BUILDING INFORMATION MODELING FOR ASSESSMENT OF STRUCTURAL MATERIAL IMPACT ON BUILDING STRUCTURES

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
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BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(Prof. Dr Nasir Shafiq)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2014

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 have not been undertaken or done by unspecified sources or persons.

MUHAMMAD AZWAN BIN KAMARUZZAMAN

ABSTRACT

Building construction is one of the largest contributors of carbon emissions that implicate the environment. Therefore, selection of building structural material is very crucial to reduce carbon emissions from construction industry. The aim of this project is using Building Information Modelling tools to determine the best carbon reduction practices by using composition of different types of conventional building material. The objective of this study is (1) Assessment of CO_2 emissions produced from different conventional structural materials used in construction of buildings using Building Information Modelling (BIM), (2) Analysis and comparison of CO_2 emissions generated by different combination of conventional structural materials, and (3) Selection of the best structural materials combination that generates the lowest carbon emissions to be practice in building construction. The study will involve in modelling and design of a selected building using BIM tools. Different grades and class of the main structural material that are concrete and steel will be put in combination into the design of several models of the selected building. Quantity of concrete and steel for each model will be calculated to convert into CO_2 equivalent for carbon emission determination. Input for CO_2 equivalent will be obtain from Inventory Carbon and Energy (ICE) developed by Hammond and Jones (2011) as reference due to the absence of Malaysia standard for embodied carbon conversion factor. Building model that generates the lowest carbon emissions will be selected and recommended as the best conventional structural material combination to be practiced in the construction industry. In the end of this project work, concrete grade of 35Mpa combined with reinforcement steel grade of 460Mpa yielded the lowest carbon emission thus is recommended to be best practice Malaysian building construction industry for this set of material data.

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CHAPTER 1
INTRODUCTION

1.1 Background of Project

Building and construction industry comprises the development of commercial, residential, and infrastructure in a country. Growing country will have enormous construction activities in order to move into a more stable economic hierarchy. Malaysia of course is one of the developing countries that we see the construction sector is actively runs around the country especially developments in the rural area. Years of building and constructing have given superb experience to builders enabling them to design such powerful structures and are respected in the eyes of the world.

Aspiration of evolving into a developed country and the high-level of Malaysian economic growth has triggered changes in the construction industry as well as providing a good opportunity for the building sectors to grow. The construction industry encompasses multidisciplinary of professional fields such as architecture, township planning, civil, electrical, and mechanical engineering, land surveying, landscaping, and many others that are related. **Table 1** shows the recent construction sector performance in Malaysia for the last quarter year of 2013 have increased by 8.1% from the previous quarter which indicates growing of building activities in the country as stated by Department of Statistics Malaysia (2013).

Table 1: Performance of Malaysian construction sector
(Department of Statistic Malaysia, 2013)

HIGHLIGHTS

Performance of the construction sector

Quarter	No. of projects	Value of construction work done (RM '000)	Percentage change (%)	
			(QoQ)	(YoY)
Q4 / 2013	**9,652**	**24,692,364**	**8.1**	**11.3**
Q3 / 2013	9,753	22,851,629	0.6	12.0
Q4/ 2012	9,324	22,190,736	8.8	25.6

Nevertheless, every creation has its negative impacts including the construction industry which affect the environment. Earth's temperature increase leads to global climate change and global warming. Global warming is due to excessive greenhouse gas (GHG) emissions. NRC (2010) stated that rising of GHGs especially carbon dioxide (CO_2) concentration is amplifying the natural greenhouse effect and causing Earth's surface temperature to rise. The concentrations of the GHG have increased dramatically over the past two centuries fault by human activities with evident of almost 30 billion tons of CO_2 produced.

Levine et al, (2007) cited that the construction sector contributes up to 30 to 40% of GHG emissions during the building's life time because of large energy consumption in the industry. Main construction materials pose as an important element in GHG emissions in this case as they are the source where the emission came from. **Figure 1** illustrates the comparison of energy used, greenhouse gas index, etc. between common construction designs based on material type chosen by Hattie Hartman's sustainability to measure emission.

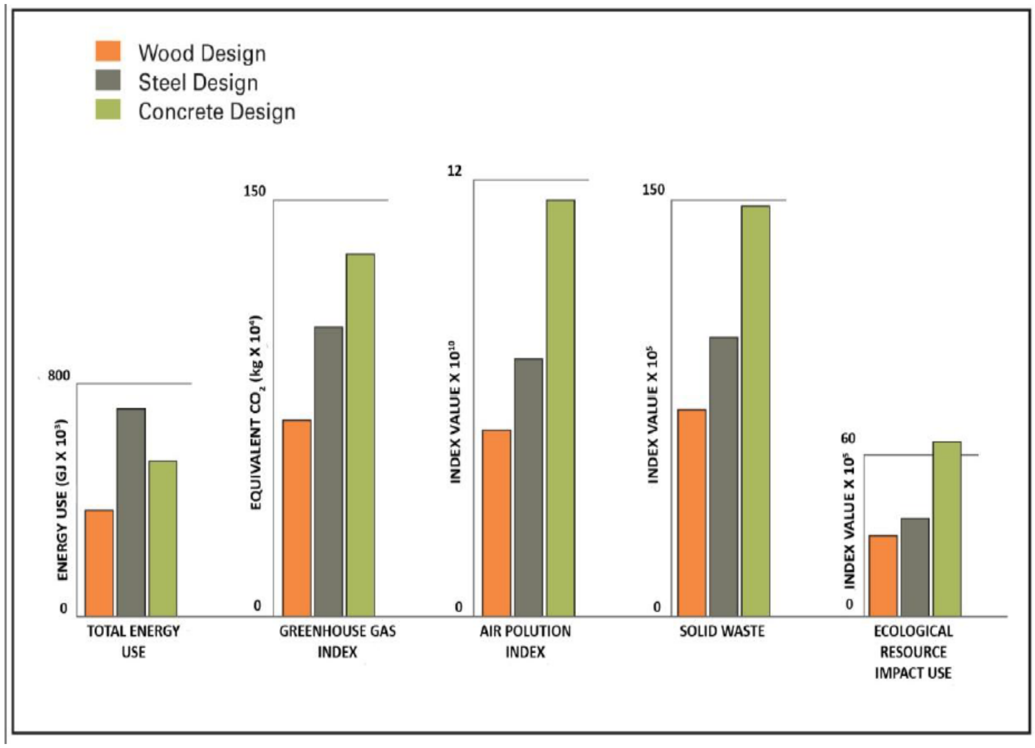


Figure 1: Hattie Hartman's sustainability to measure emission chart.

Indeed building materials selection is vital to achieve reduction in carbon emission thus promoting a more sustainable and an eco-friendly building that helps keep the surrounding environment in a safe zone. Practice of green designs is already implemented in the construction industry to reach out this cause. A new evolution in construction industry is achieved by the introduction of Building Information Modeling (BIM). Detail analysis of construction buildings and study of carbon emissions could be done more effectively using real-time 5D model by attaching material elements to the virtual building. The mission to reduce carbon emission would be more efficient when equipped with the latest technology for analysis purposes.

1.2 Problem Statement

Construction sector is one of the main sources of environmental problems and health issues even though the industry contributes numerous benefits towards the nation development. However, emissions from construction sector have caused such intense effect to the Earth's temperature and climate change which eventually may result in adverse impact to the nation economy, society, and environment. Contribution of CO_2 produced from construction affects highly towards global warming and global climate change.

CO_2 emissions in Malaysia are increasing per year and prediction says that the figure will continue to rise if such mitigation plan is not taken. Based from the **figure 1.2.1** below, the trend of CO_2 emission will rises in the future years according to World Bank (2008).

Figure 1.2.1: CO_2 emissions (metric tons per capita) in Malaysia (World Bank, 2008).

According to Nation Master (2013), Malaysia is ranked at 30th place for largest carbon emission (CO_2) with 123,603 metric tonnes while United States of America with CO_2 emission of 5,762,050 metric tonnes which is the largest in the world. The change of carbon emission in Malaysia produced by manufacturing and construction industry increased by 132.35% from year 1990 until 2009 (WRI, 2009). Concrete and steel as the main structural building materials are observed to be the main cause of high CO_2 emissions from the construction industry need to be managed of its selection and usage in building construction industry to avoid unnecessary increment of CO_2 concentration to the surrounding environment.

1.3 Objectives of the Project

The following are the identified objectives that are expected to be achieved upon project thesis completion:

1) Assessment of CO_2 emissions produced from different conventional structural materials used in construction of buildings using Building Information Modelling (BIM).

2) Analysis and comparison of CO_2 emissions generated by different combination of conventional structural materials.

3) Selection of the best structural materials combination that generates the lowest carbon emissions to be practice in building construction.

1.4 Scope of Work

Construction of a building structure consists of using various building materials and is vastly active for country developing missions. Nevertheless, carbon emission from building materials in construction has become a vital implication on degradation of the surrounding environment. Concrete and steel especially as the main building material produce high CO_2 emissions from its creation leads to the global warming and climate change.

The scope of this project is limited to CO_2 emission analysis from the main structural materials used in building construction. A multistory conventional office building is chosen as a case study for this project. BIM tools will be used to virtually construct the selected building with different composition of proposed conventional materials that would affect the total carbon emission of the building. Afterwards, carbon emission for different models of the office building is calculated, assessed, and compared to determine the best practice combination of conventional structural materials in the building construction industry that yields the least carbon emissions.

The input of embodied carbon value from Carbon and Energy (ICE) database will be needed as the base to analyse carbon emissions using BIM. With a proper input, BIM tool will automatically assist with the generation of the carbon emissions of the building. Usage of BIM in this study will help fasten the process of data analysis of different combination of structural materials and also promotes BIM to be practice in Malaysian construction industry for a better construction quality.

1.5 Feasibility of study

For the limited time period on this project, a conventional two-storey office building is selected as the case study. As BIM is very new in Malaysian construction industry, training to use BIM tools will be needed in order to model and design the building structure correctly. A two storey building is considered suitable as a starting point rather than a high rise building that would take tremendous of time due to fresh knowledge on BIM tools usage for building design and modelling. This project can be finished within the timeframe given and it is believe to be feasible.

CHAPTER 2
LITERATURE REVIEW

2.1 Climate Change, Global Warming and Greenhouse Gasses (GHGs)

Over the years, various destructive natural disasters can be witness all over the world. These phenomenon are the one of the implication of drastic climate change and leads to the rise of Earth's surface temperature. Continuous rises of the planet surface temperature will result to global warming due to high concentration of GHG emissions that can also change the climate patterns. A study by IPPC (2007) indicates that the Earth's surface temperature in the 21st century will rises by a minimum of 1.1 to 2.9^0C and worse by 6.4^0C. Therefore, if no action plan is taken, the rises of the planet surface temperature may be continuous over the next incoming years. Natural disasters such as tsunamis, flash floods, and intense heat waves were the effect of the climate change (EPA, 2013). This proves that climate changes are due to disturbance of the environment caused by concentrated GHG emissions. Global warming and climate change shares common properties because due to the excessive emission of GHGs thus causing unwanted temperature rise that would impact the earth climate (Loaiciga, 2009). Climate change and has a firm relationship with global warming through temperature rises. This proved that increasing concentration of carbon dioxide and other GHGs affect the climate changes.

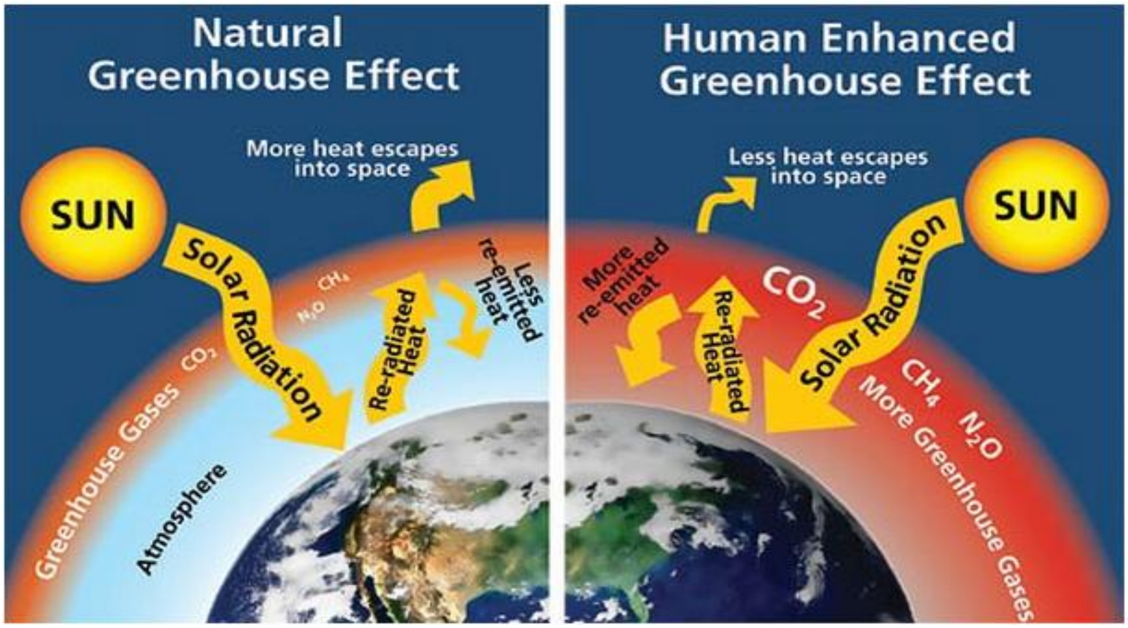


Figure 2.1.1 : The greenhouse effect source: NPS

According to the Burnett (2006), GHGs consist of six gases that hold the potential to contribute to climate change and global warming covered by the Kyoto Protocol. These GHGs includes Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Sulphur Hexaflouride (SF_6), Perfluorocarbons (PFC_s), and Hydrochlorocarbons (HFC_s). Saafaai et al, (2010) stated that the most vital component of the GHG is CO_2 which contribute largest on global warming due to human activities with 70% rate to the greenhouse effect followed by CH_4 with 24% and N_2O for about 6%.

2.2 Building Construction and Carbon emission

Building and GHG emissions are indistinguishably linked. Building related GHGs emission is likely between 8.6 metric million metric tons CO_2-eqv in 2004 as claimed by IPCC report (Levine et al, 2007). Thus, building construction has a major contribution to carbon emission that polluted the environment. IPPC (2007) stated that record estimation of the GHG emissions increase by 2.6% with 35.6 billion tonnes at the end of 2012 compared to the previous year. Manufacture of cement, fossil fuels burning, including solid, liquid, and gas consumption from the construction industry are the major CO_2 emissions contributor. In addition, Price et al. (2006) cited that the construction industry contributes up to 90% in most countries.

In the construction industry, CO_2 gas emission depends on several sources which are use of fossil fuels for power generation of purchased electricity and steam, use of fossil fuels for chemical processing and metal smelting and cement and lime manufacturing thus making CO_2 the most emitted GHG gas from the industry (Buchanan, 1994). It is clear that the building construction industry is one of the biggest potential for mitigation plan to reduce GHG emissions and preserve the green environment cause.

2.3 Embodied energy (Carbon)

According to Hammond G. and Jones C. (2008), embodied energy (carbon) from a building material can be defined as the consumed energy (carbon released) over its life cycle. **Figure 2.3.1** shows the typical life cycle of a construction building.

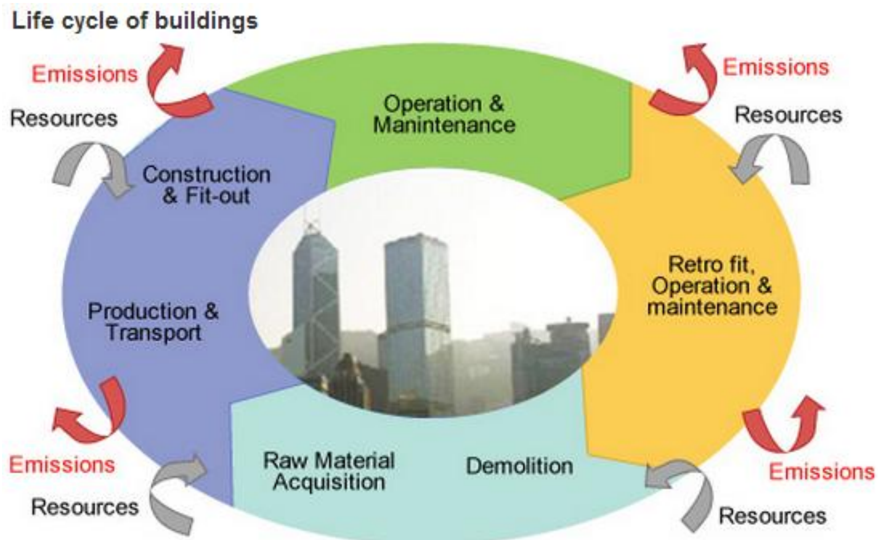


Figure 2.3.1: Life cycle of building source: EMSD

The life cycle at least will include from extraction, manufacturing, until transportation of the material. The boundaries ideally would be fixed from the extraction of the materials until the end of the product life that is demolition and is called 'Cradle-to-Grave'. Common practice is only to include the embodied energy release from the original state of the material until it leaves the manufacturer gate. This is called 'Cradle-to-Gate' which comprises all the energy from raw extraction to end of production of the material. Lastly, the final boundary condition which is known as 'Cradle-to-Site' that includes energy consumed until the material reached the purpose of use at the building site. Hammond G. and Jones C. (2008) also stated that the difference of energy consumed between Cradle-to-Gate and Cradle-to-Site analysis with material of high density and high embodied energy can be considered negligible.

2.4 Main Structural Materials in Malaysian Construction Industry

2.4.1 Concrete

Concrete is an artificial material produced by mixing of cementing material, coarse and fine aggregates and water caused by the chemical reaction of the water and cement (Gielen D.J, 1997). Cement is widely used in the production of concrete. Green Ration Book (2010) stated that 0.9 pounds of CO_2 are produced in the manufacturing of cement and 3900lbs of concrete would emit approximately 400lbs of carbon into the air. From Hammond G. and Jones C. (2011) on their study on developing Inventory of Carbon and Energy (ICE Version 1.6a), the embodied of carbon for general concrete is 0.100 $kgCO_2/kg$. Although it is a small multiplier, concrete is the highest material in term of quantity usage in conventional building construction thus acts as the major contributor to CO_2 emission of a building.

2.4.2 Steel

Steel in construction is used as the reinforcement of concrete and as a cladding material. Steel usage is very significant in the construction industry. Currently, China dominates the production of steel and also consumes it by 45%. Steel is consumed every year with an average number of more than 1.4 billion tonnes according to Worldsteel, (2013). Nevertheless, steel is one of the construction materials that can be recycled and reuse repeatedly and maintaining its original performance and quality. The connection used such as bolting and nuts made the separation possible for reuse purposes (Gielen D.J, 1997). Worldsteel (2013) cited that steel contribute about 6.7% of the Co_2 emission in the world. According to Hammond G. and Jones C. steel have embodied carbon of 1.77$kgCO_2/kg$ which is reluctantly higher than the embodied carbon of a concrete. This proves that steel is no doubt as the major contributor of CO_2 emissions in the construction industry.

2.5 ICE database

Carbon emissions factors are taken from the standard data provided by Inventory Carbon and Energy (ICE) (Hammond and Jones, 2011) for this project. ICE is developed by University of Bath that is used as a conversion rate for building materials embodied carbon. This database is used widely in United Kingdom and other countries as carbon conversion standards. The inventory boundaries the conversion rate of embodied carbon from life cycle of 'cradle to gate'. Table 2 below illustrates the standard carbon emission rates for some building materials..All the materials have their own embodied carbon data and can be used as reference in calculating building carbon emissions.

Table 2.5.1 : Iventory of carbon and energy (ICE Version 1.6a) Source: Hammond and Jones (2011).

INVENTORY OF CARBON & ENERGY (ICE) SUMMARY				
Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon
Ceramics				
General	10.00	0.66	0.70	Very large data range, difficult to select values for general ceramics.
Fittings	20.00	1.07	1.14	Ref. 1.
Sanitary Products	29.00	1.51	1.61	Limited data.
Tiles and Cladding Panels	12.00	0.74	0.78	Difficult to select, large range, limited data. See Ref. 292.
Clay				
General (Simple Baked Products)	3.00	0.23	0.24	General simple baked clay products (inc. terracotta and bricks)
Tile	6.50	0.45	0.48	
Vitrified clay pipe DN 100 & DN 150	6.20	0.44	0.46	
Vitrified clay pipe DN 200 & DN 300	7.00	0.48	0.50	
Vitrified clay pipe DN 500	7.90	0.52	0.55	
Concrete				
General	0.75	0.100	0.107	**It is strongly recommended to avoid selecting a 'general' value for concrete.** Selecting data for a specific concrete type (often a ready mix concrete) will give greater accuracy, please see material profile. Assumed cement content 12% by mass.
16/20 Mpa	0.70	0.093	0.100	Using UK weighted average cement (more representative of 'typical' concrete mixtures).
20/25 MPa	0.74	0.100	0.107	
25/30 MPa	0.78	0.106	0.113	
28/35 MPa	0.82	0.112	0.120	
32/40 MPa	0.88	0.123	0.132	
40/50 MPa	1.00	0.141	0.151	

2.6 Office Buildings

Nowadays office buildings is tend to be designed with greener solutions for sustainable design and environmental friendly. Office buildings especially high rise types mainly use reinforced concrete and steel for the structural design. Office building in a study was found to be the most significant building type, responsible for at least 27% of total sector emissions in 1990 (Bush, Shane et al 1997). Energy consumption for office building in Malaysia according to the statistic of BEI is up to 200-300 kWh/m2 per year and proven that energy consumption and CHGs are highest in office building.

2.7 Building Environmental Assessment (BEA)

There are many Building Environmental Assessment tools (BEA) that are used in the cause towards green building. Some of the assessment tools used are:

- BREAAM - BRE, UK
- Eco-Quantum - IVAM, Netherlands
- LEED - USA
- TEAM - Ecobilan, France
- Envest 2 - BRE, UK
- ATHENA - Canada

However, there are weaknesses and limitation of the tools that is important to be pointed out for the benefits of environmental assessment in the near future (Haapio A. and Viitaniemi P., 2008).

Some of the weaknesses are:

- Most of the BEA tools do not include financial aspects in the evaluation except TEAM.
- Users of BEA tools will not know which of the tools is best for different type of buildings and which tool gives the most reliable result.
- The tools do not mention if they report uncertainties, or margin error in the results.
- BEA tools often use the predicted service life of a building in assessments. How the service lives of the material and buildings affect the result must be analysed thoroughly.

BIM as a new alternative of BEA tools is used for a more detail and effective analysis of a sustainable building construction.

2.8 Building Information Modelling (BIM)

AGC (2005) cited that BIM is the method of development that includes using of computer generated model to effectively manage planning, designs, construction and operation of a project. BIM model generated is data-rich, intelligent, object oriented, and illustrate parametric digital representation of the project. Various ways and views of data could be easily extracted to be analysed to produce important information for decision making and designs improvement.

BIM and the conventional 2D CAD can be differentiate as 2D CAD can only deals with independent 2D views such as plans, sections, and elevation of a project. Changes of one of the design entity in the project require revision on all the independent views to be updated to avoid errors. Moreover, 2D drawings are only graphical entities such as lines, circle and arcs compared to BIM which have intelligent model data representation, where entities are defined in context of building elements such as columns, beams, spaces, and walls (CRC Construction Innovation, 2007). **Figure 2.8.1** demonstrates the practical use of BIM.

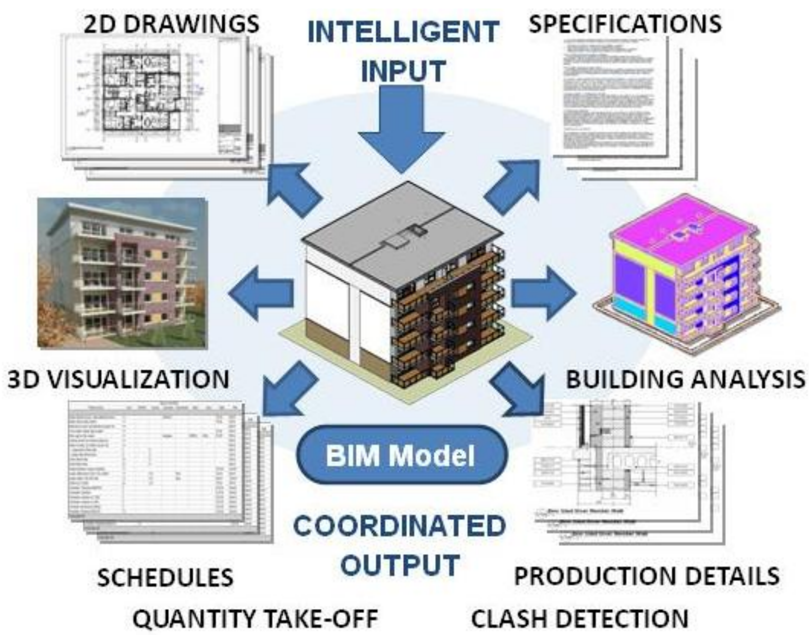


Figure 2.8.1: Use of BIM source: Crowley C., (2013)

Benefits of BIM according to Azhar et al. (N.D.):

- Controlled whole-life cycle costs and environmental data – environmental performance is more predictable, enabling for action plans and creative solutions.
- Better production quality – Output documentation is more flexible and exploits automation of data.
- Better building design – Proposals can be studied thoroughly, simulations can be perform and performance benchmarking for improvement of designs.
- Better customer service – Intelligent and rich visualization of the buildings can be generated
- Faster and efficient – information of the project is more easily shared, value-added and reused, and alteration of data is more error free and easier.

Wide access to data analysis and simulations in BIM helps designer to reduce errors in designing buildings. It concludes that the usage of BIM in analyzing building life cycle is more effective than conventional 2D CAD to help study the construction process and promote innovative ideas for the cause of green building designs.

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

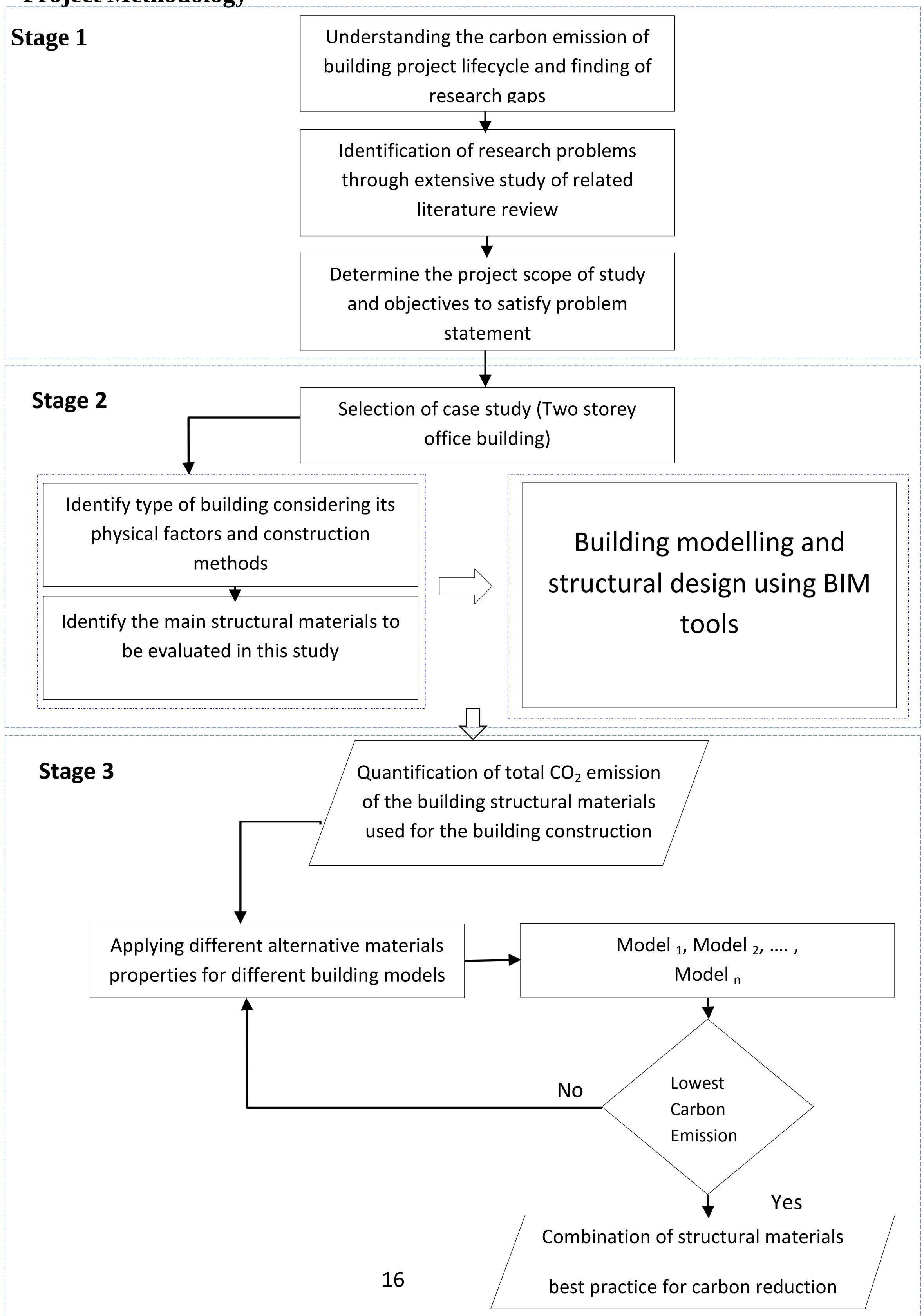
The objective of this project work is to determine the lowest carbon emission produced from different combination of conventional structural material that is concrete and steel. This project work involves the designing structural frame of a building and in the boundary of ‘cradle to gate’ of life cycle building. There are three stages engaged in this research methodology to obtain accurate and sufficient results.

The initial stage of the methodology consists of understanding the carbon emission of a building through its lifecycle. Relationship of building materials and carbon emission is studied in this process. Afterwards, identification of research problems through extensive study of related literature review is made to know the gravity and weight of the problems. The literature review involved extensive study on current and previous research about impacts of carbon emissions from construction industry to the surrounding environment and also the usage of Building information Modelling (BIM) in the building construction industry.

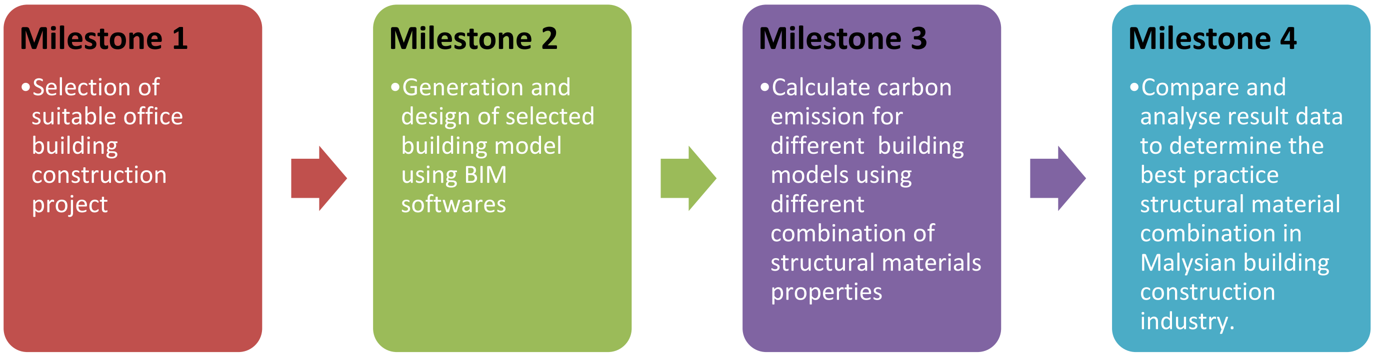
Next stage, selection of building type is made and an office building is chosen to be designed and modeled in this project work. The main structural materials are identified of its properties to be used in designing several models of the building. Different grade of concrete and steel will be combined for a building model design and structural framing of the building will be constructed virtually using BIM tools.

Third stage will involve quantification of the structural materials using BIM and carbon emissions of each building models will be calculated. Material combinations that yield the lowest carbon emission will be recommended to be used in the Malaysian building construction industry.

3.2 Project Methodology



3.3 Project Key Milestones



3.4 Project Activities Gantt Chart

FYP 1 Gantt Chart

No	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of FYP														
2	Define Objectives, Scope of Work, Methodology, Milestones, Project Planning and Literature Study														
3	Submission of Extended Proposal														
4	Proposal Defence drafting														
4	Viva: Proposal Defence														
5	BIM training/Project Work continues														
7	Draft Report														
8	Submission of Final Report														

FYP 2 Gantt Chart

No	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continues														
2	Progress Report Submission														
3	Project Work Continues														
4	Pre-Sedex														
5	Final Report Draft Submission														
6	Submission of Dissertation (Soft Bound)														
7	Technical Paper Submission														
8	Viva														
9	Submission of Project Dissertation (Hard Bound)														

CHAPTER 4

RESULT & DISCUSSION

4.1 Introduction

The flow of project work will be elaborated in detail in this chapter. A two-storey commercial office building is selected for this project. Case project is located at Indera Mahkota, Pahang, Malaysia and is under construction using conventional construction method. The main material that is going to be assessed in this project is typically concrete and reinforcement steels. Different concrete and steel grades will be match up with each other to be evaluated for lowest carbon emission. Hence, conversion rate of materials into carbon dioxide equivalent will be used to obtain result in term of carbon emission.

Using BIM, each model of the same building with different material combination will be designed and constructed virtually using Eurocode 2 to obtain the materials quantity in kilograms. Afterwards, a conversion unit to convert the materials quantity to carbon dioxide equivalent is used to determine the carbon emission. The result of those models will be compared with each other to know reasoning and discussed for a clear conclusion for this project work. Ultimately, the model with the lowest carbon emission output will be recommended as for its main materials that are concrete and steel to be practice in the Malaysian construction industry towards green building implementation.

4.1.2 Case Study Background

Office buildings nowadays are getting their popularity in construction sector as it is vital in the role of developing the economic and industry towards Malaysia vision 2020. Noted that the main contributor of GHGs are from the construction industry, it is necessary to investigate the source of GHGs from building construction and establish alternatives in order to reduce the impact of the building to the environment. A two-storey commercial office building is selected rather than a high rise building is simply due to feasibility of this project work that involves designing the main structural frame of the building and modelling each of the building model with BIM which would take a long period of time for a high rise building. Therefore, a two-storey building is adequate for the purposes of this study and time period given.

4.2 Findings

In order to obtain the building materials quantity in term of carbon dioxide equivalent (CO2-eqv), conversion factor is needed to standardize the units of measurement of the main building materials into kilograms of carbon dioxide equivalent (CO2-eqv). For each building materials, the carbon emission factor will be different as different amount of energy (embodied carbon) is used to create one kilogram of the building materials. The embodied carbon will act as the conversion factor in term of kgCO2 /kg.

Database from Inventory of Carbon & Energy (ICE) by Prof. Geoff Hammond (Hammond G.) and Craig Jones (Jones C.) will be used due to the absence of carbon conversion rates of construction building materials in Malaysia. This ICE is popularly being used in United Kingdom and several countries around the world for carbon emission analysis according to Hammond G.P. and Jones C.I. (2011).

Table below illustrate the example of the conversion factor database from Inventory of Carbon & Energy (ICE) by Prof. Geoff Hammond (Hammond G.) and Craig Jones (Jones C.).

Table 4.2.1: ICE Database Conversion Factor manual

Materials	**Embodied Energy & Carbon Coefficients**	
	EE – MJ/KG	**EC – kgCO2/kg**
CONCRETE		
General	0.75	0.100
20/25 Mpa	0.74	0.100
25/30 MPa	0.78	0.106
30/35 Mpa	0.82	0.112
32/40 Mpa	0.88	0.123
40/45 Mpa	0.94	0.132
40/50 Mpa	1.00	0.141
STEEL		
General	20.10	1.37
Bar & Rod	17.40	1.31

The quantification of CO_2 emitted from individual building materials is calculated by multiplying the building materials quantity in kilograms with the corresponding embodied carbon factor. Each model of office buildings with different material combination will yield different quantity of building materials thus resulting in different values of carbon emission from each building model where it will be analyzed to find the lowest carbon emission.

4.2.2 Building selection

A two-storey commercial office building is selected for this project. Case project is located at Indera Mahkota, Pahang, Malaysia and is under construction using conventional construction method. Below are several plan details of the building:

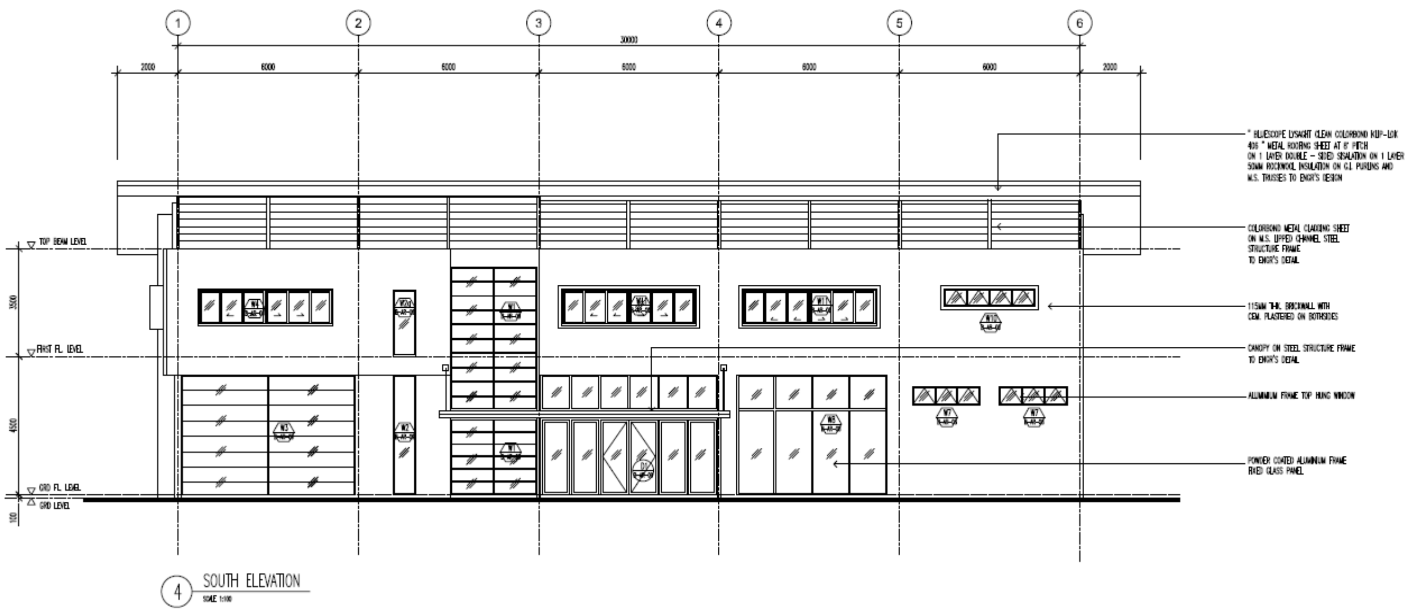


Figure 4.2.2.1: Front view of the selected office building

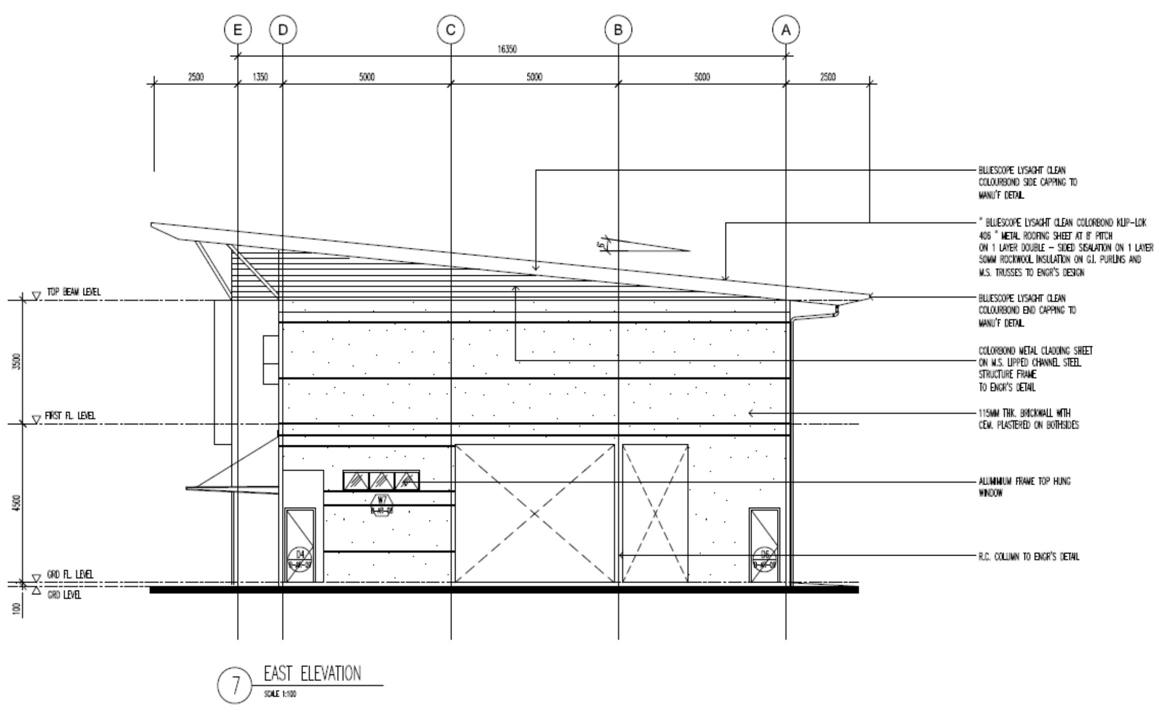


Figure 4.2.2.2: Side view of building

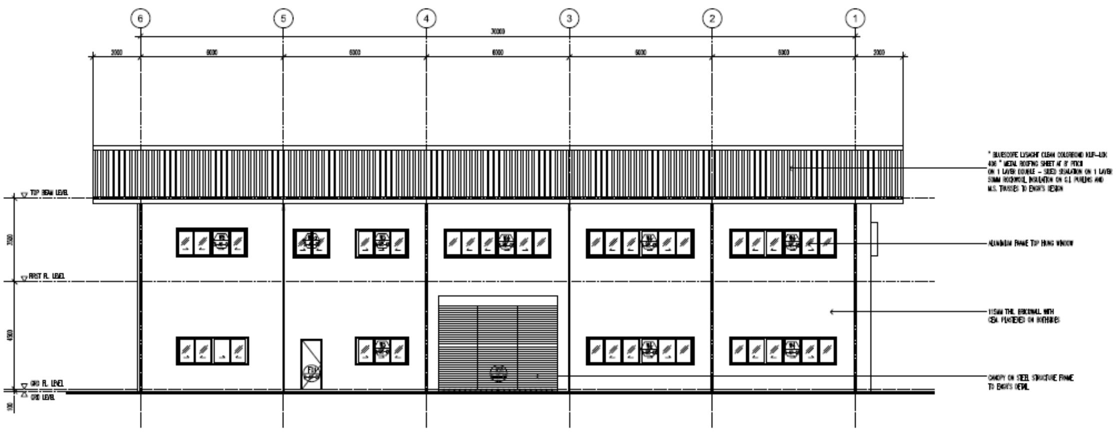


Figure 4.2.2.3: Back view of building

Further details of the building architectural characteristic can be referred at the back of this report .

4.2.3 Building Material Properties

Structural material evaluation is limited to conventional building materials that are concrete of steel. In this study different grades or class of concrete and steel will be combined to generate different material composition design to cater the building load.

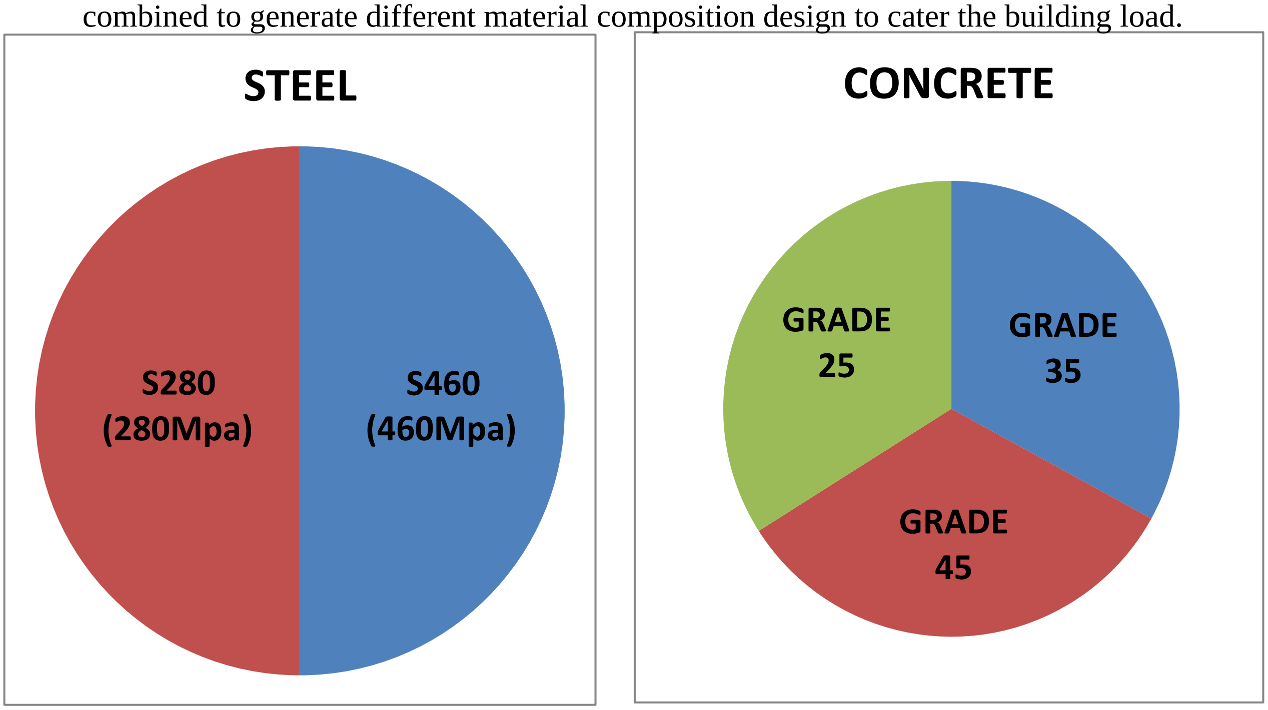


Figure 4.2.3.1: Concrete class and steel grade used

Each grade of concrete will be paired with reinforcement steel of strength of 280MPa and 460MPa for a model. Therefore, each model will have different design quantities of concrete and steel used to cater the building load. There will be a total of 6 models generated from this project work. The matching of materials will be the same as for the other concrete grades.

Figure 4.2.3.2: Material pairing example for building models generation

4.2.4 Design parameters

The structural design is done according to Eurocode 2. Below are the typical loads taken in designing the structural frame of the building:

Table 4.2.4.1 : Design loads and Material densities used

Design Loads	KN/m2
Flat roofs, no access	1.0
Office for general use (+0.5 extra)	3.0
Earth safe bearing pressure	160.0
Material Densities	KN/m3
Concrete, compacted	25.0
Brick, pressed	22.0
Steel Bar	78.5

To save time, the structural frame will be design based on one critical structural element which takes up the largest loading. Therefore, similar length of a member of a structural element may be designed as the critical.

Main structural component for the building models are:

- Roof beams
- First floor beams
- Ground Floor Beams
- Columns
- Staircases
- Slabs
- Pad footing

Each structural element will be design according to the material specified for the model thus having different sizing and characteristics.

4.2.5 BIM Tools and Building Modelling

For this project, **Autodesk Revit 2013** software will be used to model the architectural and structural component of the building for carbon emission analysis. Below are the complete building modeled and typical floor plans.

Figure 4.2.5.1: Architectural modelling showing the completed office building

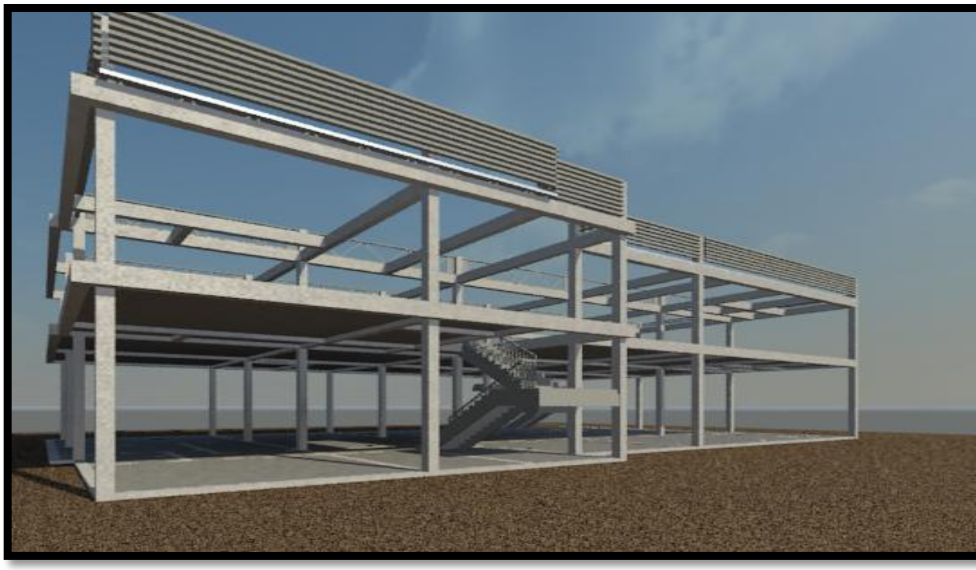


Figure 4.2.5.2: Structure visualization from BIM

With the use of BIM software, modelling and drafting of the building plan is faster and easier. It is also a platform where engineer could do detail study of the building using the tool provided by the software. Errors of structure can be predetermined before construction and help engineers visualize the building structure and design properly.

Building will be composed of elements in BIM such as beams, walls, columns, floors, etc rather than just a line in CAD drawing. Value of various parameters can be assign to these elements and make it possible for parameter analysis such as cost, energy, carbon emissions, and much more. It is a rich informative building model and so various changes can be made to satisfy designer's needs.

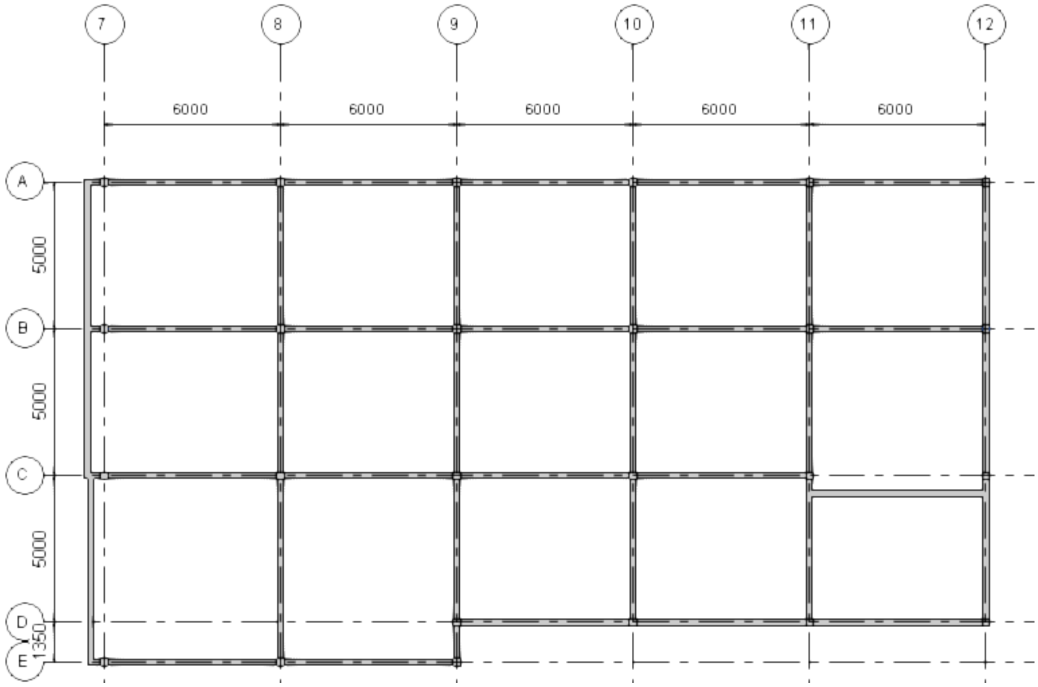


Figure 4.2.5.3 : Typical Roof Floor Beam Layout

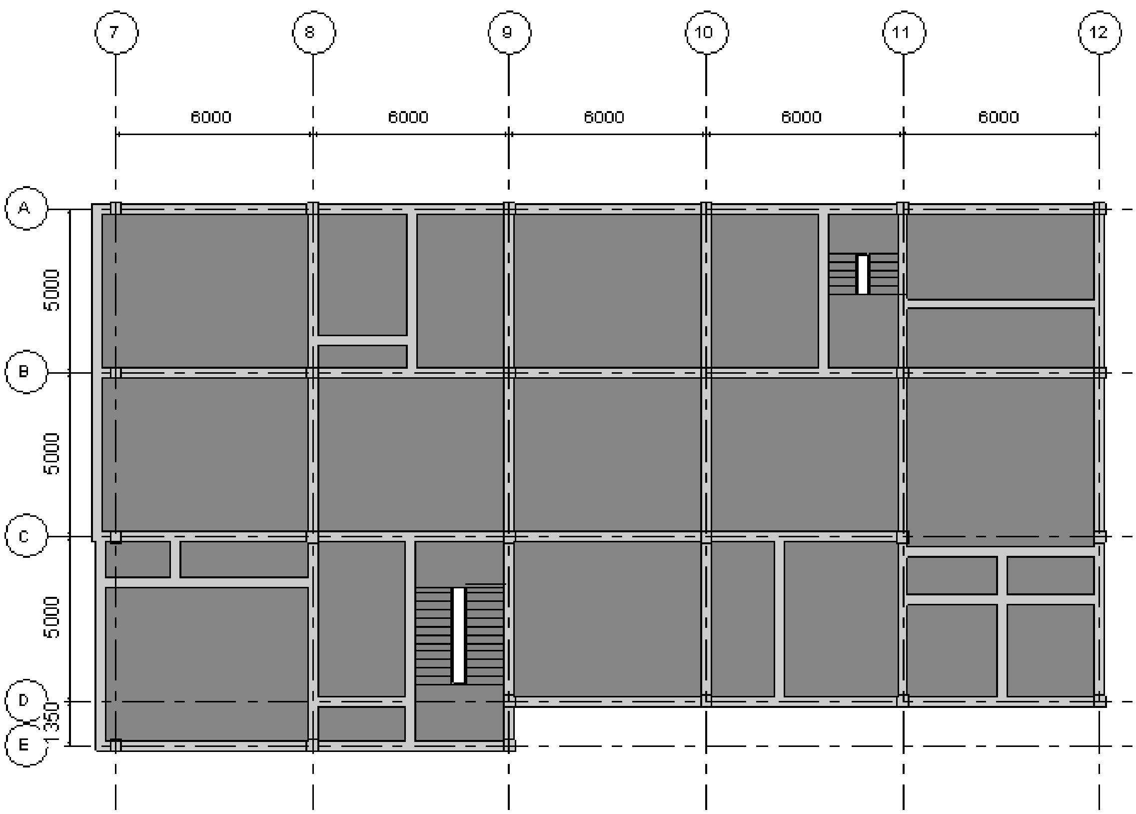


Figure 4.2.5.4: Typical First Floor Beam and Slab layout

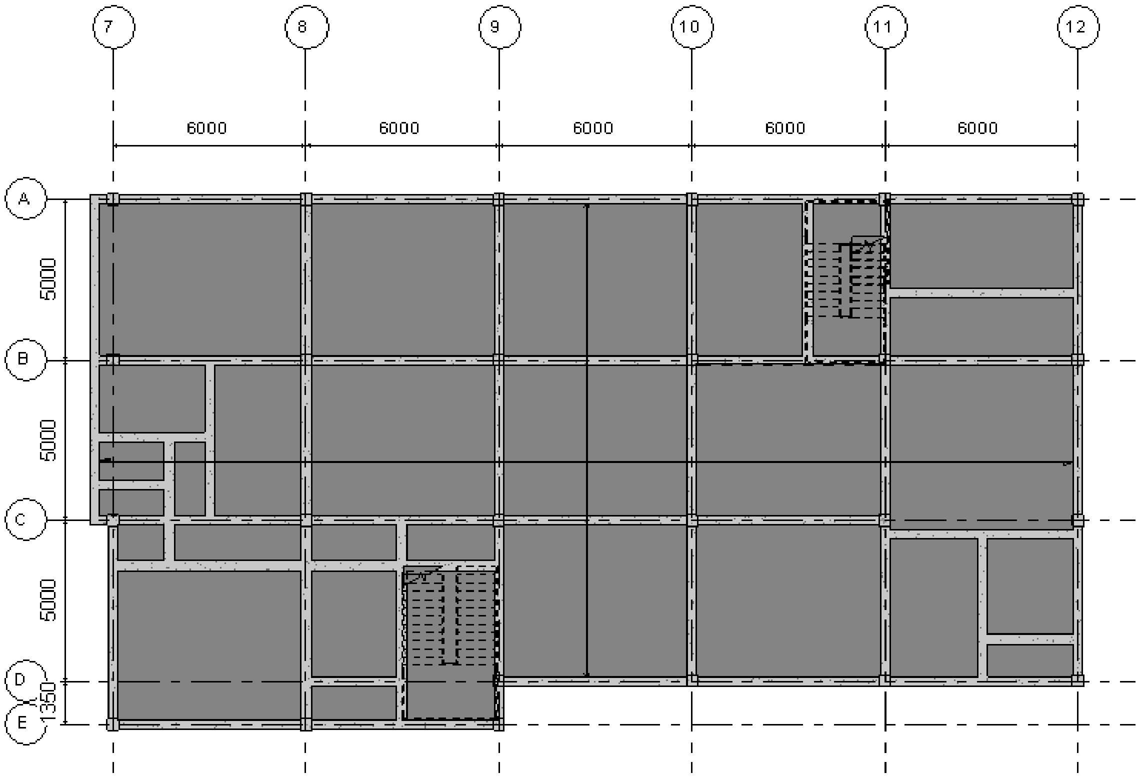


Figure 4.2.5.5: Typical Ground Beam and Slab layout

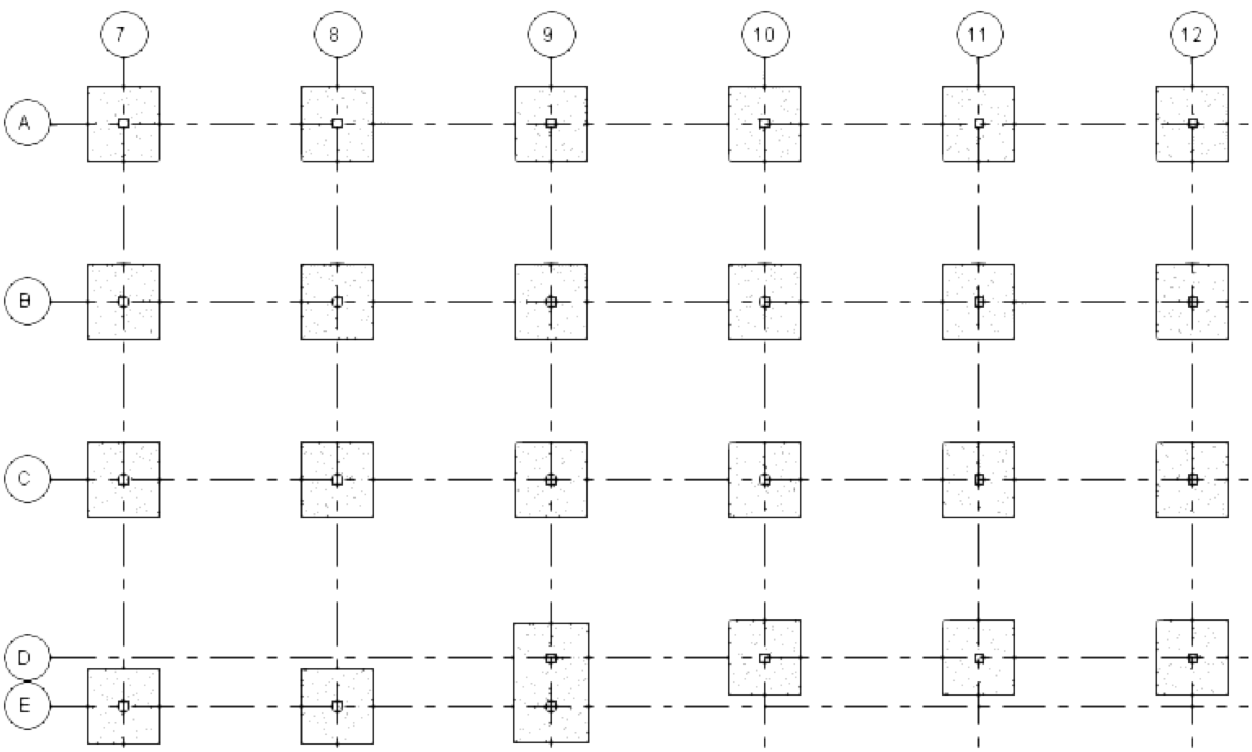


Figure 4.2.5.6: Typical Foundation Layout

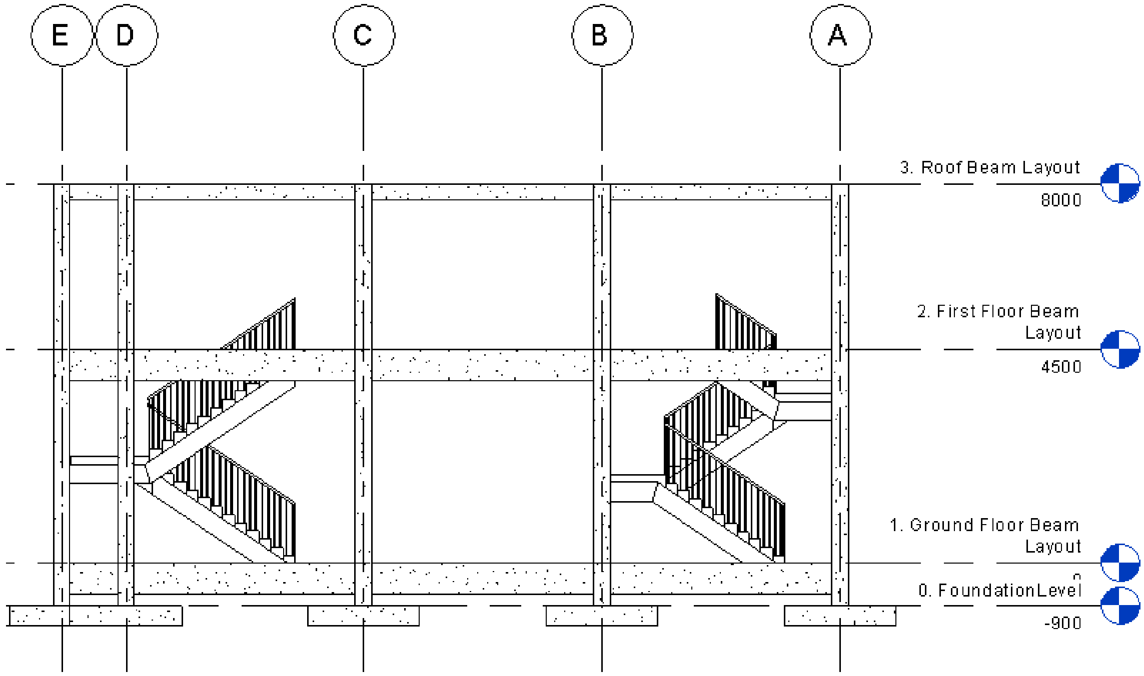


Figure 4.2.5.7: Side Elevation

4.3 Building Models and Results

Each model are designed using their specified pairing of materials to determine which composition of material will yield the lowest carbon emission. Full material pairing as follows.

Table 4.3.1: Pairing of materials for all building models

Building Model	Concrete Grade (MPa)	Steel Grade (MPa)
Model 1	G25	S280
Model 2	G25	S460
Model 3	G35	S280
Model 4	G35	S460
Model 5	G45	S280
Model 6	G45	S460

4.3.2 Model 1 : Concrete G25 x Steel 280Mpa

For this model below are the characteristics of the structural element as designed using Eurocode 2.

Table 4.3.2.1: Structural element and member sizing for Model 1

Element	Sizing (mm)
Roof Beam	**225 x 300mm**
First Floor Beam	**300 x 650mm**
Ground Floor Beam	**300 x 650mm**
Slab	**200mm**
Column	**350 x 350mm**
Foundation Pad Footing	**2100 x 2350 x 400mm**
Staircases	**As per architectural detail**

Total concrete and reinforcement steel bar used

Total Concrete G25xs280

No	Elements	Volume (m3)	Mass (KG)
1	RC Beams	122.9263725	307315.9313
2	Columns	27.25625	68140.625
3	Slabs	164	410000
4	Staircases	3.9357	9839.25
5	Foundation	51.7	129250
	TOTAL	**369.818323**	**924545.8063**

Total Steel G25xs280

No	Elements	Mass (KG)
1	Roof Beams	1377.00
2	First Floor Beams	3617.02
3	Ground Beams	3658.50
4	Slabs	7407.62
5	Columns	1555.39
6	Staircases	286.17
7	Footings	2719.28
	TOTAL	**20620.98**

Total carbon emission (KGCO$_2$)

Table 4.3.2.2: Total CO_2 emission for Model 1

Material	Mass (KG)	Embodied Carbon (KGCO$_2$/KG)	CO_2 Equivalent (KGCO$_2$)
Concrete	924 545.8063	0.100	92 454.58
Steel	20 620.98	1.310	27 013.48
		TOTAL CO_2	**119 468.06**

The table above illustrates the total carbon emission for the building model that used concrete grade of 25 MPa and steel grade 280 Mpa with a total of **119 468.06 kg** of carbon dioxide equivalent. The quantity of concrete can be seen much higher than the quantity of steel with **924 545.8063kg** and steel used is only **20 620.98kg** but the carbon emission for concrete is well reduced from the number because of the energy needed to create **1kg** of this concrete grade is only **0.100kgCO$_2$/kg** compared to steel having a high embodied carbon of **1.310** multiplier per kg for its quantity.

Concrete grade 25Mpa contributed **92 454.58kg** of CO_2 emissions and steel bar of grade 280Mpa contributed **27 013.48kg** of CO_2 emissions thus totaling to **119 468.06kg** of CO_2 released from the building construction.

4.3.3 Model 2 : Concrete G25 x Steel 460 Mpa

For this model below are the characteristics of the structural element.

Table 4.3.3.1: Structural element and member sizing for Model 2

Element	Sizing (mm)
Roof Beam	**150 x 300mm**
First Floor Beam	**250 x 450mm**
Ground Floor Beam	**250 x 450mm**
Slab	**200mm**
Column	**250 x 250mm**
Foundation	**2100 x 2100 x 400mm**
Staircases	**As per architectural detail**

Total concrete and reinforcement steel bar used

Total Concrete G25x460

No	Elements	Volume (m3)	Mass (KG)
1	RC Beams	70.8255	177063.75
2	Columns	13.90625	34765.625
3	Slabs	164	410000
4	Staircases	3.9357	9839.25
4	Foundation	44.1	110250
	TOTAL	**296.76745**	**741918.625**

Total Steel G25xs460

No	Elements	Mass (KG)
1	Roof Beams	1156.00
2	First Floor Beams	3144.72
3	Ground Beams	3210.86
4	Slabs	4683.57
5	Columns	1502.12
6	Staircases	210.19
7	Footings	1281.61
	TOTAL	**15189.07**

Total carbon emission ($KGCO_2$)

Table 4.3.3.2: Total CO_2 emission for Model 2

Material	Mass (KG)	Embodied Carbon ($KGCO_2/KG$)	CO_2 Equivalent ($KGCO_2$)
Concrete	741 918.625	0.100	74 191.86
Steel	15 189.07	1.310	19 897.68
		TOTAL CO_2	**94 089.54**

Usage of higher reinforcement steel strength (S460MPa) with the same grade of concrete for the building construction made most of the structural frame member to be reduced in sizing by approximately by 10-25%. Reduction in concrete quantity from smaller structural section will result in lesser carbon emission from the previous building model.

The total carbon emission for this building model that used concrete grade of 25MPa and steel grade 460Mpa is **94 089.54kg** of carbon dioxide equivalent. The quantity of concrete used is **741 918.625kg** and reinforcement steel used is **19 897.68kg.** The same multiplier is used of embodied carbon is used for concrete of the same grade while steel will remain the same regardless its yield strength due to the energy creating **1kg** of the same steel type is the similar.

Concrete grade 25Mpa contributed **74 191.86kg** of CO_2 emissions and steel bar of grade 460Mpa contributed **19 897.68kg** of CO_2 emissions thus totaling to **94 089.54kg** of CO_2 released from this building construction which is **21.24%** less than **Model 1.**

4.3.4 Model 3 : Concrete G35 x Steel 280 Mpa

For this model below are the characteristics of the structural element.

Table 4.3.4.1: Structural element and member sizing for Model 3

Element	Sizing (mm)
Roof Beam	**200 x 350mm**
First Floor Beam	**250 x 550mm**
Ground Floor Beam	**250 x 550mm**
Slab	**150mm**
Column	**300 x 300mm**
Foundation	**2100 x 2100 x 400mm**
Staircases	**As per architectural detail**

Total concrete and reinforcement steel bar used

Total Concrete G35xs280

No	Elements	Volume (m3)	Mass (KG)
1	RC Beams	89.80795	224519.875
2	Columns	20.025	50062.5
3	Slabs	125.85	314625
4	Staircases	3.9357	9839.25
5	Foundation	44.1	110250
	TOTAL	**283.71865**	**709296.6**

Total Steel G35xs280

No	Elements	Mass (KG)
1	Roof Beams	1400.00
2	First Floor Beams	3560.00
3	Ground Beams	3594.08
4	Slabs	7833.23
5	Columns	1567.60
6	Staircases	287.54
7	Footings	2503.15
	TOTAL	**20745.60**

Total carbon emission ($KGCO_2$)

Table 4.3.4.2: Total CO_2 emission for Model 3

Material	Mass (KG)	Embodied Carbon ($KGCO_2/KG$)	CO_2 Equivalent ($KGCO_2$)
Concrete	709 296.6250	0.112	79 441.22
Steel	20 745.6000	1.310	27 176.74
		TOTAL CO_2	**106 617.96**

For this model, concrete grade of 35Mpa combined with reinforcement steel of 280Mpa is used to construct the building structural frame. From the structural sizing, we could see a **10-20%** reduction of sizing compared to usage of concrete grade 25Mpa with the same reinforcement steel strength.

The quantity of concrete used is **709 296.6250kg** while reinforcement steel used is **20 745.60kg** in order to construct the building structural frame. The embodied carbon conversion factor for concrete of grade 35Mpa is **0.112 kgCO_2/kg** of concrete while the embodied carbon for steel bar remains the same. This will give a higher figure of CO_2 emission number if the same quantity of concrete with different grade is to be compared.

Hence, concrete grade 35Mpa contributed **79 441.22kg** of CO_2 while usage of reinforcement steel bar of grade 280Mpa yields **27 176.74kg** of CO_2 resulted in a total of **106 617.96kg** of CO_2 emission from this building model.

4.3.5 Model 4 : Concrete G35 x Steel 460 Mpa

For this model below are the characteristics of the structural element.

Table 4.3.5.1: Structural element and member sizing for Model 4

Element	Sizing (mm)
Roof Beam	**150 x 300mm**
First Floor Beam	**200 x 400mm**
Ground Floor Beam	**200 x 400mm**
Slab	**150mm**
Column	**230 x 230mm**
Foundation	**2000 x 2000 x 400mm**
Staircases	**As per architectural detail**

Total concrete and reinforcement steel bar used

Total Concrete G35xS460

No	Elements	Volume (m3)	Mass (KG)
1	RC Beams	53.17579	132939.475
2	Columns	11.77025	29425.625
3	Slabs	125.85	314625
4	Staircases	3.9357	9839.25
5	Foundation	40	100000
	TOTAL	**234.73174**	**586829.4**

Total Steel G35xs460

No	Elements	Mass (KG)
1	Roof Beams	1125.94
2	First Floor Beams	3266.00
3	Ground Beams	3185.88
4	Slabs	4580.75
5	Columns	1250.13
6	Staircases	210.19
7	Footings	1218.48
	TOTAL	**14837.37**

Total carbon emission ($KGCO_2$)

Table 4.3.5.2: Total CO_2 emission for Model 4

Material	Mass (KG)	Embodied Carbon ($KGCO_2/KG$)	CO_2 Equivalent ($KGCO_2$)
Concrete	586 829.3500	0.112	65 724.89
Steel	14 837.3700	1.310	19 436.95
		TOTAL CO_2	**85 161.84**

The structural member of this building frame can be seen reduced in sizing due to having higher reinforcement steel strength (S460Mpa).

The total carbon emission for this building model that used concrete grade of 35MPa and steel grade 460Mpa is **85 161.84kg** of carbon dioxide equivalent. The quantity of concrete used is **586 829.35kg** and reinforcement steel used is **14 837.37kg.** The same multiplier is used of embodied carbon is used for concrete of the same grade while steel will remain the same regardless its yield strength due to the energy creating **1kg** of the same steel type.

Concrete grade 35Mpa contributed **65 724.89kg** of CO_2 emissions and steel bar of grade 460Mpa contributed **19 436.95kg** of CO_2 emissions thus totaling to **85 161.84kg** of CO_2 released from this building construction which is **20%** less than **Model 3.**

4.3.6 Model 5 : Concrete G45 x Steel 280 Mpa

For this model below are the characteristics of the structural element.

Table 4.3.6.1: Structural element and member sizing for Model 5

Element	Sizing (mm)
Roof Beam	**200 x 300mm**
First Floor Beam	**225 x 500mm**
Ground Floor Beam	**225 x 500mm**
Slab	**125mm**
Column	**250 x 250mm**
Foundation	**2000 x 2100 x 350mm**
Staircases	**As per architectural detail**

Total concrete and reinforcement steel bar used

Total Concrete G45xS280

No	Elements	Volume (m3)	Mass (KG)
1	RC Beams	74.06895	185172.375
2	Columns	13.90625	34765.625
3	Slabs	104.875	262187.5
4	Staircases	3.9357	9839.25
5	Foundation	36.75	91875
	TOTAL	**233.5359**	**583839.8**

Total Steel G45xs280

No	Elements	Mass (KG)
1	Roof Beams	1551.20
2	First Floor Beams	3937.80
3	Ground Beams	3982.88
4	Slabs	7834.76
5	Columns	1527.88
6	Staircases	287.54
7	Footings	2441.50
	TOTAL	**21563.56**

Total carbon emission ($KGCO_2$)

Table 4.3.6.2: Total CO_2 emission for Model 5

Material	Mass (KG)	Embodied Carbon ($KGCO_2/KG$)	CO_2 Equivalent ($KGCO_2$)
Concrete	583 839.80	0.132	77 066.85
Steel	21 563.56	1.310	28 248.26
		TOTAL CO_2	**105 315.11**

For **Model 5**, the material combination is concrete grade 45Mpa, a high strength concrete with steel bar strength of 280Mpa. The member sections of this building will be the smaller much smaller than the other previous models with the same reinforcement steel strength.

583 839.80kg of concrete grade 45Mpa is used with **21 563.56kg** of reinforcement steel bar to construct the building structural framing. The embodied carbon for this concrete grade is **0.132kgCO_2/kg** of concrete while always, steel embodied carbon remain the same with **1.310 kgCO_2/kg** of steel bar. Therefore, CO_2 emissions will be high from this type of concrete in context on the comparison of quantity used with other concrete grades.

The concrete used contributed **77 066.85kg** of CO_2 emission while the reinforcement steel bar contributed **28 248.26kg** of a total of **105 315.11kg** CO_2 emission from this building structural frame.

4.3.7 Model 6 : Concrete G45 x Steel 460 Mpa

For this model below are the characteristics of the structural element.

Table 4.3.7.1: Structural element and member sizing for Model 6

Element	Sizing (mm)
Roof Beam	**125 x 300mm**
First Floor Beam	**200 x 400mm**
Ground Floor Beam	**200 x 400mm**
Slab	**125mm**
Column	**230 x 200mm**
Foundation	**1900 x 1900 x 350mm**
Staircases	**As per architectural detail**

Total concrete and reinforcement steel bar used

Total Concrete G45xS460

No	Elements	Volume (m3)	Mass (KG)
1	RC Beams	51.554065	128885.1625
2	Columns	10.235	25587.5
3	Slabs	104.875	262187.5
4	Staircases	3.9357	9839.25
4	Foundation	31.5875	78968.75
	TOTAL	**202.187265**	**505468.1625**

Total Steel G45xs460

No	Elements	Mass (KG)
1	Roof Beams	1235.00
2	First Floor Beams	3381.10
3	Ground Beams	3431.08
4	Slabs	5153.34
5	Columns	1229.82
6	Staircases	210.19
7	Footings	1155.34
	TOTAL	**15795.87**

Total carbon emission (KGCO$_2$)

Table 4.3.7.2: Total CO_2 emission for Model 6

Material	Mass (KG)	Embodied Carbon (KGCO$_2$/KG)	CO_2 Equivalent (KGCO$_2$)
Concrete	505 468.1625	0.132	66 721.80
Steel	15 795.87	1.310	20 692.59
		TOTAL CO_2	**87 414.38**

For the last model, highest of concrete and steel grade is used in designing the building structural frame. All the structural elements sizing is the smallest among all models.

Concrete used is **505 468.1625kg**, the lowest quantity for this project work while steel rebar used is **15 795.87kg** for this building model. Quantity of steel used is reduced by **10%** from **Model 5** with the same concrete grade.

Overall, concrete usage contributed **66 721.80kg** of CO_2 emission and steel with **20 692.59kg** of CO_2 emission totaling to **87 414.38kg** of CO_2 emission for this building model which is **17%** lesser than **Model 5.**

4.3.8 Results analysis and discussion

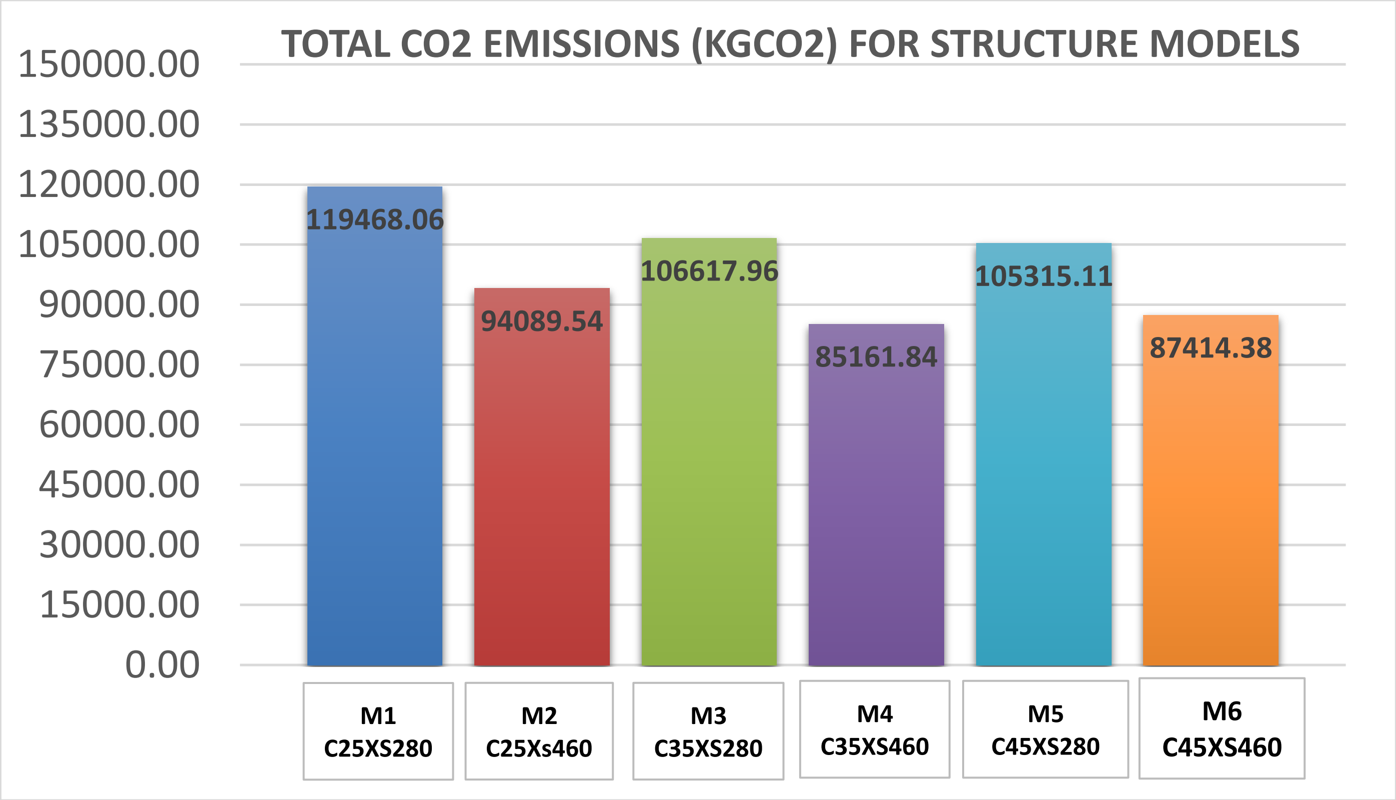
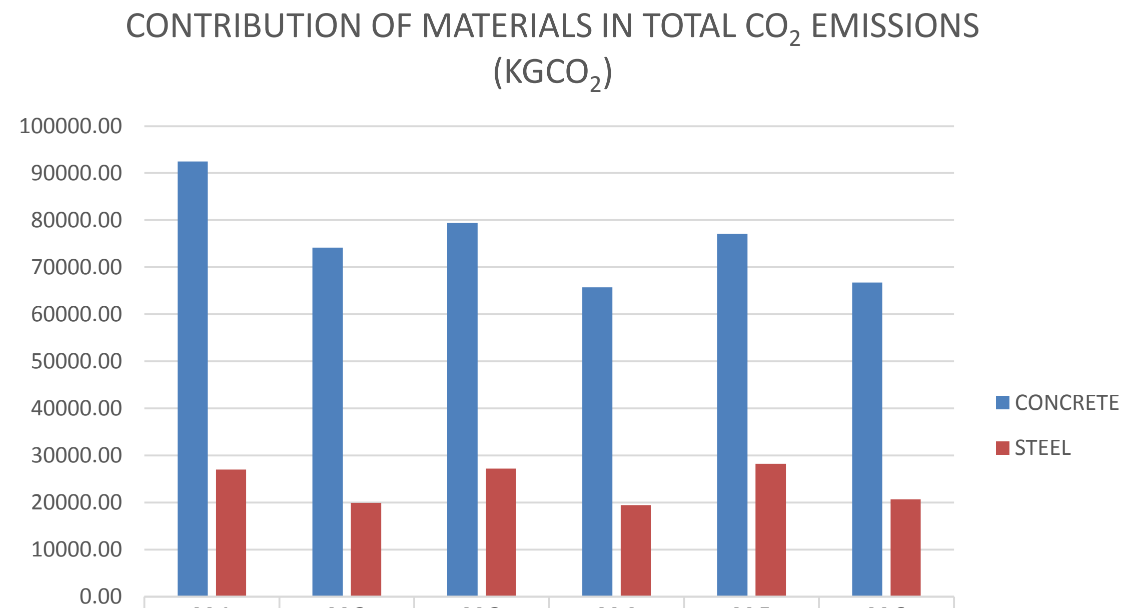


Figure 4.3.8.1: Total CO_2 emissions for all structure models

From figure 4.3.8.1, **Model 4** (C35xS460MPa) yielded the lowest CO_2 emissions with **85 161.84kg** of CO_2 followed second by **Model 6** (C45xS460Mpa) with **87 414.38kg** CO_2, third by **Model 2** (C25xS460MPa) with **94 089.54kg** CO_2, **Model 5** (C45xS280MPa) with **105 315.11kg** CO_2, **Model 3** (C35xS280MPa) with **106 617.96kg** CO_2, and lastly **Model 1** with the highest CO_2 emission with **119 468.06kg** of CO_2 equivalent.



	M 1 C25XS280	M 2 C25XS460	M 3 C35XS280	M 4 C35XS460	M 5 C45XS280	M 6 C45XS460
CONCRETE	92454.58	74191.86	79441.22	65724.89	77066.85	66721.80
STEEL	27013.48	19897.68	27176.74	19436.95	28248.26	20692.59

Figure 4.3.8.2: Contribution of materials in total CO_2 emissions

From figure 4.3.8.2, concrete is the main contributor for high CO_2 emission although its embodied carbon value per kg material is much lower than of steel rebar due to high volume used as the structural framing shaping. Hence, type of concrete will be a vital manipulative element in reducing carbon emission. Selection of concrete grade and type is important in reducing carbon emission as different types of concrete have different values of embodied carbon.

Concrete grade 35Mpa is seen to be the lowest contributor to CO_2 emission of the building compared to concrete grade 35Mpa and 45Mpa assuming steel reinforcement strength is the same. For steel, obviously steel of higher grade is preferred to yield a low carbon emission rather than a low strength steel of the same type. This denoted that combination of concrete grade 35Mpa with steel reinforcement of 460Mpa strength is the best material to be used for this building construction for highest carbon reduction from this set of project work material group.

Taking **Model 1** (C25xS280) as a benchmark model since it consisted of materials that yield the highest CO_2 emission; we can compare the reduction percentage of other models in term of carbon emission.

Table 4.3.8.3: Comparison between models in term of carbon emission reduction

Model	Total Carbon Emission ($KgCO_2$)	Carbon Reduction Compared to M1	Percentage Reduction
M 1 C25xS280Mpa	119 468.06		
M 2 C25xS460Mpa	94 089.54	**25 378.52**	**21.24 %**
M 3 C35xS280Mpa	106 617.96	**12 850.10**	**10.75%**
M 4 C35xS460Mpa	85 161.84	**34 306.22**	**28.76%**
M 5 C45xS280Mpa	105 315.11	**14 152.95**	**11.85%**
M 6 C45xS460Mpa	87 414.38	**32 053.68**	**26.83%**

The table above illustrate the percentage amount of carbon emission reduction of all the structure models comparing to **Model 1**. The calculation of percentage is done as shown below:

$$\frac{M1\ (KgCO2)-Mn(KgCO2)}{M1\ (kgCO2)}\ x\ 100\% = \text{Percentage Reduction}$$

From the table data, changing the concrete grade to 35Mpa (**Model 3**) and 45Mpa (**Model 5**) with the same reinforcement steel strength can reduce in CO_2 emission by **10.75%** to **11.85%** respectively. Changing the reinforcement steel strength to 460Mpa will resulted in more reduction of CO_2 emissions as per demonstrate in **Model 2**, carbon emission is reduced to **21.24%**. This is due to less quantity of steel being used as its strength increases and the high embodied carbon $kgCO_2/kg$ value for steel compared to concrete. When both material used changed into the highest grade for this project work, **Model 4** (C35xS460Mpa) and **Model 6** (C45MpaxS460Mpa) achieve a total reduction of carbon emission by **28.76%** and **26.83%** respectively.

From the result obtained, lowest carbon emission cannot be achieved simply by using the highest grade of concrete and steel. Comparing **Model 6** and **Model 4**, **Model 4** with a low grade of concrete (35Mpa) yet same reinforcement steel strength (460Mpa) yield a slight low total of CO_2 with **85 161.84kg** in quantity compared to **Model 6** which both of the material having the highest grade (C45xS460Mpa) with a total of **87 414.38kg** of CO_2 released. This is because the quantity of steel used in **Model 6** (**20 692.59kg**) is slightly more compared to **Model 5** (**19 436.95kg**). It is identified that the Model 6 uses more reinforcement steel quantity on structural slab of the building and the embodied carbon of concrete grade 45Mpa is **0.132kgCO_2/kg** is more higher than of concrete grade 35Mpa (**0.112kgCO_2/kg**). Structural model with concrete grade 35Mpa is designed to have slab thickness of 150mm while structural model with 45Mpa concrete grade is to be design to have a slab thickness of 125mm (Refer structural model element characteristic table). It seems that having a slab thickness of 125mm with concrete grade 45Mpa need more reinforcement steel to cater the design loading than a 150mm slab using concrete grade 35Mpa due to more deflection hence more steel reinforcement is needed. In this case, the design of a structural element sizing is also important in carbon reduction. Designers need to find a suitable section design that would yield the max reduction of building material used thus result in carbon emission reduction.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In the previous chapter, all the project work result and findings have been discussed thoroughly. This final chapter will summarize the project work findings in relation to the objective and aim of this project. Finally, a recommendation is provided in order for further studies can be done effectively for this scope of research topic.

5.1 Review of Project Work Objectives

The aim of this project work is to determine the carbon reduction best practice for conventional building material that is concrete and steel in the Malaysian building construction industry. In conjunction to achieve the project work aim, the following objectives are identified.

1) Assessment of CO_2 emissions produced from different conventional structural materials used in construction of buildings using Building Information Modelling (BIM).

2) Analysis and comparison of CO_2 emissions generated by different combination of conventional structural materials.

3) Selection of the best structural materials combination that generates the lowest carbon emissions to be practice in building construction.

5.2 Research Conclusion

Building construction industries is one of the main contributor to a country development but also catalyst the negative impacts to environment if it is not plan properly. Awareness of building construction negative impacts to the environment such as implication of GHGs emission should be instilled in engineers and designers to move towards green building design to reduce the damage done.

At the end of this project work, total carbon emission for all the design Models have been obtained successfully. CO_2 emission have been calculated successfully for all structure models using BIM tools and proven that BIM helps the process of material quantification to be done in a short amount of time. The total emission for each models are compared to each other and a thorough discussion is made. From the project work, **Model 4** (C35xS460Mpa) is selected as the best carbon reduction practice for conventional building materials as it yields the lowest carbon emission with **85 161.84kg** of CO_2 equivalent. Following second by **Model 6** (C45xS460Mpa) with **87 414.38kg** CO_2, third by **Model 2** (C25xS460MPa) with **84 089.54kg** CO_2, **Model 5** (C45xS280MPa) with **105 315.11kg** CO_2, **Model 3** (C35xS280MPa) with **106 617.96kg** CO_2, and lastly **Model 1** with the highest CO_2 emission with **119 468.06kg** of CO_2 equivalent (Figure 4.3.8.1). Taking **Model 1** (C25xS280Mpa) as a benchmark model, CO_2 reduction highest can be achieved is by **28.76%** in total reduction by **Model 4** (C35xS460Mpa).

Building material selection is crucial in practicing carbon reduction in construction industries. Material with a low embodied carbon ($kgCO_2/kg$) and high in properties strength is recommended to be used in building construction. Having a low embodied carbon value material but low in properties strength will result in more usage of the material thus increased in the total carbon emission. This goes the same as material having a high properties strength but also having a high embodied carbon value would result in high total carbon emission although the usage of material is smaller. Therefore, thorough analysis of material effects on total carbon emission of a building should be done before the material is selected to be used in construction.

Based on the project work data, the best concrete to be used is **concrete grade 35Mpa** with embodied carbon value of 0.112kgCO_2/kg and the best reinforcement steel to be used is **steel of strength 460Mpa** as its embodied carbon value is the same for both grade of steel compared in this project. Overall, the total emission of carbon reduction also depends on the designers input of structural sizing. The best is to have the minimum structural member sizing that is adequate to cater the building and design load as it reduces the quantity of concrete used. Nevertheless, smaller structural member will require a high number of reinforcement steel to help cater the design load and prevent the member from failing. Ultimately, designers have to use an optimum member sizing having the optimum concrete and steel quantity needed without further increasing the other around if one is reduced.

In conclusion, **Model 4 (C35xS460Mpa)** is chosen to be as the recommended model to be followed in Malaysian building construction industry as it yields the lowest carbon emission from this group set of material data. All the objectives and aim of this project work is achieved and the project is considered successful.

5.3 Recommendation

For a sustainable development, carbon reduction best practice should be developed in Malaysian building construction industry. The building lifecycle ‘cradle to gate’ consists of raw materials consumption which resulted in high amount of carbon emission. In conjunction to improve the sustainability of Malaysian building construction industry, some recommendation is provided. Selection of building materials to be used in construction is vital in this case. Building materials that have a high embodied carbon will lead to harm the environment and affect the climate patterns and global temperature.

Concrete and steel as the main building materials and as the major contributors to a building carbon emission cab be reduced by using alternative low carbon materials. As an example, usage of granulated slag (GGBS) and fly ash in design of concrete mix as alternative for cement will significantly reduce the total carbon emissions as embodied carbon value will be lower than of a concrete. In addition, reusable building materials can be an alternative materials beside recycled steel. Larger carbon reduction can be achieved when the building material is reused without processing.

Other recommendation is to improve the building design for optimal structural system. Unnecessary structural elements can be cut off to reduce the quantity of building material used. Reduction of building quantity will lead to carbon emission reduction for a building structure. In case of continuing this project work, more set of materials are recommended to be analyzed and instead of just concrete and steel. Other building material such as glass, wood, steel framing, tiles, and many more should be included in the study and also other concretes grade and reinforcement steel strength as well. If each building material can be selected carefully for carbon reduction best practice, CO_2 emission from building construction industry can be reduced significantly in order to achieve a sustainable development without harming the environment and risking the earth’s future.

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APPENDICES