35 to 40 % of embodied energy
Yu et al. (2011)	11.0 % reduction of the embodied energy (carbon) for the use of recycled building materials and 51.3 % for recycling of construction / demolition waste,
Nasir Shafiq et al. (2015)	24 % reduction in embodied carbon footprint

3. Research Methodology

The methodology followed for the research case study has been detailed graphically in Figure 1:

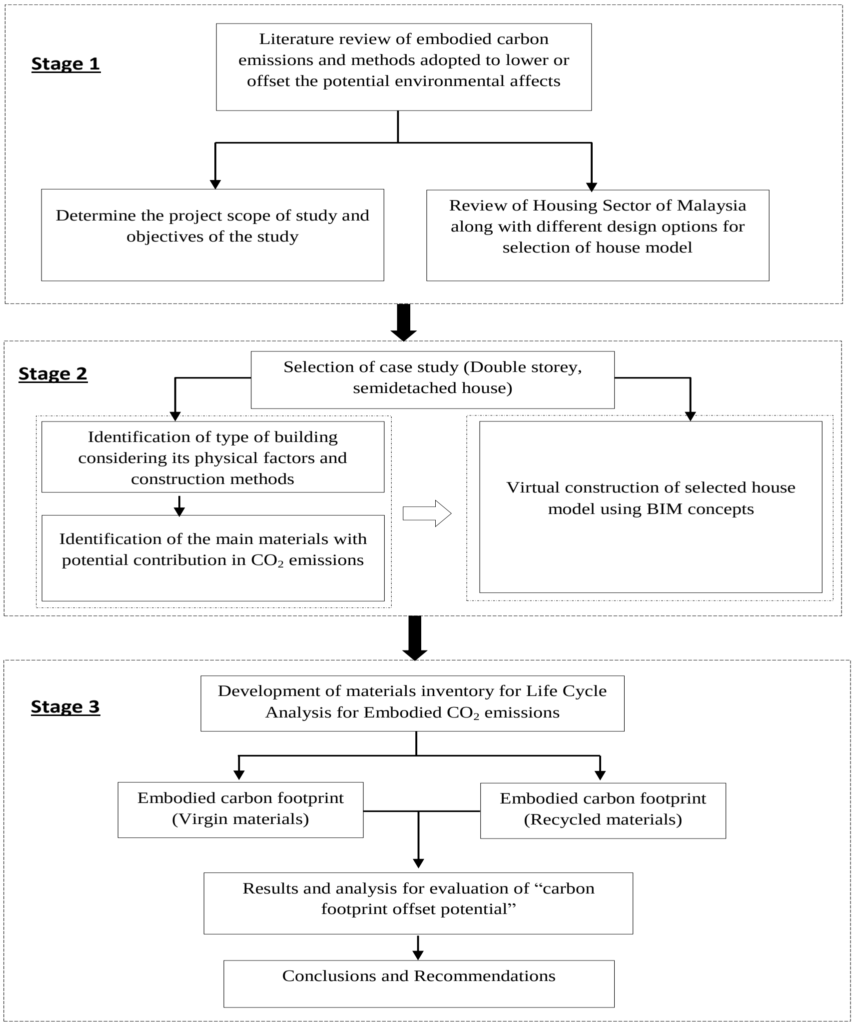

Figure 1: Graphical representation of research methodology

4. Case study details

A four bed room, double storey, semi- detached house constructed conventionally in Malaysian tropical region was selected as a case study. The virtual model of the house was developed using Building Information modelling (BIM), shown in Figure 2. The area of house was 409 m^2 and type of structure was reinforced cement concrete (RCC). Life Cycle Analysis (LCA) methodology was used to calculate the carbon footprint with boundary limitation of “Cradle to gate”. However, transportation was not included.

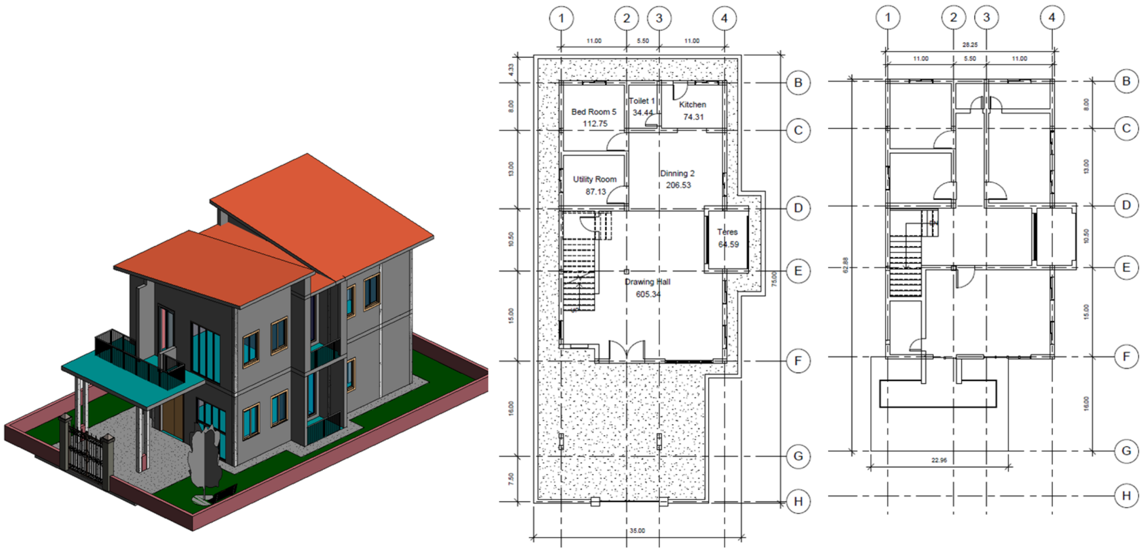

Figure 2: Virtual model of case study using building information modelling

5. Results and discussions

The quantities of the materials resulting from the virtual model of the housing project along with their units are given in Table 2:

Table 2: Quantity of materials from housing project

Description of material	Unit	Quantity
Aluminum	m^2	44.60
Bricks	m^3	107.42
Concrete	m^3	95.88
Ceramic Tiles	m^2	523
False Ceiling	m^2	254.44
Glass	m^2	46.08
Mild Steel	kg	2,445.75
Paint	m^2	434.61
Plaster	m^3	11.04
PVC Doors Panels	m^2	5.20
Steel Rebar	kg	6,297.56
Wood	m^2	20.34

The quantities of construction materials were converted into a standard unit of measurement “weight” to achieve the carbon footprint of these materials having different units. In first cycle of calculations, the carbon footprint or the conventional materials was quantified. In the 2nd cycle, recyclable materials replaced the conventional ones and carbon footprint was re-quantified by incorporating different percentage combinations (05 nos.) of recycled materials i.e. 25 %, 50 %, 75 %, 90 % and 100 %. The carbon footprint was achieved by adopting the standard embodied carbon emission factor published in Inventory of Carbon & Energy, ICE (Hammond and Jones, 2008) and resulting embodied carbon footprints are presented in Table 3:

Table 3: Carbon footprint (kg CO_2) from various percentages of recycled materials adopted

Description of materials	0 % Recycle (Virgin form)	25 % Recycle	50 % Recycle	75 % Recycle	90 % Recycle	100 % Recycle
Aluminium	1,255.41	995.59	735.78	475.96	320.07	216.15
Bricks	32,178.91	32,178.91	32,178.91	32,178.91	32,178.91	32,178.91
Concrete	31,611.54	31,611.54	31,611.54	31,611.54	31,611.54	31,611.54
Ceramic Tiles	6,534.59	6,534.59	6,534.59	6,534.59	6,534.59	6,534.59
False Ceiling	1,115.15	1,115.15	1,115.15	1,115.15	1,115.15	1,115.15
Glass	1,106.56	1,106.56	1,106.56	1,106.56	1,106.56	1,106.56
Mild Steel	2,918.02	2,304.03	1,690.04	1,076.05	707.65	462.06
Paint	486.34	486.34	486.34	486.34	486.34	486.34
Plaster	4,143.16	4,143.16	4,143.16	4,143.16	4,143.16	4,143.16
PVC Doors Panels	95.65	95.65	95.65	95.65	95.65	95.65
Steel Rebar	16,877.46	13,319.34	9,761.22	6,203.10	4,068.22	2,644.98
Wood	200.90	200.90	200.90	200.90	200.90	200.90
Carbon footprint (kg-CO_2)	98,523.69	94,091.76	89,659.83	85,227.91	82,588.75	80,795.98

The percentage contribution of each material on individual basis has been graphically represented in Figure 3. The results highlighted that recyclable metals (steel rebar, mild steel and aluminium) were among the top three contributors of the carbon footprint in the virgin form. Bricks contributed 33 %, concrete 32 % whereas the recyclable metals contributions were 21 %. It was also observed that almost 86 % of total embodied carbon emissions were contributed from these three major types of materials and rest 14 % from other materials. However, when different combinations of recycling contents were adopted, the percentage contribution of metals in cumulative carbon footprint for each of case scenario reduced from 21 % to almost 4 % for the whole study.

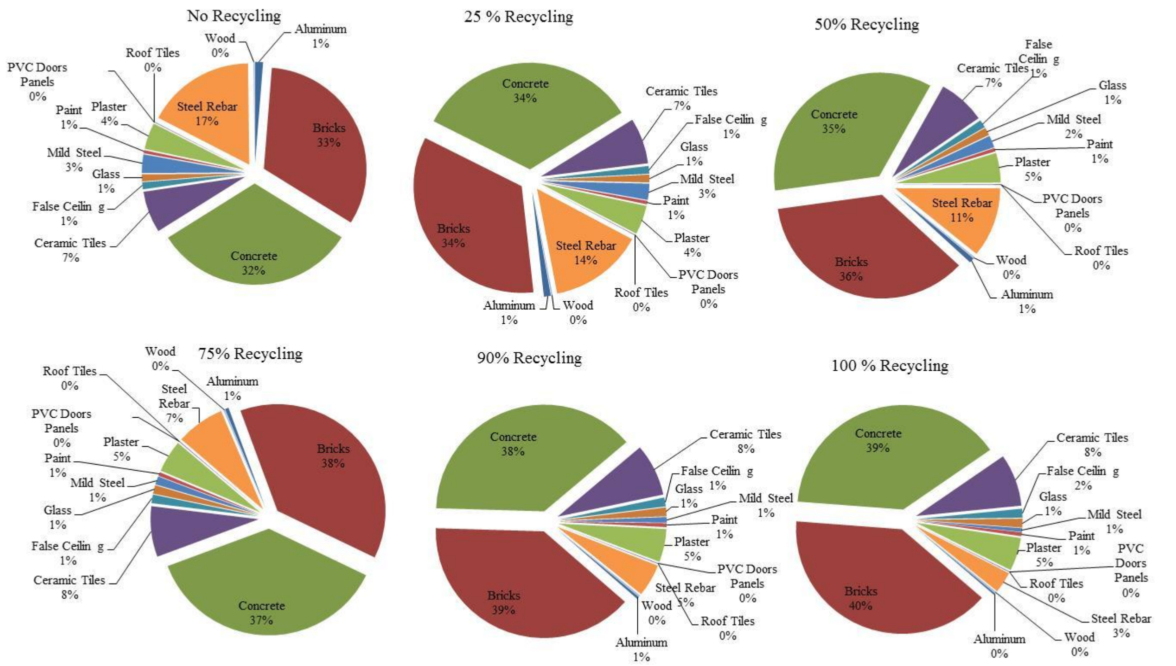

Figure 3: Percentage contributions of materials in carbon footprint for different scenarios adopted

The contribution of each of the recyclable materials has been shown graphically in Figure 3. It was observed that the incorporation of recycling reduced the CO_2 emission of steel rebar by 14.23 t CO_2, mild steel by 2.60 t CO_2 and 1.04 t CO_2 for aluminium metal. The reduction observed for individual has been shown in Figure 4

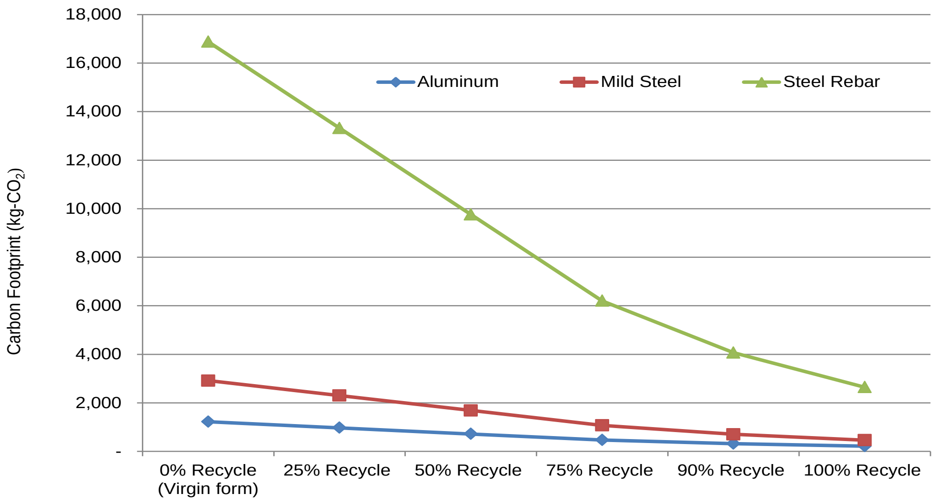

Figure 4: Graphical representation of CO_2 reduction by recycled materials on individual basis

The results highlighted that the carbon footprint reduction is directly proportional to the percentage content incorporation of recycled materials. In other words, as the content of recycled materials was increased, the cumulative carbon footprint of the housing project projects was reduced. The same trend has been shown graphically in Figure 5. The value of R^2 in the trend line was very significant i.e. near to 1 which means that there was a strong correlation between the reduction in carbon footprint and quantity of recycled materials used.

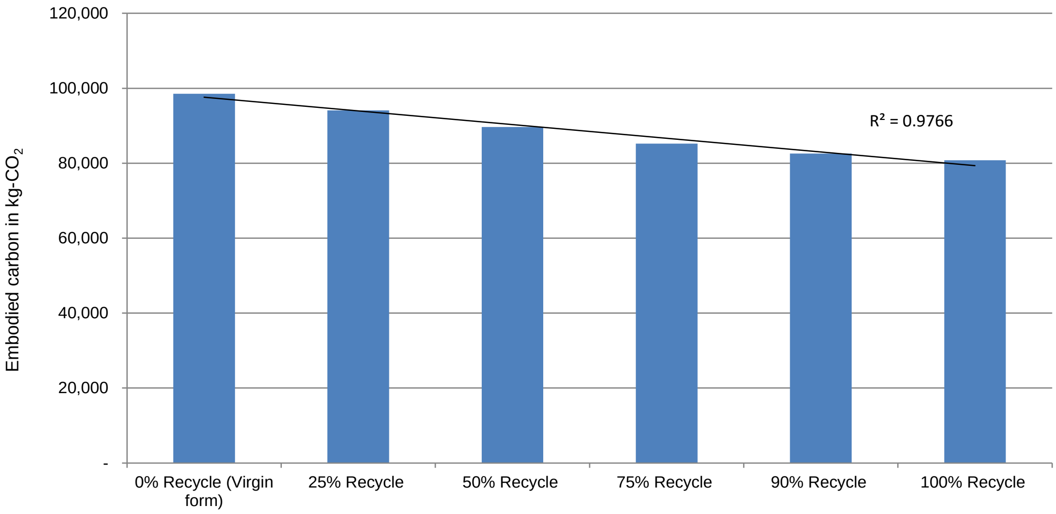

Figure 5: Reduction trend in carbon footprint w.r.t changing percentage of recycled materials

The detail of reduction in overall carbon footprint for each of the adopted scenarios has been detailed in the Table 4

Table 4: Carbon footprint reduction potential of recycled materials

Recycling (%)	Reduction in carbon footprint (%)	Carbon footprint / unit area(kg CO_2/m^2)
0 (virgin form)	-	241.00
25	4.50	230.13
50	9.00	219.37
75	13.5	208.50
90	16.19	202.04
100	18.00	197.62

The study achieved a reduction between the ranges of 4.5 % to 18.0 % where the content of recycled materials varied from 25 % to 100 %. In other words, a maximum reduction of 18 % resulted from the housing project when 100 % recycled materials were incorporated for conventional construction materials. The carbon footprint on unit area basis reduced from 241 kg CO_2/m^2 to 197.62 kg CO_2/m^2.

6. Conclusions and Recommendations

The study highlighted the utilization of recycled materials in conventional construction bears good potential for reduction of embodied carbon footprint in housing sector of Malaysia. The outcomes of the study are summarized as below.

- The embodied carbon footprint of conventional house is possible to be reduced by incorporation of recycled materials in conventional hosing construction.
- Maximum 18 % of reduction was achieved with utilization of 100 % content of recycled materials.
- The carbon footprint reduction ranged from 4.5 % to 18.00 % where the content of recycled materials varied from 25 % to 100 %.
- The carbon footprint on unit area basis reduced by 43.40 kg CO_2/m^2.

For future studies, the number of case studies shall be increased to predict a standard trend in carbon footprint reduction of such construction projects.

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