# Assessment and Reduction of Carbon Footprint of Constructed Model by Proportional Carbon Emission Calculations

by

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Dissertation submitted in partial fulfillment of
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Bachelor of Engineering (Hons)
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# CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

(Assoc. Prof. Dr. Amirhossein Malakahmad)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein has not been undertaken or done by unspecified sources.

(NUR ARINAH BINTI HISHAM ALBAKRI)

# ABSTRACT

Global attention to carbon emissions that are perturbing the environment causing grievous global warming and associated consequences is turning to an individual's contribution or "carbon footprint". Carbon footprint is commonly expressed as the total amount of greenhouse gases (GHG) produced directly or indirectly as a result of an activity. It has become an indicator for sustainable development in numerous sectors including the construction industry. While there have been several studies documenting calculators that estimate the carbon footprint of individual activities, the literature describing the process of carbon footprint calculations for construction industry remains limited. In the effort to reduce the carbon footprint of a constructed model, this project presents a tool developed by the Environment Agency that assesses the carbon footprint via proportional carbon emission calculations. The carbon calculator relies on primary data collected from a construction project and three components of a constructed model; wall, floor and column. The carbon footprint of the construction project and the materials used for each component of the constructed model are then assessed thoroughly. Consequently, construction materials such as green concrete, green brick, cement brick and bamboo play an important role in reducing the total carbon footprint of a project with carbon emissions of 1.8 $tCO_2e$, 3.6 $tCO_2e$, 3.2 $tCO_2e$ and 0.2 $tCO_2e$ respectively. In addition, a set of guidelines based on Best Management Practices (BMP) is established to be adopted in construction sites with the aim to reduce the carbon emission significantly.



*Keywords:* Carbon footprint; Carbon calculator; Greenhouse gases (GHG); Construction industry; Best Management Practices (BMP).

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# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# ABBREVIATIONS AND NOMENCLATURES

| | |
|---|---|
| BMP | Best Management Practices |
| C&D | Construction and demolition |
| $CH_4$ | Methane |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide equivalent |
| Defra | Department of Environment, Food and Rural Affairs |
| FRIM | Forest Research Institute Malaysia |
| FYP | Final Year Project |
| GHG | Greenhouse gases |
| GWP | Global Warming Potential |
| $H_2O$ | Water |
| HFC | Hydrofluorocarbon |
| IPCC | Intergovernmental Panel on Climate Change |
| LUCF | Land use, change and forestry |
| $N_2O$ | Nitrous oxide |
| $O_3$ | Ozone |
| PFC | Perfluorocarbon |
| PRSB | PETRONAS Research Sdn Bhd |
| RA | Recycled Aggregates |
| RCA | Recycled Concrete Aggregates |
| $SF_6$ | Sulphur hexafluoride |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USEPA | United States Environmental Protection Agency |
| UTP | Universiti Teknologi PETRONAS |
| WRI | World Resources Institute |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background

The world has witnessed a dramatic increase in environmental concerns and issues related to global climate change over the past decade, and the consequences are highly associated with emissions of greenhouse gases (GHG). As a result, industrialized nations are obliged to lower their GHG emissions according to the United Nations Framework Convention on Climate Change (UNFCCC). Specifically, since construction operations are highly energy-intensive, they account for significant environmental impacts, including emission of GHG and other engine exhaust associated with material procurement or delivery and on-site construction activities (Ahn et al., 2013). Thus, all industries including the construction industry should join the efforts to reduce GHG emissions.

The construction sector plays an essential role in improving the environment by continuing to improve the environmental performance of the country's buildings and infrastructure (United States Environmental Protection Agency (USEPA), 2009b). Due to its products' longevity, the construction industry is in a unique position to support environmental benefits both through daily job site practices and through lasting structural improvements. Hence, USEPA (2009b) defines the construction industry as the national economic sector engaged in "the preparation of land and the construction alteration, and repair of buildings, structures, and other real property".

Moreover, since the construction industry has a significant environmental footprint, especially in terms of GHG emissions and energy consumption, substantial amounts of GHG that have an indirect radiative effect are emitted from construction activities and processes such as during production, installation, maintenance, and end-of-life disposal of construction materials. According to Sacramento Metropolitan Air Quality

Management District (2013), among the most common construction activities include site preparation (land clearing and grubbing), earthmoving (grading, trenching, soil compaction, cut and fill operations including hauling of material), paving of roadway surfaces, the erection of buildings and structures, and the application of architectural coatings. Apart from that, some buildings may also entail the demolition of buildings prior to site preparation. All of which contribute to the implication of GHG emissions unless they are controlled and minimized by optimizing the utilization of construction resources. This includes the optimal utilization of the available construction crews and materials in such a way that reduces GHG emissions while minimizing construction cost and duration. For instance, if a large number of small GHG emissions sources within the construction industry were to adopt energy- and climate-conscious practices, aggregate emissions could be reduced substantially and thus, able to better address the GHG implications of increasingly popular "green construction" practices (USEPA, 2009b). Therefore, it can help designers and construction professionals in making environmentally-conscious yet cost-effective decisions during building design and construction phases.

On the other hand, carbon footprint is the total amount of GHG emissions caused by an organization, event, or product (Rahman et al., 2011). It serves as an assessment tool to measure the quantitative expression of GHG emissions from an activity. As a result, it helps in emission management and evaluation of mitigation measures (Carbon Trust, 2012). Correspondingly, having quantified the emissions, the important sources of emissions can be identified and areas of emission reductions and increasing efficiencies can be prioritized (Pandey et al., 2011). Hence, this provides the opportunity for environmental efficiencies and cost reductions. Likewise, consistency and clarity in calculating emissions are important in order to compare emissions within and across sectors, and for companies to plan and assess progress.

Consequently, the project outcome is to reduce the amount of carbon dioxide ($CO_2$) (embodied carbon in tonnes) with the intervention of green innovation. The most appropriate carbon calculator to be used in construction sites is selected via an assessment of a construction project and the efficiency of green materials of a constructed model is evaluated using the same carbon calculator. Apart from that, Best Management Practices (BMP) to be adopted in construction sites are proposed.

## 1.2 Problem Statement

Construction industry is considered as a major stimulant towards Malaysia's economy. However, it also generates large amount of not only construction waste, but demolition waste as well. In Malaysia, waste is the third highest sector emitting 35.94 $MtCO_2e$ as of 2009 just behind energy sector and land use and forestry sector which emits 194.31 and 49.97 $MtCO_2e$ as of 2009 respectively (World Resources Institute (WRI), 2011). According to Begum et al. (2009), the last two decades in Malaysia has observed extensive building and infrastructure development projects that led to an increase in construction waste generation. Moreover, in a study conducted by Mohd Nasir et al. (1998), 28.34% of waste comes from industrial and construction waste in the Central and Southern regions of Malaysia.

Similarly, due to Malaysia's rapid development in construction industry, excessive construction materials, improper waste management and lack of awareness are the common issues observed in construction sites. For instance, not all materials delivered on site are utilized extensively causing some of these materials are being constituted as part of the waste. Consequently, material wastage brings about additional cost to the overall construction project as well as a reduction in the profit of the contractor, considering the cost of storing and transporting construction waste along with the loss of revenue from not reclaiming waste (Akinkurolere and Franklin, 2005). Therefore, managing construction and demolition (C&D) waste is vital and should not be taken lightly as the environmental effects of the industry are directly related to the quality and quantity of waste it generates (Begum et al., 2009). Likewise, according to Alwi et al. (2002), C&D waste can significantly affect the performance and productivity of an organization.

Besides that, in terms of GHG emissions, Malaysia is emitting 287.32 $MtCO_2e$ as of 2010 excluding land use change and forestry (LUCF) while the total GHG emissions including LUCF is 337.29 $MtCO_2e$ as of 2010 (WRI, 2011). These values are relatively low as compared to other countries such as China, Russia and the United States of America which emits up to 10,385.54 $MtCO_2e$ as of 2010 (WRI, 2011). However, for a country with a population of 29,791,949 as of 2013 (World Population Review, 2013), the amount of GHG emissions is considerably significant.

Therefore, efforts are being made to achieve more efficient operations of buildings with a view to reduce the construction industry’s contribution to energy consumption and GHG emissions.

One of the components in such emissions is carbon dioxide, which affects climate change and thus causes global warming. Nevertheless, these emissions can be reduced significantly through C&D waste utilization which contributes to reduction of raw materials in the construction and building industry. Moreover, around 79% of C&D wastes are recyclable. Accordingly, the design optimized with respect to the carbon footprint yields a carbon footprint lower by 5% to 10% than the design optimized with respect to cost, depending upon the parameter values used in the calculations (Yeo and Potra, 2013).

## 1.3 Objectives

The main objective of this study is to assess and reduce the carbon footprint of a constructed model by proportional carbon emission calculations:

- To assess the available carbon footprint calculators and select the most appropriate calculator to be used in construction sites

- To apply the chosen calculator to evaluate the efficiency of green materials on less carbon emission

## 1.4 Scope of Study

The carbon calculator developed by the Environment Agency which is the government agency, sponsored by United Kingdom’s government, Department of Environment, Food and Rural Affairs (Defra) measures the GHG impacts of construction industry in terms of carbon dioxide equivalency ($CO_2e$). It does this by calculating the embodied $CO_2e$ of materials together with the $CO_2e$ associated with their transportation. It also considers parameters such as personnel travel, site energy use and waste management among others.

Besides that, the tool can be used to aid the selection of green construction materials at the *Optioneering* appraisal stage. It highlights where one can make big carbon savings on specific construction projects. It can also be used to assess an organization's overall carbon footprint from a construction project and identify ways to reduce it.

## 1.5 Relevancy and Feasibility

This project addresses the pressing issue of a need to assess the carbon footprint by proportional carbon emission calculations via calculating the GHG impacts of construction materials and adopting Best Management Practices (BMP) in construction sites with the aim to reduce the carbon footprint of the whole project. The author then aptly infers this to deem the project as industrially relevant.

As for the time bases, the project progressed as planned and although there were several hiccups along the way thus far, the project is able to complete as scheduled.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Greenhouse Gases (GHG)

Greenhouse gases (GHG) are necessary to life as we know it, because without them, the planet's surface would be about 15ºC cooler than present (USEPA, 2013). However, as the concentrations of these gases continue to increase in the atmosphere, the Earth's temperature is escalating above past levels. According to USEPA (2009a), the ten warmest years on record (since 1850) have all occurred in the past 13 years. Consequently, the increase in global temperature is attributed to the rising rate of GHG emissions due to anthropogenic activities. Similarly, scientists are certain that human activities are changing the composition of the atmosphere, and that increasing the concentration of GHG will change the planet's climate though they are uncertain by how much it will change, at what rate it will change or what the exact effects will be, as reported in the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011 (2013).

Based on Kyoto Protocol adopted in 1997, six types of GHG were defined, namely Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($N_2O$), Hydrofluorocarbon (HFC), Perfluorocarbon (PFC) and Sulphur hexafluoride ($SF_6$), all of which are related to global warming potentials which must be reduced. However, the most abundant GHG in the atmosphere are water vapor ($H_2O$), $CO_2$, $CH_4$, $N_2O$ and ozone ($O_3$) (Lee et al., 2011). These gases absorb some of the energy being radiated from the surface of the Earth and trap it in the atmosphere, essentially acting like a blanket that makes the Earth's surface warmer than it would be otherwise (USEPA, 2013). The process is commonly known as the "greenhouse effect". Figure 2.1.1 depicts the GHG effect schematically.

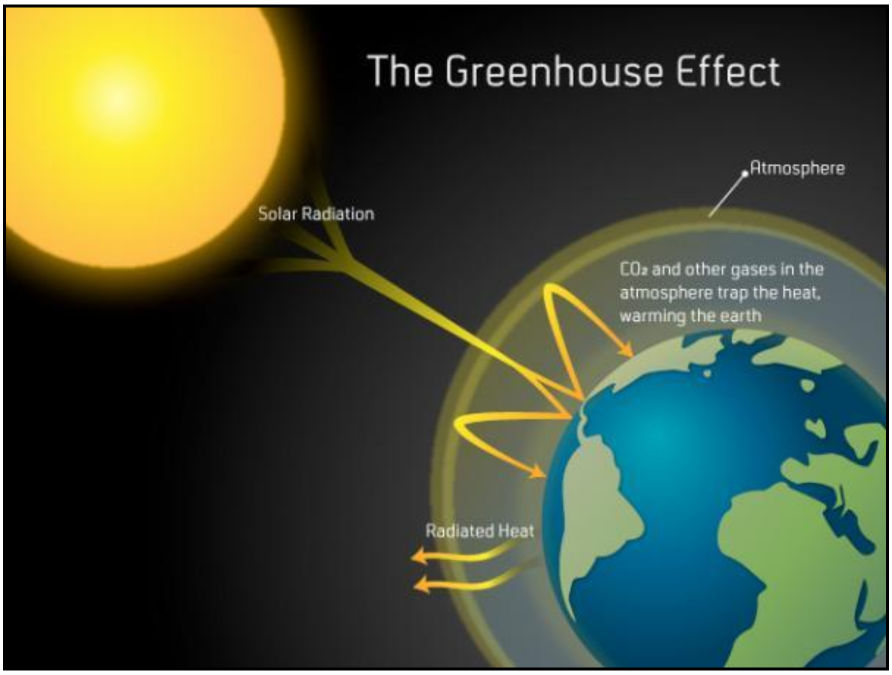



FIGURE 2.1.1. Schematic of GHG Effect

Source: http://www.pacificcarbontrust.com

Of all the GHG, $CO_2$ has the largest share, forming around 77% of total GHG (USEPA, 2013). Hence, emissions of other GHG are converted in units of $CO_2$ equivalent ($CO_2$e), using the warming potential related to each gas (Radu et al., 2013) as shown in Table 2.1.1. In addition, Global Warming Potential (GWP) concept was developed by the Intergovernmental Panel on Climate Change (IPCC) to compare the ability of each GHG to trap heat in the atmosphere relative to another gas. Similarly, the GWP of a GHG is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kilogram (kg) of a trace substance relative to that 1 kg of a reference gas (IPCC, 2001). Direct radiative effects occur when the gas itself is a GHG. Since the reference gas used is $CO_2$, thus GWP-weighted emissions are measured in $CO_2$e.

TABLE 2.1.1. Global Warming Potentials (100-Year Time Horizon)

| Greenhouse Gases | GWP (100-year) |
|---|---|
| $CO_2$ | 1 |
| $CH_4$ | 28 |
| $N_2O$ | 265 |
| $SF_6$ | 23,500 |
| $CF_4$ | 6,630 |

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011 (2013)

## 2.2 $CO_2$ Emission

Carbon dioxide is the most important gas within the context of GHG emissions. $CO_2$ is also the most abundant gas in the atmosphere and has a high calorific power (Hosseini et al., 2013). Moreover, it is the primary GHG that is contributing to recent climate change. As part of the carbon cycle, $CO_2$ is absorbed and emitted naturally through animals and plants respiration, volcanic eruptions, and ocean-atmosphere exchange. Human activities, such as the burning of fossil fuels and changes in land use also release large amounts of carbon to the atmosphere, causing $CO_2$ concentrations in the atmosphere to rise.

Furthermore, in relation to the GHG impacts in terms of $CO_2$, it is noted that construction activities as a whole consume significant amounts of energy and generate considerable levels of $CO_2$ and other diesel exhaust emissions (Ahn et al., 2013). Thus, making it the third highest contributing industrial sector for GHG emissions – ranking just behind the oil and gas sector and the chemical manufacturing sector – and accounts for 8% of total GHGs emissions from all industrial sectors (USEPA, 2013). Besides that, the atmospheric lifetime of a gas is defined as the period of time that a kg of that particular gas remains in the atmosphere before removing by chemical reaction (Hosseini et al., 2013). For instance, Table 2.2.1 tabulates the life time of $CH_4$ and $CO_2$ which is around 12 and up to 200 years respectively. Consequently, proves that $CO_2$ leaves long lifetime effects towards the Earth's inhabitants on top of being the major contributor of GHG emissions.

TABLE 2.2.1. Global Atmospheric Concentration, Rate of Concentration Change, and Atmospheric Lifetime (Years) of Selected Greenhouse Gases

| Atmospheric Variable | $CO_2$ | $CH_4$ | $N_2O$ | $SF_6$ | $CF_4$ |
|---|---|---|---|---|---|
| Pre-industrial atmospheric concentration | 280 ppm | 0.700 ppm | 0.270 ppm | 0 ppt | 40 ppt |
| Atmospheric concentration | 390 ppm | 1.750-1.871 ppm | 0.322-0.323 ppm | 6.8-7.4 ppt | 74 ppt |
| Rate of concentration change | 1.4 ppm/yr | 0.005 ppm/yr | 0.26%/yr | Linear | Linear |
| Atmospheric lifetime (years) | 50-200 | 12 | 114 | 3,200 | >50,000 |

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011 (2013)

In addition, based on Table 2.2.1, the atmospheric $CO_2$ concentrations have increased by almost 40% since pre-industrial times, from approximately 280 ppm in the 18$^{th}$ century to 390 ppm in 2010. The current $CO_2$ level is higher than it has been in at least 800,000 years (USEPA, 2013).

On top of that, over 30 billion tons of $CO_2$ is released into the atmosphere annually (National Research Council, 2010). This build-up in the atmosphere is like a tub filled with water and more water flows from the faucet than the drain can take away. Figure 2.2.1 illustrates the carbon 'bathtub' and its components according to USEPA (2013).

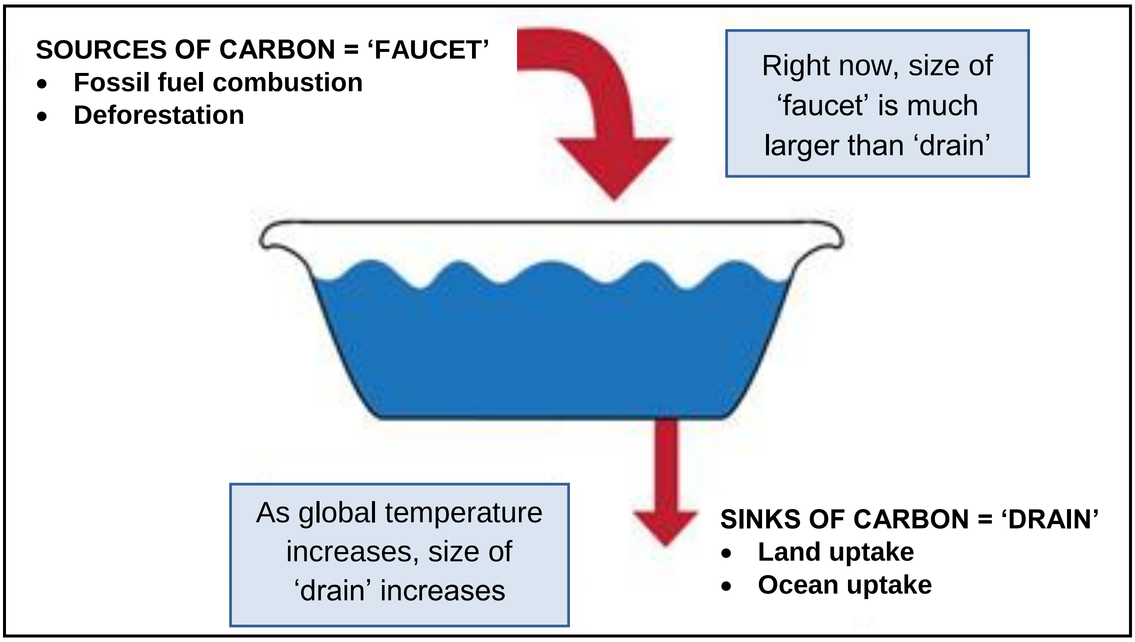



FIGURE 2.2.1. The Carbon 'Bathtub' and its Components

Source: http://www.epa.gov

Based on Figure 2.2.1, if the amount of water flowing into a 'bathtub' is greater than the amount of water leaving through the 'drain', the water level will surely rise. Relatively, $CO_2$ emissions are the flow of water into the world's carbon bathtub. Sources of $CO_2$ emissions such as fossil fuel burning, cement manufacture and land use, represent the 'bathtub's faucet' while the sinks of $CO_2$ in the ocean and on land (such as plants) that take up $CO_2$ is represented by the 'drain'. In a nutshell, anthropogenic activities have caused the flow from the $CO_2$ 'faucet' being much larger than the 'drain' can cope with as the level of $CO_2$ in the atmosphere (level of water in the 'bathtub') is rising.

## 2.3 Carbon Footprint

The term "carbon footprint" can be traced back to as a subset of "ecological footprint" (Wackernagel and Rees, 1996). According to Pandey et al. (2011), ecological footprint refers to the biologically productive land and sea area required to sustain a given human population expressed as global hectares. Therefore, based on this concept, carbon footprint refers to the land area required to absorb the entire $CO_2$ produced by mankind during its lifetime. Furthermore, the concept began to be publicized independently, referring to the impact of human activities on the environment and especially on the climatic conditions, in terms of GHG emissions; or briefly called "carbon emissions" (Radu et al., 2013). In other words, carbon footprint is a measure of an individual's contribution to global warming in terms of the amount of GHG produced by an individual and is measured in units of carbon dioxide equivalent (Lynas, 2007). Likewise, Wiedmann and Minx (2008) define carbon footprint as the total amount of GHG emissions that is directly and indirectly caused by an activity, organization and event or is accumulated over the life stages of a product. Besides that, other terms used associated or sometimes as a synonym of carbon footprint are embodied carbon, carbon content, embedded carbon, carbon flows, virtual carbon, GHG footprint and climate footprint (Pandey et al., 2011).

Consequently, with growing awareness regarding climate change, a remarkable concern over the responsibility of contributing to the emissions of GHG has grown not only among the industrialist, but in individuals as well. Thus, this led to the surge of personal carbon footprinting facilities (consultancies and online calculators) particularly in developed countries (Kenny and Gray, 2009). Similarly, according to Padgett et al. (2008), numerous websites have been created to help calculate an individual's carbon footprint, or an estimate of $CO_2$ emissions that an individual is directly responsible for over a given period of time.

Hence, carbon footprint calculation serves as an assessment tool in terms of GHG emissions and serves to manage and reduce these emissions. Its detailing helps to identify weaknesses such as areas of high emissions that can be eliminated or improved upon calculating the carbon footprint. Thus, carbon footprint is an indicator of sustainable development.

## 2.4 Carbon Calculators

On the contrary, the methodologies for carbon footprint calculations are still evolving and it is emerging as an important tool for GHG management. The concept of carbon footprinting has permeated and is being commercialized in all areas of life and economy. Correspondingly, calculators that estimate an individual's $CO_2$ emissions have become more prevalent on the internet. However, there is little consistency in definitions and calculations of carbon footprint among the studies. Since carbon footprinting is intended to be a tool to guide relevant emission cuts and verifications, its standardization at international level is therefore necessary (Pandey et al., 2011).

Carbon calculators generally work by accepting user inputs characteristic of individual behavior and by returning an amount of $CO_2$ emitted as a direct result of such behavior in the form of a user's carbon footprint (Padgett et al., 2008). Most of which, require users to input data manually. Hence, according to Rahman et al. (2011), not only that it provides a poor user experience, but it also makes the calculations less accurate. The recent rise in carbon calculators has been accompanied, however, by variation in output values given similar inputs for individual behavior. The variation in outputs may be due to different calculating methodologies or conversion factors; the calculators, however, frequently lack the level of transparency needed to understand the reasons for these variations.

In addition, Kenny and Gray (2009) observed that most of these calculators claim to be based on recommended guidelines, but rarely any two of them yield similar outputs for the same set of inputs. In a study conducted by Padgett et al. (2008), values can vary as much as several metric tonnes per annum per activity. These variations in output could influence both the types of steps individuals take and the overall level of effort.

Moreover, carbon calculators use quantitative models to estimate carbon emissions caused by user's activities. These calculators are provided by government agencies, non-governmental organizations, and private companies. Some of these carbon calculator providers also promote methods for mitigating $CO_2$ emissions through offsets or investments in renewable energy technology. Although they promote public awareness regarding carbon emission due to individual's behavior, there are concerns on the accuracy and credibility of these existing calculators as they are static and fail to take into account the dynamic behavior of human nature (Rahman et al., 2011).

As a result, numerous methodologies and models for calculating carbon footprint are developed globally. For instance, Wiedmann and Minx (2007) described two methods of calculating the carbon footprint using Life Cycle Assessment (LCA); Process Analysis (PA) and Environmental Input-Output Analysis (EIO). According to Pandey et al. (2011), LCA estimates the GHG embodied at each identified step of the product's life cycle, technically known as GHG accounting. Therefore, standards and guidance are available for GHG accounting.

On the other hand, carbon calculators reveal a lack of uniformity among calculators (Padgett et al., 2008). Similarly, as reported by Kenny and Gray (2009), there are no standards or codes of practice associated with these carbon calculators, thus, leading to potentially significant differences and inconsistencies between them. Hence, it creates a gap between its definition and its application in practice.

Consequently, this project examines 14 carbon calculators that are available online. They are segregated alphabetically according to their region, category, scope and references as tabulated in Table 2.4.1. Furthermore, these calculators provide a range of uses from personal carbon footprinting to industrialized carbon footprinting. Most of the personal carbon calculators, also known as individual calculators, include factors such as household, personal travel, public transportation and waste management. Similarly for carbon calculators that are developed for an event or organizational purposes, factors like energy consumption, public transportation and waste management contribute to the amount of carbon footprint emitted. On the contrary, industrialized carbon footprinting are done through carbon calculators that are construction industry related, for instance. Among the key parameters in calculating the carbon footprint of a construction project include the construction materials used, construction techniques, site energy consumption, transportation of materials, site accommodation and last but not least, waste management. Comparisons between all 14 carbon calculators are tabulated further in this chapter.

TABLE 2.4.1. Comparison of 14 Carbon Calculators

| Calculator | Region | Category | Scope | Sources | References |
|---|---|---|---|---|---|
| AggRegain | UK | Construction Industry | Construction Techniques, Supply Alternatives (use of primary or recycled and secondary aggregates) | ✓ | http://www.aggregain.wrap.org.uk/sustainability/try_a_sustainability_tool/co2_emissions.html |
| American Forests | USA | Individual | Energy Consumption, Personal Travel, Public Transportation, Waste Management | ✓ | http://www.americanforesam.org/discover-forests/carbon-calculator/ |
| Be Green | USA | Individual | Energy Consumption, Personal Travel, Public Transportation | X | http://www.greenmountaig.com/green-mountain-energy-company-store/carbon-calculator |
| Build Carbon Neutral | USA | Construction Industry | Building Size, Primary Structural System, Landscape, Ecosystem | X | http://www.buildcarbonnebuild.org |
| Carbon Footprint | UK | Individual | Household, Energy Consumption, Personal Travel, Public Transportation, Waste Management | ✓ | http://www.carbonfootprica.com/calculator.aspx |
| Carbon Fund | USA | Individual, Events, Organization | Household, Energy Consumption, Personal Travel, Public Transportation | X | https://www.carbonfund.oor/ |
| Chuck Wright | USA | Individual | Energy Consumption, Personal Travel, Public Transportation | ✓ | http://chuck-wright.com/calculators/cacarb.html |
| Combat Climate Change | Ireland | Individual, Organization | Household, Energy Consumption, Personal Travel, Public Transportation | ✓ | http://www.askaboutirelaas.ie/enfo/irelands-environment/Change/calccalcul-tools/ |
| Environment Agency | UK | Construction Industry | Materials Used, Site Energy Consumption, Personal Travel, Waste Management | ✓ | https://www.gov.uk/government/publications/carbon-calculator-for-construction-projects |
| Environmental Protection Agency (EPA) | USA | Individual | Household, Energy Consumption, Personal Travel, Waste Management | ✓ | http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html#c=waste&p=reduceAtHome&m=calc_instructions |
| Highways Agency | UK | Construction Industry | Construction, Maintenance, Operational Activities, Energy and Utilities, Materials, Transport, Waste Removal | ✓ | http://www.highways.gov.uk/publications/major-projects-knowledge-sharing-ha-carbon-calculation/ |
| Resurgence | UK | Individual | Household, Energy Consumption, Personal Travel, Public Transportation | ✓ | http://www.resurgence.org/education/carbon-calculator.html |
| TerraPass | USA | Individual, Events, Organization | Household, Personal Travel, Public Transportation | X | http://www.terrapass.com/calculate-carbon-footprint/ |
| The Conservation Fund | USA | Individual | Household, Energy Consumption, Personal Travel, Public Transportation, Waste Management | X | https://gozero.conservationfund.org/calc/household |

✓ denotes available sources to background calculations
X denotes no sources to background calculations

Nevertheless, Kenny and Gray (2009) suggested three elements for the selection of the carbon calculators based on the suitability of its uses in respective industries. For instance, since this project focuses on assessing the GHG impacts of construction materials in terms of $CO_2$ emissions, hence, the input required must be related to the parameters of the construction industry. The elements are as follows (Kenny and Gray, 2009):

(i) *Complexity and relevance*. The selected model needs to include as many sources of $CO_2$ as possible with relation to the construction activities, and the calculation methods are of construction activities oriented rather than business oriented.
(ii) *Reliability*. The model has to be developed by an expert team or organization with resourceful references.
(iii) *Recommendation*. The selected model is recommended or developed by a government department, state energy or environmental agency.

Therefore, based on the abovementioned elements in the selection of the most appropriate carbon calculator to be used throughout this project, four out of fourteen calculators which are of construction industry based are compared comprehensively based on each criteria tabulated in Table 2.4.2:

TABLE 2.4.2. Comparison of Four Construction Based Carbon Calculators

| Carbon Calculator | Complexity and Relevance | Reliability | Recommendation |
|---|---|---|---|
| AggRegain | • Assess the $CO_2$ output resulting from four types of construction involving aggregates; bitumen bound, concrete, hydraulically bound and unbound<br>• Access to background calculations where $CO_2$ from different processes are estimated | Developed by TRL Limited, Costain and Taylor Woodrow Technology under a contract from Waste and Resources Action Programme (WRAP) | Recommended by WRAP |
| Build Carbon Neutral | • Limited parameters of construction based project activities and specific materials<br>• Limited quantitative inputs<br>• Simplified version, easy to use and ±25% accuracy | Cooperative effort led by Mithun Architects + Designers + Planners and Lady Bird Johnson Wildflower Centre at the University of Texas, Austin with assistance from University of Washington | Has yet to be recommended by any government department, state energy or environmental agency |
| Environment Agency | • Parameters covers all of the construction industry elements<br>• Provides tips on emission reductions based on carbon intensive materials | Developed by the Environment Agency – government agency sponsored by United Kingdom's government, Department of Environment, Food and Rural Affairs (Defra) | Recommended by Defra |
| Highways Agency | • Quantify volumes of $CO_2$ in relation to its construction, maintenance and internal activities<br>• Cost-effective and efficient methods | Owned by Highways Agency (United Kingdom's government agency), Executive Agency of the Department for Transport (DfT) | Recommended by the United Kingdom's government |

As a result, to compare emissions output for specific input across carbon calculators tabulated in Table 2.4.2, a construction project of a demolition of an office building converted to a lab at PETRONAS Research Sdn Bhd (PRSB) located in Bangi, Selangor is selected as the baseline to further assess the capability and competency of all four carbon calculators prior to the selection of the most appropriate one to be extensively used throughout this project. The data collected consist of all the materials involved in the project; the quantities of the materials, the distance travelled from the source of the material to the site, mode of transportation and amount of waste produced, required to be input into the carbon calculators. Consequently, the carbon footprint of the project is assessed via all four carbon calculators; AggRegain, Build Carbon Neutral, Environment Agency, and Highways Agency. Thorough analysis and comparison of the project's carbon footprint obtained from each carbon calculator is discussed further in **Chapter 4: Results and Discussion**.

In a nutshell, based on the comprehensive analysis discussed in Chapter 4: Results and Discussion; the chosen carbon calculator used throughout this project is developed by the Environment Agency which is a government agency, sponsored by the United Kingdom's government, Department of Environment, Food and Rural Affairs (Defra). The Environment Agency (2007) developed the tool due to its broad interest in the environmental impacts associated with construction, being itself a significant construction client (its construction spend (£200 million for 2007-2008) accounts for approximately 3% of the construction in civil engineering sector). Moreover, the tool was developed with the construction parameters in mind; predominantly fluvial and coastal construction projects. Consequently, other construction clients, contractors and consultants may find it useful when assessing their own activities.

# CHAPTER 3
# METHODOLOGY AND PROJECT WORK

## 3.1 Methodology

**Objective 1: To assess the available carbon footprint calculators and select the most appropriate calculator to be used in construction sites**

As there are abundant of carbon calculators available online, the selection of the most appropriate carbon calculator is crucial in achieving the project's objectives. Hence, a thorough analysis is conducted in selecting the carbon calculator that suits the nature of the project (construction industry based) as depicted in Figure 3.1.1 below:

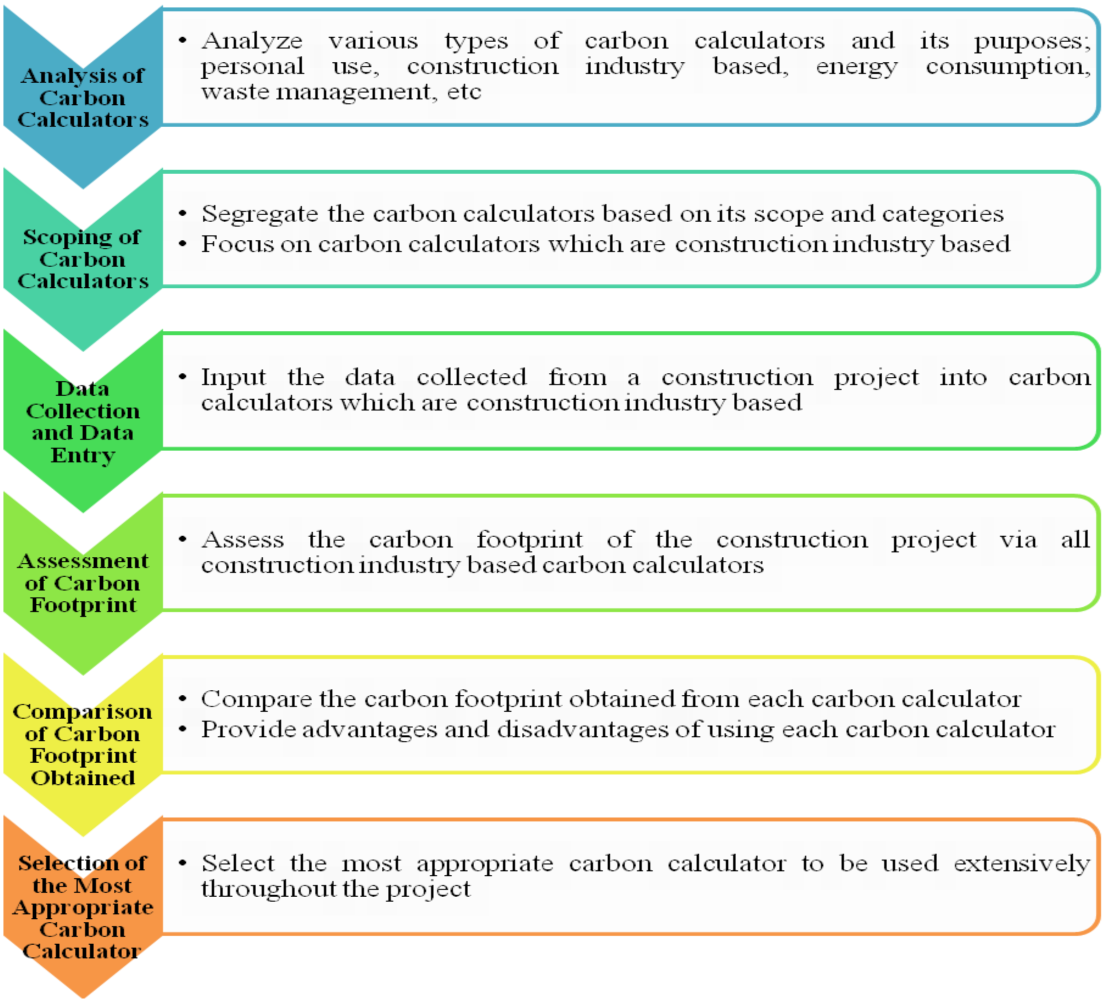



FIGURE 3.1.1. The Methodology in Selecting the Carbon Calculator

**Objective 2: To apply the chosen calculator to evaluate the efficiency of green materials on less carbon emission**

Based on the comprehensive analysis discussed in **Chapter 4: Results and Discussion**; the chosen carbon calculator used throughout this project is developed by the Environment Agency. According to Environment Agency (2007), the carbon emission calculations are broken down into three major sections. The first part involves the construction input where all the data and relevant parameters are entered by the user at this stage. These data may include materials' quantity (tonnes), waste disposal, plant and equipment, site accommodation, distance of source of materials to construction site (km), mode of transportation and personal travel as depicted in Figure 3.1.2. Furthermore, more of these parameters can be added as they are not fixed and can vary depending on site conditions. The second stage involves the background data which the calculations are based on; embodied carbon per tonne of each material and carbon equivalent per tonne.km for each mode of transportation. Users can input own data for a more accurate result. Finally, the last stage reports the total carbon footprint of the project. A detailed step-by-step procedure is discussed further in the following section.

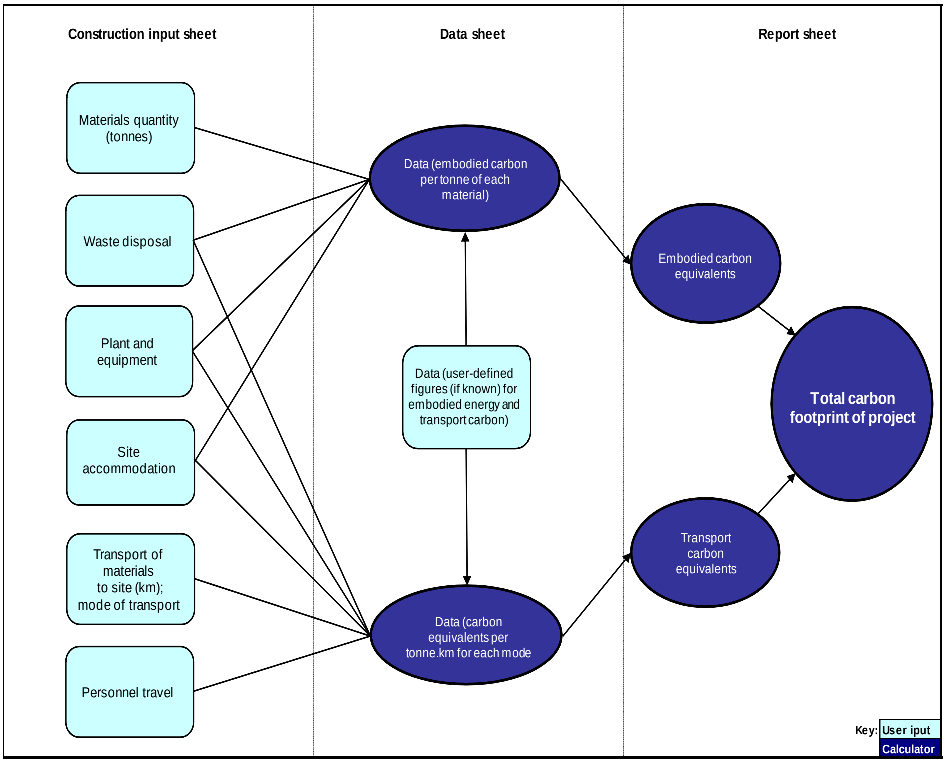



FIGURE 3.1.2. The Overview of the Carbon Calculator Software

Source: Environment Agency (2007)

According to the Environment Agency (2007), Figure 3.1.3 depicts the methodology of the carbon footprint calculations. It describes the step-by-step procedure in attaining the overall carbon footprint of a project. Five sheets are provided namely, *Project Information Sheet*, *Construction Input Sheet*, *Report Sheet*, *Data Sheet* and *Optioneering Sheet* for the user to input the relevant data related to the project.

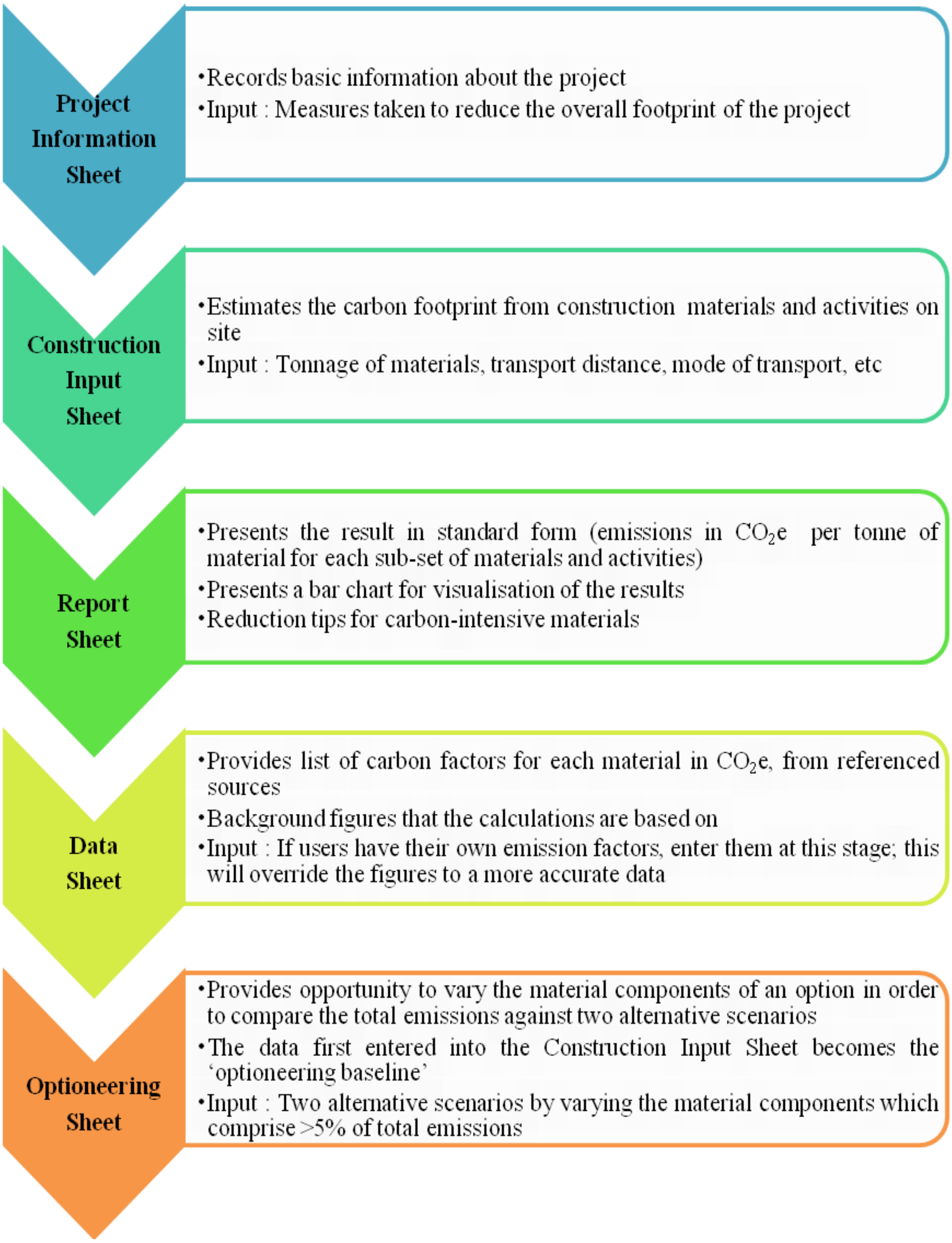



FIGURE 3.1.3. The Methodology of the Carbon Footprint Calculations

**The Assessment of Carbon Footprint of Constructed Model**

A double-storey office building is used as a building reference in assessing the carbon footprint of the materials to be used to construct the proposed building at Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh, Perak. The constructed model aims at reducing the carbon footprint of the whole project by utilizing the building materials that contribute to minimal environmental impact.

Three components; wall, floor and column are evaluated based on the construction materials used for each component. Accordingly, the assessment of carbon footprint of each material is evaluated. As a result, carbon footprint of each material with respect to its strength and performance is obtained through carbon emission calculations.

The first component, a 250 mm thick non-load bearing wall with dimension of 4.5 m height by 30 m length with four options of different materials; common brick, clay brick, green brick and cement brick used in its construction are assessed to determine their respective carbon footprint. All of which are with respect to their compressive strength of 7 MPa which is suitable for the construction of non-load bearing wall.

Besides that, the constructed model has a gross floor area (GFA) of 466.2 $m^2$ with 20 mm thickness, which accounts for the second component; floor. The materials considered for flooring are conventional concrete, green concrete, sawn hardwood, bamboo and steel. All five materials possess their own characteristic strengths which are suitable for flooring; discussed further in the next chapter.

Lastly, the third component is column. The materials are divided into two groups; concrete and steel. The concrete column has a dimension of 300 mm by 300 mm with a height of 4.5 m. Conventional concrete and green concrete are proposed of grade G35 for the construction of concrete columns for the constructed model. Besides concrete, another alternative material considered in the construction of column is steel. I-section steel columns of grade S275 are proposed with the size 305 x 305 x 97. The characteristic strengths of the materials are analyzed further in **Chapter 4: Results and Discussion**.

**Quantities Breakdown of Concrete**

The breakdown of quantities of concrete is essential as part of the methodology of assessing the carbon footprint of the constructed model. For the quantities breakdown of conventional concrete and green concrete, Ahmad (2007) conducted an experimental work in optimizing a typical concrete mixture and concluded the optimum coarse aggregate (CA) / total aggregate (TA) and total aggregate (TA) / cement (C) ratios are found to be 0.62 and 4.88 respectively. Hence, the formulas of breakdown of quantities of concrete are as follows:

$$\frac{CA}{TA} = 0.62 \qquad and \qquad \frac{TA}{C} = 4.88$$

*where*

C = Cement

TA = Total Aggregate

CA = Coarse Aggregate

FA = Fine Aggregate

All detailed calculations involved in the quantities breakdown of conventional concrete and green concrete used in floor and column are included and tabulated in **Chapter 4: Results and Discussion**.

**The Reduction of Carbon Footprint of Constructed Model**

Upon assessing the carbon footprint of the constructed model, Figure 3.1.4 depicts the methodology in the reduction of the carbon footprint of the constructed model based on referenced Best Management Practices (BMP) to be adopted in construction sites.

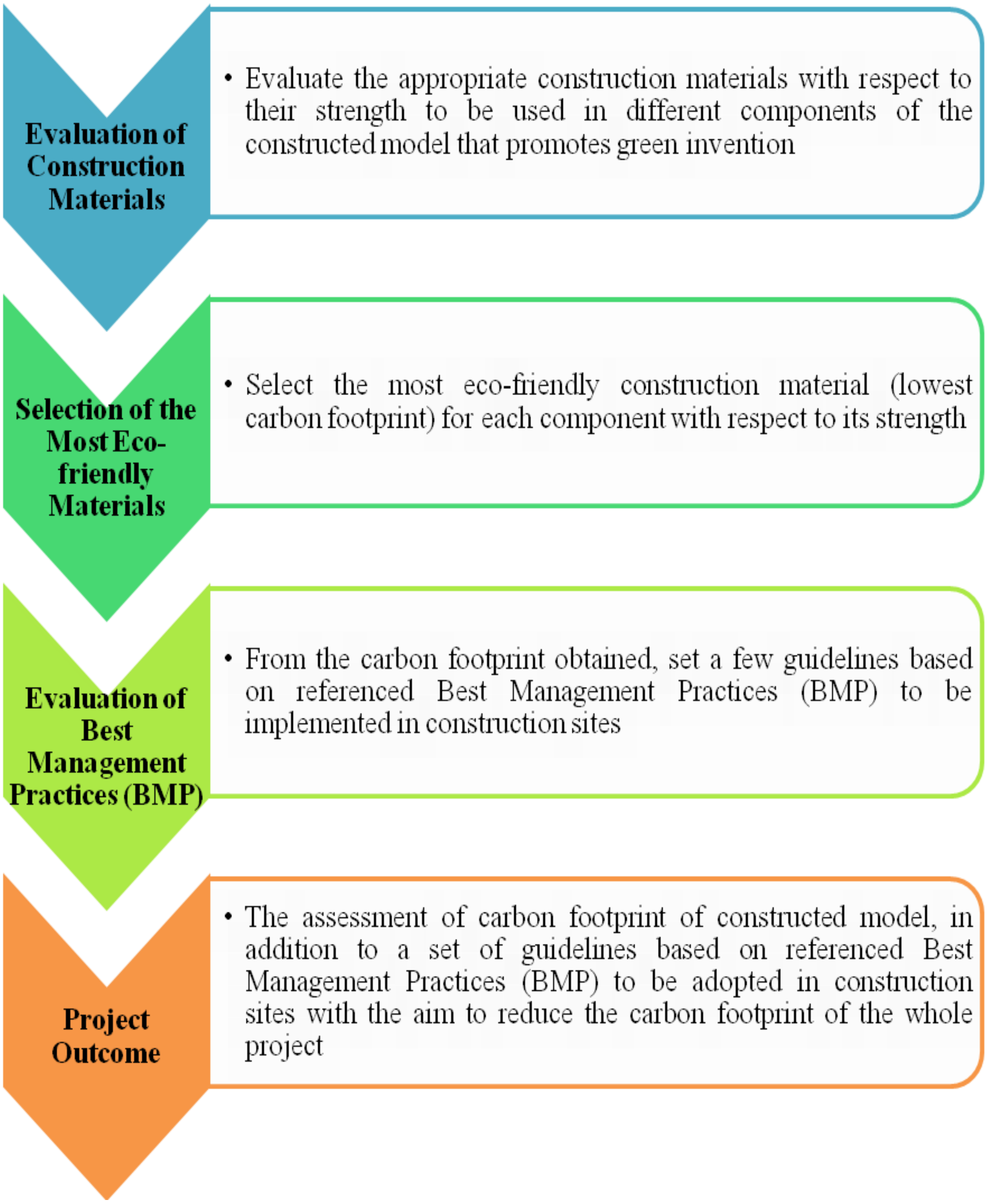



FIGURE 3.1.4. The Methodology in the Reduction of Carbon Footprint Based on Referenced Best Management Practices (BMP)

## 3.2 Project Work

### *3.2.1 Key Project Milestones*

TABLE 3.2.1.1 Key Project Milestones

| PROJECT FLOW / TASK | FYP 1 | | | | | | | | | | | | | | FYP 2 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WEEK | | | | | | | | | | | | | | WEEK | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| Selection of FYP title | | ● | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FYP Seminar/Talk | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Preliminary Research | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Detailed Study | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Submission of Extended Proposal | | | | | | ● | | | | | | | | | | | | | | | | | | | | | | | |
| Proposal Defence Presentation | | | | | | | | | | | ● | | | | | | | | | | | | | | | | | | |
| Project Work : | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| a) Development of Methodologies | | | | | | | | | | | | | ● | | | | | | | | | | | | | | | | |
| Submission of Interim Report | | | | | | | | | | | | | | ● | | | | | | | | | | | | | | | |
| Project Work : | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| a) Collection of Data | | | | | | | | | | | | | | | | | | | ● | | | | | | | | | | |
| b) Assessment of GHG impacts via carbon calculations | | | | | | | | | | | | | | | | | | | | | ● | | | | | | | | |
| c) Selection of appropriate design and management choice | | | | | | | | | | | | | | | | | | | | | | | ● | | | | | | |
| Submission of Progress Report | | | | | | | | | | | | | | | | | | | | | ● | | | | | | | | |
| Pre-SEDEX | | | | | | | | | | | | | | | | | | | | | | | | ● | | | | | |
| Submission of Dissertation (Soft Bound) | | | | | | | | | | | | | | | | | | | | | | | | | | ● | | | |
| Submission of Technical Paper | | | | | | | | | | | | | | | | | | | | | | | | | | ● | | | |
| Viva Presentation | | | | | | | | | | | | | | | | | | | | | | | | | | | ● | | |
| Submission of Project Dissertation (Hard Bound) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ● |

### *3.2.2 Project Timeline (Gantt Chart)*

TABLE 3.2.2.1 Project Timeline (Gantt Chart)

| PROJECT FLOW / TASK | FYP 1 | | | | | | | | | | | | | | FYP 2 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WEEK | | | | | | | | | | | | | | WEEK | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| Selection of FYP title | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FYP Seminar/Talk | | ■ | | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | |
| Preliminary Research | | | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | |
| Detailed Study | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | |
| Submission of Extended Proposal | | | | | | ■ | | | | | | | | | | | | | | | | | | | | | | | |
| Proposal Defence Presentation | | | | | | | | | | | ■ | | | | | | | | | | | | | | | | | | |
| Project Work : | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | |
| a) Development of Methodologies | | | | | | | | | | | | | ■ | | | | | | | | | | | | | | | | |
| Submission of Interim Report | | | | | | | | | | | | | | ■ | | | | | | | | | | | | | | | |
| Project Work : | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| a) Collection of Data | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | |
| b) Assessment of GHG impacts via carbon calculations | | | | | | | | | | | | | | | | | | | | ■ | ■ | | | | | | | | |
| c) Selection of appropriate design and management choice | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | |
| Submission of Progress Report | | | | | | | | | | | | | | | | | | | | | ■ | | | | | | | | |
| Pre-SEDEX | | | | | | | | | | | | | | | | | | | | | | | | ■ | | | | | |
| Submission of Dissertation (Soft Bound) | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | | | |
| Submission of Technical Paper | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | | | |
| Viva Presentation | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | | |
| Submission of Project Dissertation (Hard Bound) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ |

# CHAPTER 4
# RESULTS AND DISCUSSION

In the effort to reduce the carbon footprint of a constructed model, this chapter introduces the constructed model of which the construction materials and its carbon footprint are analyzed with respect to its strength. Furthermore, the results shown in this chapter explore the key points in achieving the project's objectives besides promoting sustainable development via a lesser carbon emission as a whole.

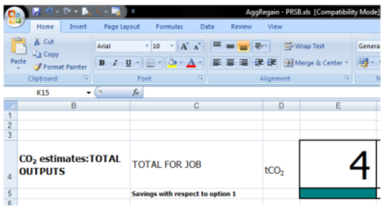
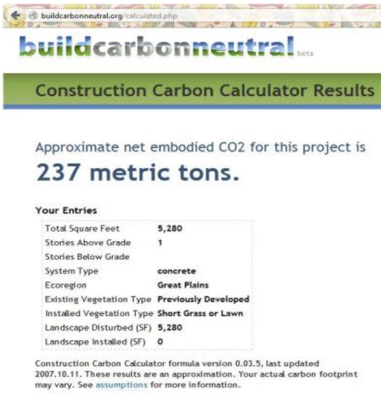
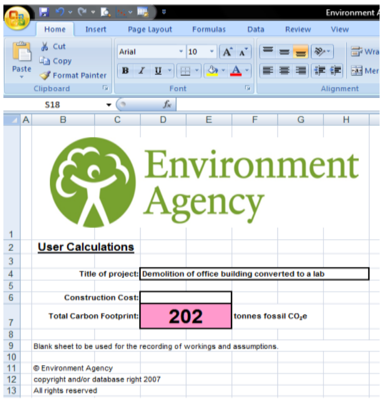
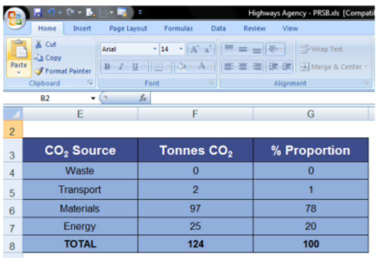
## 4.1 Selection of Carbon Calculator

To compare emissions output for specific input across carbon calculators, a construction project of a demolition of an office building converted to a lab at PETRONAS Research Sdn Bhd (PRSB) located in Bangi, Selangor is selected as the baseline to further assess the capability and competency of all four construction industry based carbon calculators mentioned in **Chapter 2: Literature Review**.

The data collected consist of all the materials involved in the project; the quantities of the materials, the distance travelled from the source of the material to the construction site, mode of transportation and amount of waste produced, which are required to be input into the four carbon calculators; namely AggRegain, Build Carbon Neutral, Environment Agency and Highways Agency.

The results and analysis of the carbon footprint obtained from each carbon calculator are tabulated in Table 4.1.1. These calculators provide a range of calculating methodologies while maintaining enough similarity to facilitate comparison. Consequently, giving an insight on the output produced for the same set of input. Besides that, the advantages and disadvantages of each carbon calculator are discussed further in relation to the elements of assessing the carbon footprint of the PRSB project before the selection of the most appropriate calculator to be comprehensively used throughout this project is made.

TABLE 4.1.1  Comparison of Four Construction Industry Based Carbon Calculators

| Carbon Calculator | Carbon Footprint | Advantages | Disadvantages |
|---|---|---|---|
| AggRegain | **4 $tCO_2e$**<br><br> | • Suitable for construction that involves aggregates (bitumen bound, hydraulically bound, concrete, unbound)<br>• Provides different construction techniques and supply alternatives (use of primary or recycled and secondary aggregates)<br>• Allows variation of percentages of recycled and secondary aggregates | • Accounts for aggregate related element (only carbon emission of concrete in the case of PRSB project)<br>• Does not consider other materials such as timber, metals, glass, etc |
| Build Carbon Neutral | **237 $tCO_2e$**<br><br> | • Easy to use<br>• Considers landscape and ecosystem as part of the calculations | • Limited parameters of construction based project activities and specific materials<br>• Limited quantitative inputs<br>• No background figures that the calculations are based on<br>• The emissions are of ± 25% accuracy |
| Environment Agency | **202 $tCO_2e$**<br><br> | • Includes all the parameters of every possible materials involved in a construction project<br>• Allows input of other materials and its carbon emission factors that are not listed in the spreadsheet<br>• Provides background figures that the calculations are based on<br>• Provides opportunity to vary the material components in *Optioneering Sheet*<br>• Presents bar chart for visualization of the results<br>• Provides reduction tips for carbon intensive materials | • Alternative greener options such as green concrete, green bricks and bamboo are not included in the carbon calculator |
| Highways Agency | **124 $tCO_2e$**<br><br> | • Captures the volume of carbon produced through construction, maintenance and operational activities<br>• Collection of data is based on quarterly basis to establish baseline for future comparison and analysis<br>• Includes most of the elements in construction sites (energy and utilities, materials, transport, waste removal)<br>• Presents bar chart for visualization of the results | • Does not consider some of the materials such as glass, coatings, finishes, etc |

Based on Table 4.1.1, the carbon footprint of AggRegain, Build Carbon Neutral, Environment Agency and Highways Agency are 4 $tCO_2e$, 237 $tCO_2e$, 202 $tCO_2e$ and 124 $tCO_2e$ respectively. There is a huge gap between the carbon footprint of AggRegain and the rest of the carbon calculators due to the data input in it. AggRegain only requires input that involves construction with aggregates. In the case of PRSB project, only concrete data is accounted in the carbon footprint obtained while other construction materials are not included in the carbon emission calculations. Hence, it justifies the significant gap between AggRegain among the rest.

On the other hand, Build Carbon Neutral resulted in the highest carbon footprint obtained despite the limited data required and inadequate quantitative values to be input into the carbon calculator. Though it is user friendly as compared to the others, Build Carbon Neutral however lack of transparency in its calculating methods and does not provide background figures to which the calculations are based on. Furthermore, it is mentioned that the Build Carbon Neutral carbon calculator is an estimation tool with the allowance of ± 25% of accuracy. Nonetheless, it considers the landscape and ecosystem in which none of the other three carbon calculators included in their respective spreadsheets. By considering landscape and ecosystem, one can counter the amount of landscape disturbed with the new landscape installed.

As for the Environment Agency, all parameters of every possible materials involved in a construction project is included in the carbon emission calculations. Consequently, the carbon footprint obtained is in the middle range among all four carbon calculators with 202 $tCO_2e$. This value is logical and acceptable in relation to the comprehensive data input into the carbon calculator. Similarly for Highways Agency, most of the parameters are about the same as the Environment Agency, with the exception of the inclusion of some construction materials such as glass, coatings and finishes. Since the highest contribution of carbon footprint for PRSB project is the epoxide paint used for the floor finishes in the lab, which is not included in the calculations by Highways Agency; justifies the difference in carbon footprint between the two carbon calculators, in which lower carbon footprint is obtained by Highways Agency. Hence, the carbon calculator developed by the Environment Agency is selected as the most appropriate carbon calculator to be used in this project.

Moreover, the carbon calculator has been used extensively in the organization of the Environment Agency. Numerous case studies have been conducted by the Environment Agency (2012) to reduce $CO_2$ emissions in their projects. For instance, the Weybridge Project (2012) was a £375,000 project to build a 120m long river level footpath with access to moorings. The post construction emission was reduced by 169 $tCO_2$ as compared to the original design (from 255 $tCO_2$ to 86 $tCO_2$).

The most significant $CO_2$ savings was from the 75% reduction in concrete used in the wall. A mesh filled with concrete was used instead of precast concrete blocks. This saved 173 $tCO_2$ (59 $tCO_2$ compared to 232 $tCO_2$ for precast concrete blocks). Originally, a cast in-situ concrete wall was planned which involved more material. Further carbon savings were achieved through the use of plastic piles (89.5% recycled) instead of steel sheet piles. The carbon footprint of the plastic piling was determined using the carbon calculator to be 8.6 $tCO_2$ compared to 17 $tCO_2$ for steel sheet piles. Besides that, by using a dense foam form liner, the organization saved considerable time and cost compared to a conventional alternative. A brickwork finish was achieved to fit the surroundings using a reusable rubber form liner. This added 4 $tCO_2$ to the project. Lastly, the concrete specification changed from exposure class XC3 to XC4 to increase the speed of the construction to meet the completion deadline. The carbon footprint increased by 27 $tCO_2$ (from 228 $tCO_2$ to 255 $tCO_2$) due to time constraints.

In a nutshell, the project was delivered on time and under budget. The project team saved approximately £40,000 compared to the original design, with the same design life and the carbon footprint reduced overall by 50%, with the help of the carbon calculator. Apart from that, other case studies conducted by the Environment Agency include the Swinefleet Project (2012), Shaldon and Ringmore Project (2012), Sandford Bridge Project (2012) and Usk Town Flood Wall Project (2012).

## 4.2 Building Model

A double-storey office building is used as a building reference in assessing the carbon footprint of the materials to be used to construct the proposed building at Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh, Perak. The constructed model aims at reducing the carbon footprint of the whole project by utilizing the building materials that contribute to minimal environmental impact.

For the purpose of this project, three components are evaluated based on the construction materials used for each component. As a result, the assessment of carbon footprint of each material with respect to its strength and performance is obtained through carbon emission calculations via carbon calculator developed by the Environment Agency. The three components of the constructed model are:

- Wall
- Floor
- Column

However, assumptions are made in order to control the consistency of the results. One of the assumptions is the distance travelled for all materials from its original source to the construction site. The distance for all materials is kept constant at 250 km. By doing so, the amount of carbon footprint obtained is consistent for all materials with respect to the distance travelled from the source to the location of construction site. Other assumptions made are mentioned in the respective subsections in this chapter where applicable.

### 4.3 Wall

The carbon footprint of 250 mm thick non-load bearing wall with dimension of 4.5 m height by 30 m length is assessed and tabulated in Table 4.3.1 according to the respective materials used in its construction. Four materials are considered in the construction of the wall; common brick, green brick, clay brick and cement brick. All of which have a compressive strength of 7 MPa which is suitable for the construction of non-load bearing walls.

Common brick and clay brick are both burnt clay bricks which are used in general work. However, common brick has no special claim for attractive appearances and requires plastering. Clay brick on the other hand, gives attractive appearance in its colour and texture; hence, it is used without plastering or other surface treatments.

Green brick is an unbaked clay brick which consist of a mix composition between red soil or clay and Portland cement (Majpadu, 2010). Hence, the embodied carbon of green brick is much lower than its other counterparts due to its unbaked properties; resulting in a lower carbon footprint as a whole. Besides that, it is made mostly from recyclable and reusable material which deemed it to be called green brick.

Alternatively, cement brick is considered sustainable for a number of reasons. It is made from local materials and usually shipped short distances besides containing recycled materials (America's Cement Manufacturers, 2014). These aspects often contribute toward credits in green rating systems.

TABLE 4.3.1 Carbon Footprint of Wall

| Material | Common Brick | Clay Brick | Green Brick* | Cement Brick |
|---|---|---|---|---|
| **Density (tonnes/m$^3$)** | 1.93 | 1.82 | 1.68 | 1.05 |
| **Quantities (m$^3$)** | 33.75 | 33.75 | 33.75 | 33.75 |
| **Quantities (tonnages)** | 65.14 | 61.43 | 56.70 | 35.44 |
| **Carbon Footprint ($tCO_2e$)** | **17.4** | **16.4** | **3.6** | **3.2** |

* Unbaked clay bricks which consist of a mix composition between red soil/clay and Portland cement with compressive strength of 7 MPa (Majpadu, 2010)

From the assessment of carbon footprint of the wall (per wall, per floor), the result can be divided into two groups; higher and lower range of footprint emitted. Both common and clay bricks resulted in higher carbon footprint with 17.4 $tCO_2e$ and 16.4 $tCO_2e$ respectively due to the excessive emission of $CO_2$ in their production; firing up to three days to become hard and durable. Green brick and cement brick on the other hand, are in the lower range of emitted footprint with 3.6 $tCO_2e$ and 3.2 $tCO_2e$ due to the non-combustible nature in their production. Hence, these two materials should be considered in the construction of wall for the constructed model. Figure 4.3.1 depicts the footprint comparison of the materials for the wall construction.

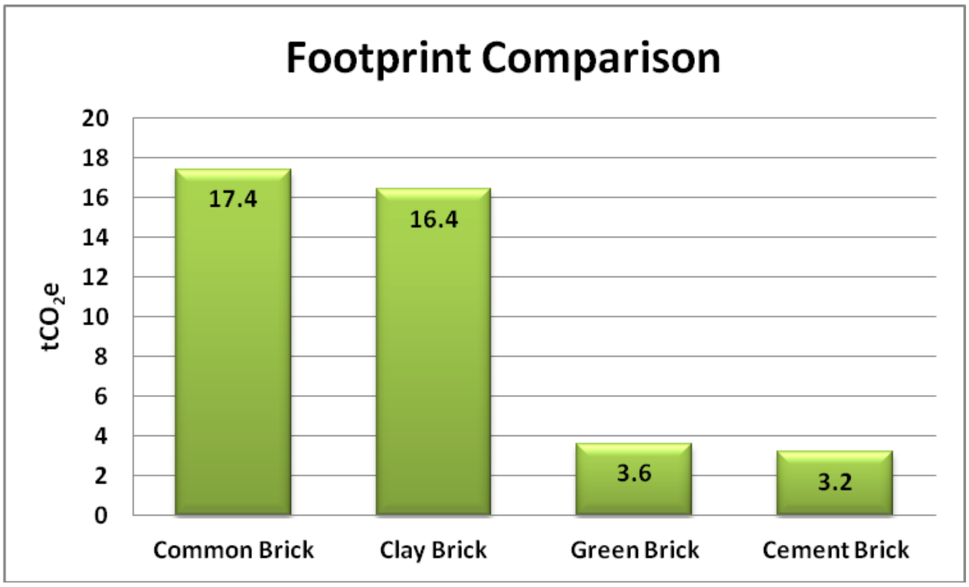



FIGURE 4.3.1. Footprint Comparison of Wall

Based on the carbon footprint assessed, a reduction of 80% is achieved if green brick or cement brick is adopted instead of the conventional fired clay brick. Similarly, according to Majpadu (2010), green brick solution represents 85% lower embodied energy and 85% lower carbon footprint than burnt clay brick. Besides that, green brick provides strong thermal insulation which is an added bonus to cater the constructed model that is proposed to be constructed in the middle of a former mining area in Tronoh, Perak. Likewise, cement brick, also known as concrete masonry is energy efficient in providing thermal mass to help moderate temperature in buildings besides being cost effective. Furthermore, concrete masonry is durable, long lasting and the tough exterior of exposed units provides an attractive finish in demanding environments (America’s Cement Manufacturers, 2014).

## 4.4 Floor

Flooring is one of the components of the constructed model where the carbon footprint of its materials is assessed and compared. With a gross floor area (GFA) of 466.2 $m^2$ with 20 mm thickness per floor, the materials considered for flooring are conventional concrete, green concrete, sawn hardwood, bamboo and steel. All five materials possess their own characteristic strengths which are suitable for flooring. The strength of each material is discussed further in the respective subsections.

In an experimental study conducted by Maier and Durham (2012), six concrete mixtures with varying amounts of recycled material were developed, batched and tested for structural and durability performance. One of it is a mixture that contained 100% virgin aggregates and 100% Portland cement, used as a control mixture for the experiment while the remaining five mixtures vary in the composition with 100%, 75%, 50% and 25% recycled aggregates (RA). The effects of varying amount of recycled material in concrete are tabulated in Table 4.4.1 below (Maier and Durham, 2012).

TABLE 4.4.1 Effects of Varying Amount of Recycled Material in Concrete

| **Replacement Amount of Recycled Material** | **25%** | **50%** | **75%** | **100%** |
|---|---|---|---|---|
| **Effect** | Beneficial | Beneficial | Non-detrimental | Detrimental |
| **Ultimate Strength at 90 days (MPa)** | 46.3 | 48.3 | 43.8 | 29.0 |

According to the experiment conducted by Maier and Durham (2012), a replacement up to 50% with recycled materials were determined to be beneficial to the concrete mixture and deemed to be the optimum replacement level. As tabulated in Table 4.4.1, a reduction in quality began to manifest at 75% and was fully visible at 100% replacement. The replacement of natural virgin aggregates with RA and crushed waste glass decreases the workability of the concrete mixture. Figure 4.4.1 illustrates the compressive strength of all six mixtures (Maier and Durham, 2012).

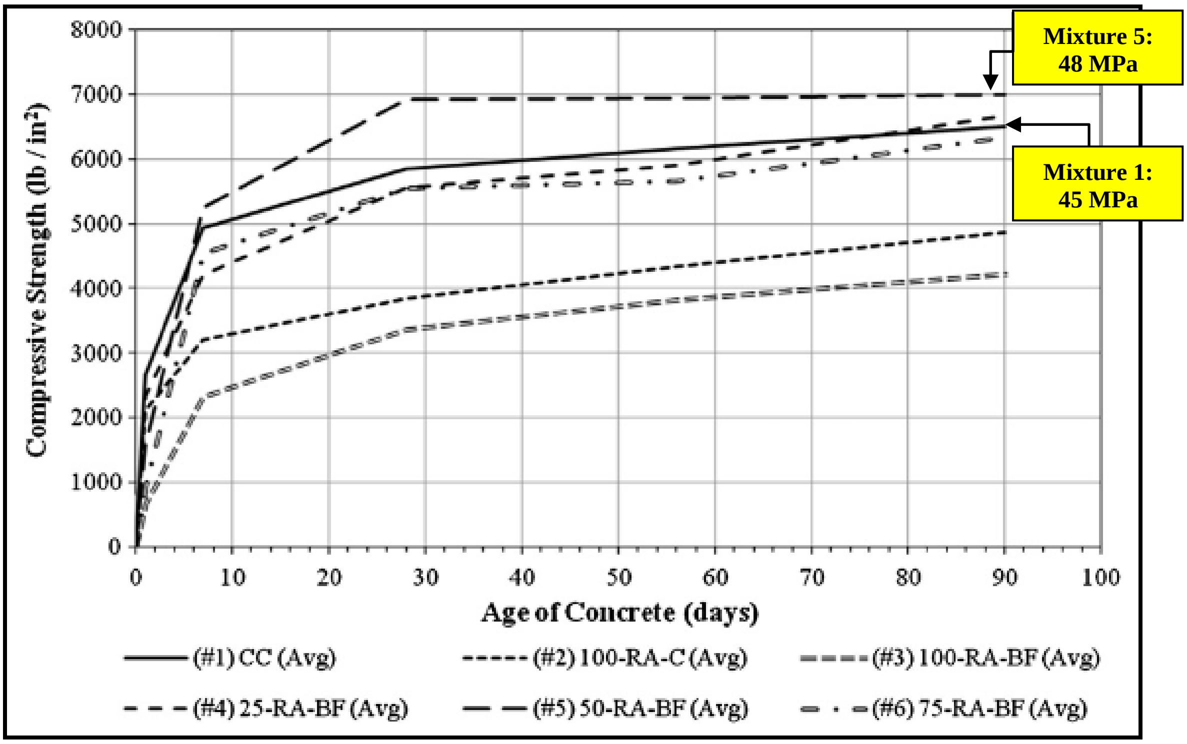



FIGURE 4.4.1. Compressive Strength of Concrete with Varying Amount of Recycled Materials

Source : Maier and Durham (2012)

Based on Figure 4.4.1, 50% replacement of recycled materials (Mixture 5) actually enhanced the concrete's properties. The experiment conducted by Maier and Durham (2012) resulted in a higher compressive strength for Mixture 5 with 48 MPa after 90 days and hence justifies the selection of the composition of green concrete to be assessed in this project. The composition of conventional concrete however, is taken from the control mixture (Mixture 1) which resulted in a slightly lower compressive strength of 45 MPa. Therefore, based on the experimental results obtained by Maier and Durham (2012), the composition of conventional concrete assessed in this project is 100% virgin aggregates and 100% Portland cement while the green concrete consists of a composition of 50-50 virgin aggregates and RA with 50% slag cement, 50% Portland cement, 50% recycled concrete aggregates (RCA), 50% virgin rock, 48% waste glass and 52% virgin sand. Both are of G35 concrete.

As for the quantities breakdown of the conventional concrete and green concrete, Ahmad (2007) conducted an experimental work in optimizing a typical concrete mixture and concluded the optimum coarse aggregate (CA) / total aggregate (TA) and total aggregate (TA) / cement (C) ratios are found to be 0.62 and 4.88 respectively.

Consequently, the quantities breakdown of the concrete is essential for the calculation of carbon footprint of the materials for the floor component of the constructed model. With a GFA of 466.2 $m^2$ and thickness of 20 mm, the volume of the floor is 9.32 $m^3$ and the quantities breakdown based on the composition of conventional concrete and green concrete for floor is tabulated in Table 4.4.2. Therefore, according to Ahmad (2007), the calculations in the breakdown of quantities of concrete are as follows:

$$\frac{CA}{TA} = 0.62 \qquad and \qquad \frac{TA}{C} = 4.88$$

*where*

C = Cement

TA = Total Aggregate

CA = Coarse Aggregate

FA = Fine Aggregate

Assuming TA + C = 9.32 $m^3$

4.88 C + C = 9.32

C = 1.585 $m^3$

TA = 4.88 C

= 4.88 (1.585)

= 7.73 $m^3$

CA = 0.62 (7.73)

= 4.79 $m^3$

FA = TA – CA

= 7.73 – 4.79

= 2.94 $m^3$

TABLE 4.4.2 Composition of Conventional Concrete and Green Concrete for Floor

| | **Quantities ($m^3$)** | **Proportion (%)** | **Quantities Breakdown ($m^3$)** | **Density (tonnes/$m^3$)** | **Tonnages** |
|---|---|---|---|---|---|
| **Conventional Concrete** | 9.32 | | | | |
| Portland Cement | | 100 | 1.59 | 1.5 | 2.385 |
| Coarse Aggregate (CA) | | 100 | 4.79 | 2.0 | 9.58 |
| Fine Aggregate (FA) | | 100 | 2.94 | 1.2 | 3.528 |
| **Green Concrete** | 9.32 | | | | |
| Portland Cement | | 50 | 0.795 | 1.5 | 1.1925 |
| Slag Cement | | 50 | 0.795 | 1.5 | 1.1925 |
| Virgin Rock (CA) | | 50 | 2.395 | 2.0 | 4.7900 |
| Recycled Concrete Aggregate | | 50 | 2.395 | 2.0 | 4.7900 |
| Virgin Sand (FA) | | 48 | 1.41 | 1.2 | 1.6920 |
| Waste Glass | | 52 | 1.53 | 0.41 | 0.6273 |

Besides concrete, bamboo is one of the materials considered as part of the construction of floor for the constructed model. According to Forest Research Institute Malaysia (FRIM), bamboo falls within the range of light-to-heavy hardwoods, the commercial timbers used for furniture and heavy construction. Tensile strength of bamboo is 193 MPa which is equivalent to those of wood or steel with 159 MPa (FRIM, n.d.). Besides that, in a test conducted in FRIM, the shear strength of Malaysia's local bamboo is 12.5 MPa, making it suitable for flooring (Bamboo Bio, 2012). Moreover, an experiment conducted by Li et al. (2013) resulted in the compressive strength of laminated bamboo to be in the range of 56 MPa to 73 MPa. Correspondingly, proves that bamboo has a higher compressive strength than concrete. On the other hand, in another experiment conducted by Lee et al. (2012), the bending strength of bamboo was found to be 87.5 MPa, which is also suitable for flooring. Bamboo flooring is now popular and exponentially growing in demand globally. In addition, bamboo produces 35% more oxygen than an equivalent stand of trees and can remove up to 12 tonnes of $CO_2$ from the air per hectare (FRIM, n.d.). As a result, the embodied carbon of bamboo is low as compared to other materials with 0.0020412 $tCO_2e$ (Symbiotic Engineering, 2007).

In contrast, steel decking is another alternative in the construction of floor. With a unit weight of 13.6 kg/$m^2$, steel of grade G550, robust profiled zinc coated steel sheeting is considered for the use in the construction of composite floor for the constructed model (Blue Scope Lysaght, n.d). Steel decking is suitable for fast-track construction, enabling projects to be completed earlier and within budget without compromising on quality. However, steel has a high embodied carbon. The carbon footprint of steel and other materials for the construction of floor are tabulated below.

TABLE 4.4.3 Carbon Footprint of Floor

| **Material** | **Conventional Concrete** | **Green Concrete*** | **Sawn Hardwood** | **Bamboo** | **Steel** |
|---|---|---|---|---|---|
| **Density (tonnes/$m^3$)** | 2.40 | 1.53 | 0.6 | 0.77 | 7.8 |
| **Quantities ($m^3$)** | 9.32 | 9.32 | 9.32 | 9.32 | - |
| **Quantities (tonnages)** | 22.37 | 14.28 | 5.592 | 7.18 | 6.34 |
| **Carbon Footprint ($tCO_2e$)** | **3.0** | **1.7** | **1.5** | **0.2** | **9.9** |

* Consists of 50% slag cement, 50% Portland cement, 50% RCA, 50% virgin rock, 48% waste glass and 52% virgin sand (Maier and Durham, 2012)

Based on the results obtained (per GFA), bamboo emits the lowest carbon footprint with 0.2 $tCO_2e$, followed by sawn hardwood, green concrete and conventional concrete with 1.5 $tCO_2e$, 1.7 $tCO_2e$ and 3.0 $tCO_2e$ respectively and last but not least, the highest carbon emitter which is steel with 9.9 $tCO_2e$. Hence, with regards to its strength and performance, bamboo flooring is desirable to be adopted in the constructed model. Figure 4.4.2 depicts the footprint comparison of the materials for the construction of floor.

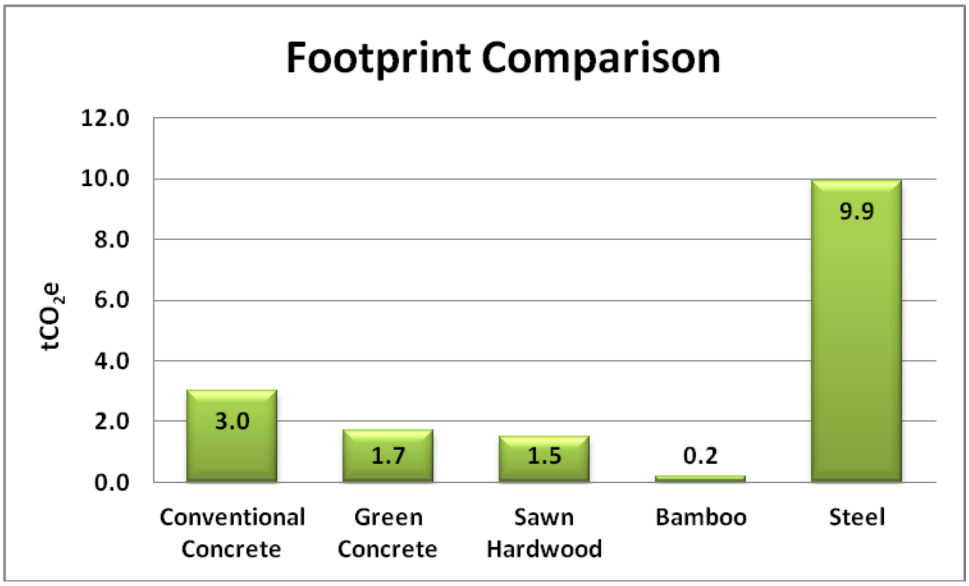



FIGURE 4.4.2. Footprint Comparison of Floor

When comparing bamboo flooring to locally sourced concrete, bamboo flooring emits 17% less $CO_2$ per tonne than the equivalent amount of locally sourced concrete (Symbiotic Engineering, 2007). However, according to the carbon footprint assessed for the constructed model, bamboo flooring obtained a reduction of 93% and 88% lower footprint than the equivalent amount of conventional concrete and green concrete respectively. Steel on the other hand, due to its high embodied carbon, resulted in an even higher footprint as compared to the rest of the materials. By replacing steel decking with bamboo flooring, a reduction of 98% is achieved for the flooring component of the constructed model. What is not often considered is the contribution bamboo forests make to the reversing of the negative effects of $CO_2e$ and other environmental factors as compared to its wood counterpart (Eco-Logic, n.d.). Since bamboo is the fastest growing plant on Earth, it means that it sequesters more carbon than slower-growing trees and hence is considered as a rapidly renewable and sustainable resource.

## 4.5 Column

The carbon footprint of column for the constructed model is assessed and tabulated in Table 4.5.1 according to the respective materials used in its construction. Three materials are considered in the construction of the columns; conventional concrete, green concrete and steel.

The column has a dimension of 300 mm by 300 mm with a height of 4.5 m and the grade of concrete is G35. Similar with the floor component of the constructed model, the same composition of both conventional and green concrete are adopted. Hence, the compressive strengths of conventional concrete and green concrete are 45 MPa and 48 MPa respectively.

As for the quantities breakdown of the concrete, likewise, in flooring, the volume of 24 columns is 9.7 $m^3$ and the quantities breakdown based on the composition of conventional concrete and green concrete for floor is tabulated in Table 4.5.1. Therefore, according to Ahmad (2007), the calculations in the breakdown of quantities of concrete are as follows:

$$\frac{CA}{TA} = 0.62 \qquad and \qquad \frac{TA}{C} = 4.88$$

*where*

C = Cement

TA = Total Aggregate

CA = Coarse Aggregate

FA = Fine Aggregate

Assuming TA + C = 9.7 $m^3$

$$4.88\,C + C = 9.7$$
$$C = 1.65\ m^3$$

$$CA = 0.62\,(8.052) = 4.99\ m^3$$

$$TA = 4.88\,C = 4.88\,(1.65) = 8.052\ m^3$$

$$FA = TA - CA = 8.052 - 4.99 = 3.06\ m^3$$

TABLE 4.5.1 Composition of Conventional Concrete and Green Concrete for Column

| | Quantities ($m^3$) | Proportion (%) | Quantities Breakdown ($m^3$) | Density ($tonnes/m^3$) | Tonnages |
|---|---|---|---|---|---|
| **Conventional Concrete** | 9.7 | | | | |
| Portland Cement | | 100 | 1.65 | 1.5 | 2.475 |
| Coarse Aggregate (CA) | | 100 | 4.99 | 2.0 | 9.98 |
| Fine Aggregate (FA) | | 100 | 3.06 | 1.2 | 3.672 |
| **Green Concrete** | 9.7 | | | | |
| Portland Cement | | 50 | 0.825 | 1.5 | 1.2375 |
| Slag Cement | | 50 | 0.825 | 1.5 | 1.2375 |
| Virgin Rock (CA) | | 50 | 2.495 | 2.0 | 4.9900 |
| Recycled Concrete Aggregate | | 50 | 2.495 | 2.0 | 4.9900 |
| Virgin Sand (FA) | | 48 | 1.469 | 1.2 | 1.7628 |
| Waste Glass | | 52 | 1.591 | 0.41 | 0.6523 |

Besides concrete, another alternative material considered in the construction of column for the constructed model is steel. I-section steel columns of grade S275 are proposed with the size 305 x 305 x 97. The mass/meter of the steel section is 96.9 kg/m. Moreover, the grade of steel indicates the yield strength of 275 MPa. On the other hand, the tensile strength of the column section is 460 MPa (Rainham Steel, n.d.). Thus, the steel columns are able to carry the load of the structure, serving the same purpose as its counterpart; concrete columns. In terms of carbon footprint emitted by each material, the result of the assessment is tabulated in Table 4.5.2.

TABLE 4.5.2 Carbon Footprint of Column

| Material | Conventional Concrete | Green Concrete* | Steel |
|---|---|---|---|
| Density ($tonnes/m^3$) | 2.40 | 1.53 | 7.8 |
| Quantities ($m^3$) | 9.7 | 9.7 | - |
| Quantities (tonnages) | 23.33 | 14.87 | 10.47 |
| Carbon Footprint ($tCO_2e$) | 3.1 | 1.8 | 16.3 |

* Consists of 50% slag cement, 50% Portland cement, 50% RCA, 50% virgin rock, 48% waste glass and 52% virgin sand (Maier and Durham, 2012)

From the assessment of carbon footprint of the column (for 24 columns), both conventional and green concrete emit a much lower footprint than that of steel. The carbon footprint of green concrete is 1.8 $tCO_2e$ while conventional concrete emits almost double of green concrete with 3.1 $tCO_2e$. The highest carbon emitter is evidently steel, due to its high embodied carbon which resulted in a higher carbon footprint with 16.3 $tCO_2e$. Hence, green concrete is the desirable material in constructing the columns of the constructed model. Figure 4.5.1 depicts the footprint comparison of the materials for the column construction.

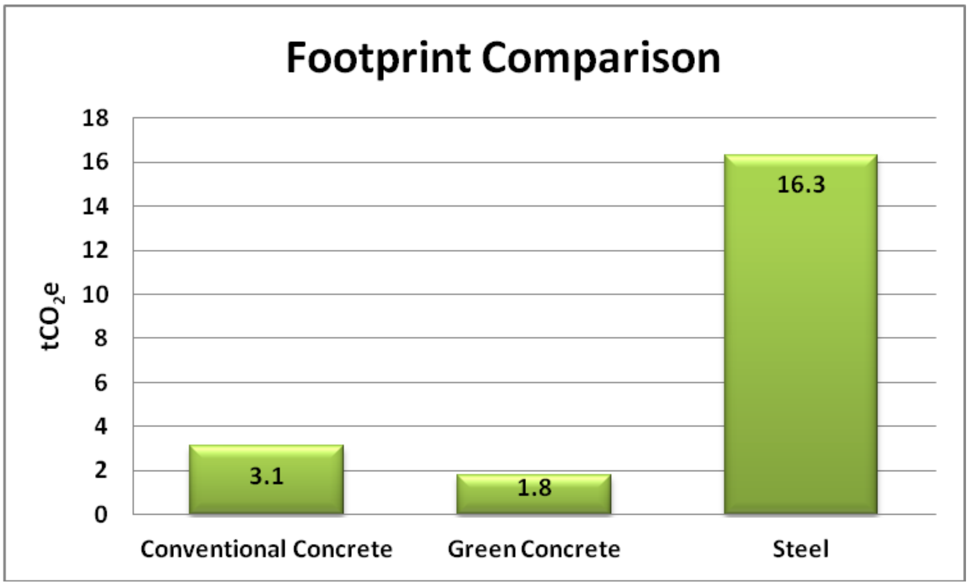



FIGURE 4.5.1. Footprint Comparison of Column

When comparing concrete columns to steel columns, a reduction of 89% or 81% is achieved if green concrete or conventional concrete is adopted in the column construction of the constructed model respectively. Furthermore, the constructed model is only a double-storey structure; hence it is unnecessary to have steel sections for the columns. Besides that, the constructed model is a low rise building, thus external factors such as wind is negligible especially in Tronoh, Malaysia where the weather condition is hot and humid. Therefore, concrete columns will suffice as compared to steel columns which are uneconomical. In addition, green concrete is the ideal material for the construction of columns for the constructed model to further reduce the carbon footprint of the project.

## 4.6 Best Management Practices (BMP)

A best management practice (BMP) is an approach that achieves an end goal in a way that has a better outcome when compared to a conventional approach. Not all BMP are appropriate for all sites or stakeholders. In relation to this research project, a set of guidelines based on referenced BMP are tabulated in Table 4.6.1 to be adopted at construction sites; with the aim to reduce the carbon footprint of the whole project.

TABLE 4.6.1. Guidelines Based on Best Management Practices (BMP)

| Element | Guidelines (BMP) | Reference |
|---|---|---|
| Materials Selection | • Choose rapidly renewable materials<br>• Choose materials with recycled content<br>• Choose materials that can be recycled<br>• Choose high performance, durable materials<br>• Choose materials that can be deconstructed and salvaged<br>• Specify local materials<br>• Avoid materials that have a toxic lifecycle<br>• Plan for recycling facilities<br>• Choose appropriate finishes to avoid heat absorption | Sustainable Land Development Resources for Design and Deliverables |
| Construction Management | • Select transport methods with increased fuel efficiency<br>• Order construction waste pickups when bins are full instead of on a weekly basis<br>• Plan materials purchases and packaging considerations to ensure only 10% (by weight arriving on the site) of total materials delivered to the site are discarded<br>• Recycle construction waste<br>• Limit transportation mileage<br>• Limit compaction with appropriate construction equipment approaches | |
| Transportation | • Design a site with good pedestrian or cyclist circulation<br>• Provide facilities for public transportation<br>• Provide car sharing facilities<br>• Reduce demand for travel by providing virtual communications tools<br>• Design a site that supports air quality goals<br>• Provide alternative fuels | |

| | | |
|---|---|---|
| Temporary Batch Plant | • Located at least 300 ft away from any recreational area, school, residence, or other structure not associated with the construction project and properly contained to facilitate cleanup efficiently. Runoff should be directed to a collection area or baker tank.<br>• No visible emissions including fabric or cartridge type filters for dry material transfers, dust-tight service hatches on silos and auxiliary bulk storage trailers, wet suppression systems at all transfer points, and covered conveyors and transporting vehicles.<br>• All plant roads shall be stabilized, watered, treated, or paved so as to control dust and tracking. All entrances and exits shall likewise be stabilized. | State of California Department of Transportation: Construction Site Best Management Practice (BMP) Field Manual and Troubleshooting Guide |

Based on the tabulated set of guidelines, four elements are prioritized; materials selection, construction management, transportation and temporary batch plant in construction sites. Each element is according to referenced BMP in which, when practiced daily in construction sites, will result in the reduction of carbon footprint of the whole construction project. These guidelines can be adopted throughout the project life cycle. For instance, materials selection is made during planning stage while construction management, transportation and temporary batch plant are in the execution stage, specifically during construction stage. Moreover, these guidelines may vary depending on site conditions and activities of high emission of carbon footprint. Nevertheless, for the purpose of this project, these four elements are the main concern.

# CHAPTER 5
# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

In conclusion, the carbon calculator developed by the Environment Agency is able to assess the carbon footprint of each component for the constructed model. In doing so, materials of lower footprint are more desirable to be used in the construction of each component of the constructed model. For example, for the construction of wall, cement brick or green brick are the ideal materials to be used due to the low footprint emitted with 3.2 $tCO_2e$ and 3.6 $tCO_2e$ respectively. As for flooring, not only that it resulted in the lowest footprint of all materials with 0.2 $tCO_2e$, bamboo flooring provides a lot of benefits environmentally on top of still accounting for its strength and performance too. Bamboo is so unique in such a way that can even reverse the negative effects of $CO_2e$. On the other hand, the construction of column resulted in the adaptation of green concrete columns which resulted in 1.8 $tCO_2e$ for the constructed model.

The carbon footprint assessment has definitely proven that these materials are really contributing to the effects of a better and lesser carbon emission in the future if they are widely recognized, used and incorporated in designs globally. Moreover, the carbon calculator acts as an important tool in the decision making process in order to determine the carbon footprint of a project, or at best, reduce the total footprint of the project before its commencement. An investment in such a tool can therefore promote sustainable development for a *'greener'* future.

Besides that, a set of guidelines based on Best Management Practices (BMP) is established to be implemented at construction sites with the aim to reduce the $CO_2$ emission significantly. By adopting these guidelines, the carbon footprint of a project can be reduced considerably. Hence, the objectives of this project are achieved.

## 5.2 Recommendation

Through the research conducted by the author, it is recommended that *'greener'* options such as bamboo, green concrete and green brick to be added in the carbon calculator software. Since the sustainable industry is evolving, the technology to verify its *'greenness'* should also be at par. Consequently, these novel options can be backed up with concrete calculations to prove its effectiveness theoretically. In a nutshell, further research can be conducted to improve the carbon calculator software for a more accurate finding. Furthermore, according to United Nations Environment Programme (2007), the importance of developing carbon calculators for construction projects is due to the fact that 13-18% of the total embodied carbon footprint of any construction project and 100% of the total embodied carbon footprint of any landscape project is released the year the project is built or installed.

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