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Analysis and Decreasing of Construction Carbon Footprint using Building Information Modeling Approach.

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ABSTRACT
Carbon emission has become a global challenge which requires a global approach before we get to a point of irreversible; the amount of CO_2e released to the atmosphere yearly from different construction industries are becoming alarming. To overcome this global climate change (GCC), global warming potential (GWP) caused by CO_2eemission, more attention must be placed on the estimation of the carbon footprint of construction materials use in civil engineering construction.
The study focuses mainly on carbon footprint analysis and its reduction during extraction of construction materials and construction processes using the Life Cycle Assessment (LCA) and Building Information Modeling (BIM) approach. LCA and BIM approachused to analyze CO_2emission from materials extraction (embodied carbon) to construction use stage
The paper proposes a simplified method of analysing carbon footprint of construction materials. I.e. concrete, steel and wood. The embodied carbon of the sub-structural and super structural part of the building using existing tools. BIM tool (Revit Autodesk) and One-click LCA Carbon calculation software are used to evaluate carbon footprint in each of the construction phases. A case study of existing building from Sweco Company, Sweden was analysed to calculate the amount of carbon footprint in each of construction stages and materials.
The results obtained reveal that the amount of CO_2e emission from materials extraction to the site (A1 – A3 in the life cycle assessment) contribute almost 80% to total construction CO_2emission, comparison also made between concrete, steel and wood materials.The study identified which of the construction stages contribute immensely to global warming.The study reveals that wood is an environmental friendly material with low carbon footprint compare to concrete and steel.

Keywords: Carbon Footprint; Life Cycle Assessment; Embodied Carbon; Construction materials; Carbon Emission; BIM.

I. INTRODUCTION

Carbon emission has become a globalchallenge over the past decade across the globe; the amount of CO_2e releases to the atmosphere from different sectors is becoming alarming. Our planet is becoming unsafe because of our daily activities most especially construction activities. The climatic change in our planet has proven that we have released enough carbon into the atmosphere.

The amount of CO_2 emission increasing daily and the rate of greenhouse gases in our buildings are escalating the reduction in greenhouse gases emissions is of utmost priority, which demands urgent attention before it becomes an irreversible climatic change in the years to come. To achieve a sustainable building environment, thorough study and research have to be done on our building industry to evaluate the amount of CO_2 in a building and to achieve an absolute CO_2 emission toward 2050 as proposed by European Union Parliament in line with the 2015 Paris Agreement. To overcome, global climate change (GCC), global warming potential (GWP) caused because of CO_2eemission, more attention must be placed on the estimation of carbon footprint in our daily activities most especially in the civil engineering industry.

The European Union (EU) aims at extreme reductions in domestic greenhouse gas emissions (GHG) by 80% in 2050 compared to 1990 level [14]. One of the basics European Union's "Europe 2020" energy strategy is the reduction of the total energy usage by using of energy efficiency improvements.

The Global Status Report 2017 prepared by the International Energy Agency (IEA) for the Global Alliance for Buildings and Construction (GABC). GABC major aims is to organize by bringing together the building and construction industry, countries and stakeholders to start the awareness and accelerate the global transition towards low-emission, energy-efficient buildings. It has been reported that more than one- third of the usage of total energy and CO_2 emissions is because of the building sector in the developed and developing nations [9].

The usage of non-renewable energy source has adverse effect on our environment; the effect is directly proportional to amount of energy consumption. CO_2 emission by a building construction occur directly and indirectly. The direct CO_2 emission emanates from consumptions of fossil fuel i.e. coal, natural gas, diesel and others oil product commodities and the indirect CO_2 emission come from the usage of electricity, the indirect CO_2 emission responsible for 85% of the total global CO_2 emission while only 14% happen due to direct emission.

Climate and Energy Framework,proposes that by 2030, twenty-seven percent (27%) of energy should be sourced from the renewable energy sources, and productivity and energy efficiency should be increased by 27% [13].

Many researchers have worked extensively on CO_2emission reduction but some of their findings were limited to causes of CO_2emissions with little emphasis on carbon footprint analysis. This study focuses on analysis of the construction materials and stages contributing immensely to carbon emissions, and it based on life cycle assessment and building information modeling method to select low carbon content and sustainable materials.

II. REVIEW OF ACHIEVEMENTS:CARBON FOOTPRINT EMISSION IN CONSTRUCTION

Over the years, the construction industry has gained much attention through the increasing effort on its carbon footprint, also known as embodied carbon. Concrete, steel, and finishes contribute roughly 75 percent of the building's total embodied carbon.

Embodied carbon impacts climate change in the near term, therefore addressing this aspect of building materials is relevant and important, [5].

Carbon emissions in construction simply means the total energy consumed or amount of greenhouse gas emissions generated to produce the materials and services required to bring the building into existence, including raw material extraction and processing, transportation, manufacturing, and the energy use and emissions caused by the construction and demolition processes [5].

The building carbon life cycle can be divided into two parts embodied carbon and operational carbon. The emission generated from raw material, transportation, and during installation is known as embodied carbon while the operation carbon is the amount CO_2 emitted during the usage these are generated from heating, cooling, and lighting. Carbon dioxide emission cradle from on-site high rise building can be generated from a concreting work [14], the on-site concrete work needs additional equipment especially in high rise building such as tower crane, concrete pump and ready-mix truck. A tower crane is one of the main equipment for concrete work in the construction of high, especially in a high-rise building. In reality, a tower crane needs a large amount of energy and very significant as carbon dioxide (CO_2) emission. [13]Study shows that each year, 6.13 billion square meters of buildings are constructed. The carbon emissions from the construction activities is approximately 3729 million approximately equivalent [2].

The urban built environment is accountable for 75% of annual global GHG emissions: buildings sector alone responsible for 40% as shown in Fig. 2.1 below. Reducing these emissions is the major solution to addressing climate change and meeting Paris Climate Agreement targets. [2], Fig.2.1 and Fig. 2.2 explained the percentage of global CO_2 emission by sector and for new construction from 2020 – 2050 respectively. Twenty eight [17], explained that the construction projects built currently as depicted in Fig. 2.2 shows that by 2030 74% of carbon emissions will emanate from their embodied carbon, and the remaining 26% from their operational carbon. Seventeen[17],explained that the construction projects built currently as depicted in Fig. 2.2 shows that by 2030 74% of carbon emissions will emanate from their embodied carbon, and the remaining 26% from their operational carbon. This simply connotes that to

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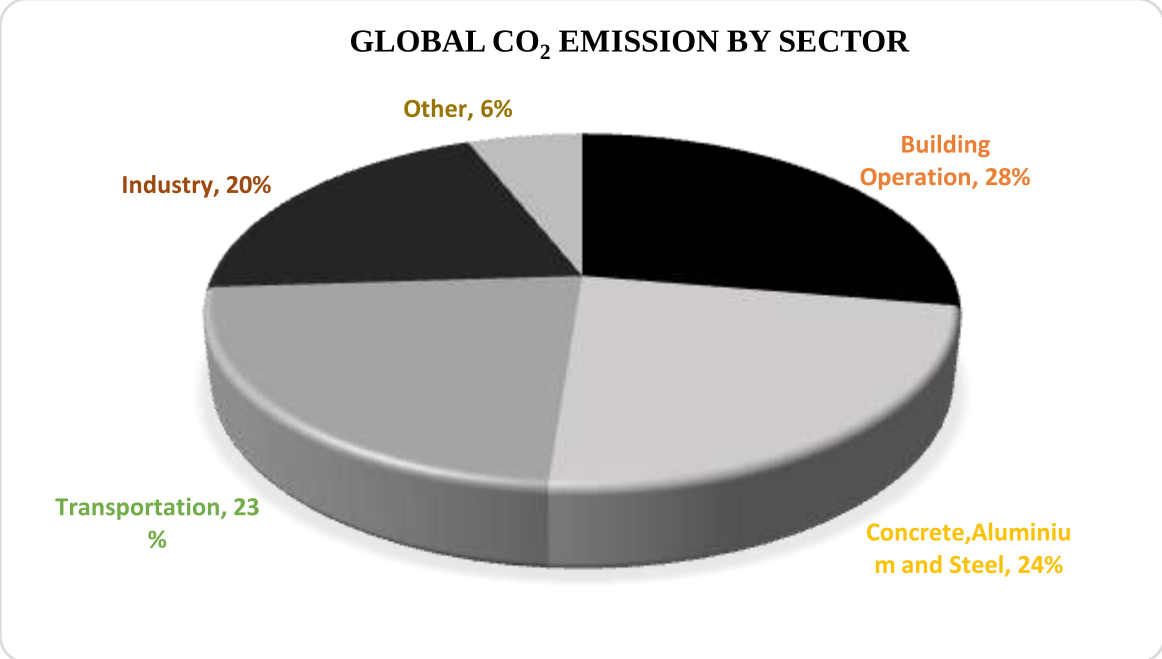
achieve short-term carbon emission targets in line with the Paris Agreement, embodied carbon reduction need to be prioritized.



Source: 2018 Global Report; International Energy Agency (IEA) [1]

Fig.2. 1: Percent of Carbon emission by sectors

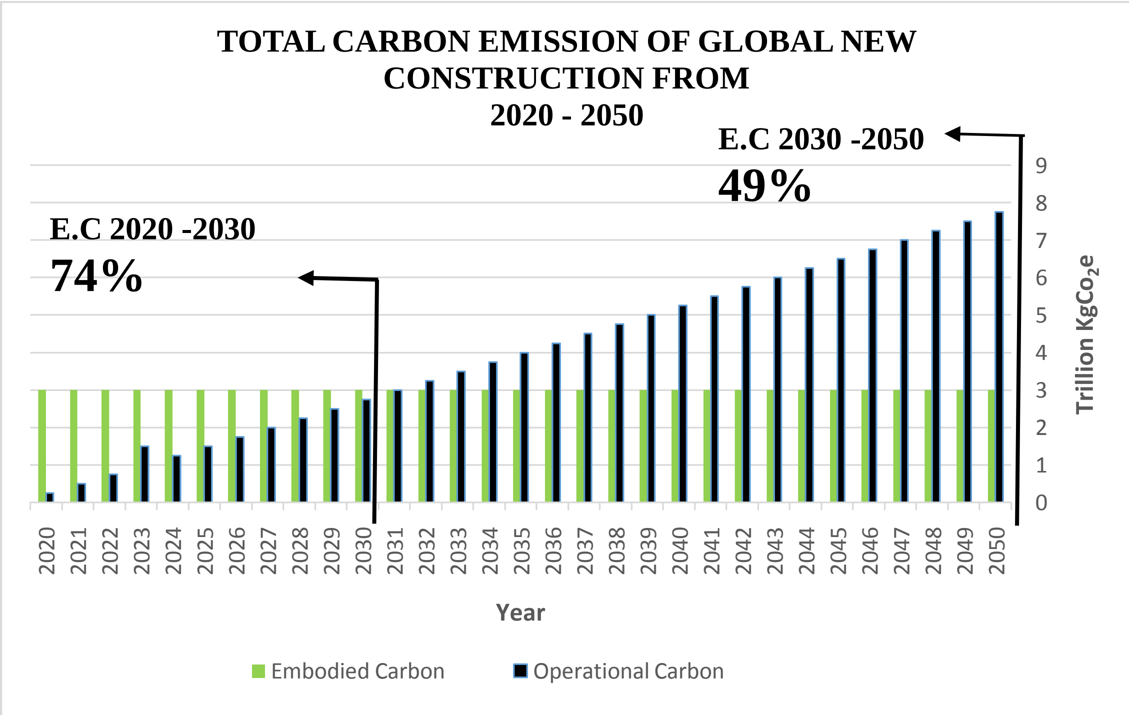


Fig.2. 2: Source; Architecture 2030 (The graph shown the Embodied and Operational Carbon projections: adapted by [17]

2.1 Carbon Emission Factor

According to IPCC, carbon emission coefficient is defined as carbon emitted by the combustionor consumption of one unit of energy. The idea of carbon emission factor is derived from the "carbon emission coefficient" by the carbon emission coefficient method, [10] gives the summary of carbon emission coefficient of some construction materials with respect to transportation distance as shown in the Tab. 2.1 below.

Tab 2.1:Carbon emission factors and transportation distance of main building materials.

Construction materials	Carbon emission factor	Mean transportation distance/km	Building materials category	Carbon emission factor	Transportation Distance/ km
Steel (large)	2.80kgCO_2/kg	60	Sand	3.49kgCO_2e/ m^3	40
Steel (Small and medium	2.19kgCO_2/kg	60	Copper conductor cable	9.41kgCO_2e/kg	70
Steel (wire)	2.2kgCO_2/ kg	60	PVC pipe	9.74 kgCO_{2e}/kg	25
Rebar	2.31kgCO_2/kg	60	Polystyrene Extruded plate	669kgCO_2e/m^3	25
Cement	0.977kgCO_2e/m^2	25	Architectural potteries	19.5kgCO_2e/ m^2	40
Concrete C30	297kgCO_2e/m^2	15	Windows(Aluminium)	46.3kgCO_2e/ m^2	55
Concrete C40	326 kgCO_2e/m^2	15	Water paints	6.55 kgCO_{2e}/kg	50
Clay brick	349kgCO_2e/per 1000 block	25	Wood	139kgCO_2e/m^3	35
Hollow clay brick	290kgCO_2e/per 1000 block	25	Waterproof coil (SBS)	2.38kgCO_2e/ m^2	25
Common Concrete block	171 kgCO_2e/m^2	25	Stone	3.17kgCO_2e/t	40
Fly ash aerated Concrete block	327 kgCO_2e/m^2	25			

Source: Journal of Thermal Science Vol.28'' [18]

2.2 Embodied Carbon

The word 'embodied carbon' simply refers to the lifecycle greenhouse gas emission, (it mostly refers to as carbon dioxide equivalents – CO_2e) which occur during the extraction, manufacture, and transportation of construction materials, it also includes the construction process and end-of-life aspects of the building. The term embodied carbon of building materials and products have been using interchangeably with the term carbon footprint in recent years. An embodied carbon or carbon footprint analysis is a subcategory of most life cycle analysis, i.e. this only takes into account the GHG environmental impact category. [9]

Different research findings have been assessed the environmental carbon emission related to buildings, some of their research areas as shown in Tab.2.2 below.

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TABLE 2. 2: Some of Past Findings on Carbon Emissions Related to Building Construction.

Author	Year	Research Findings
Georgios Synods, Constantinos A. Balaras And Dimitrios G. Koubogiannisa	2017	Concrete cause more emission because of its quantity and mass. Steel also plays its role in embodied carbon footprints
Andrea Meneghelli,	2018	The standardized development and widely accepted method for carbon footprint calculation in essential in design decision.
Luo, Zhixing & Cang, Yujie & Zhang, Nan & Yang, Liu & Liu, Jiaping.	2019	Building materials are the main sources of carbon emission during materialization
Eman Badawy Ahmed	2020	The best insulation materials that reduce carbon emissions in the building are XPS

III. MATERIAL AND METHODS

The method focuses on the analysis of carbon footprint and reduction. Building Information Modelling (BIM) plays a crucial role in preparing data and obtaining detailed information regarding the structural elements of the case study project.

In this study, Building Information Modelling (BIM) approach was used to extract the quantity of materials from 3D model.

Revit 3D model data (IFC file) was collected from Sweco Company, Sweden. The extracted material quantity from the Revit 3D model is subjected to further analysis using OneclickCLA software to assess the amount of CO_2e in each of the selected building components and determine the life cycle analysis of the carbon footprint of the building. The overall embodied carbon of each the components were calculated as further explained below. The embodied carbon activities in this study covers raw materials extraction (quarrying/mining), manufacturing, transportation, and right through to fabrication processes until the product is ready to leave the final factory gate and transport to the construction site. Fig. 3.0 a, 3.0 b and 3.0 c below show the construction CO_2emission and life cycle stages from point of materials extraction to building demolition.

Fig. 3.0 a: Building CO_2 Emission Stages

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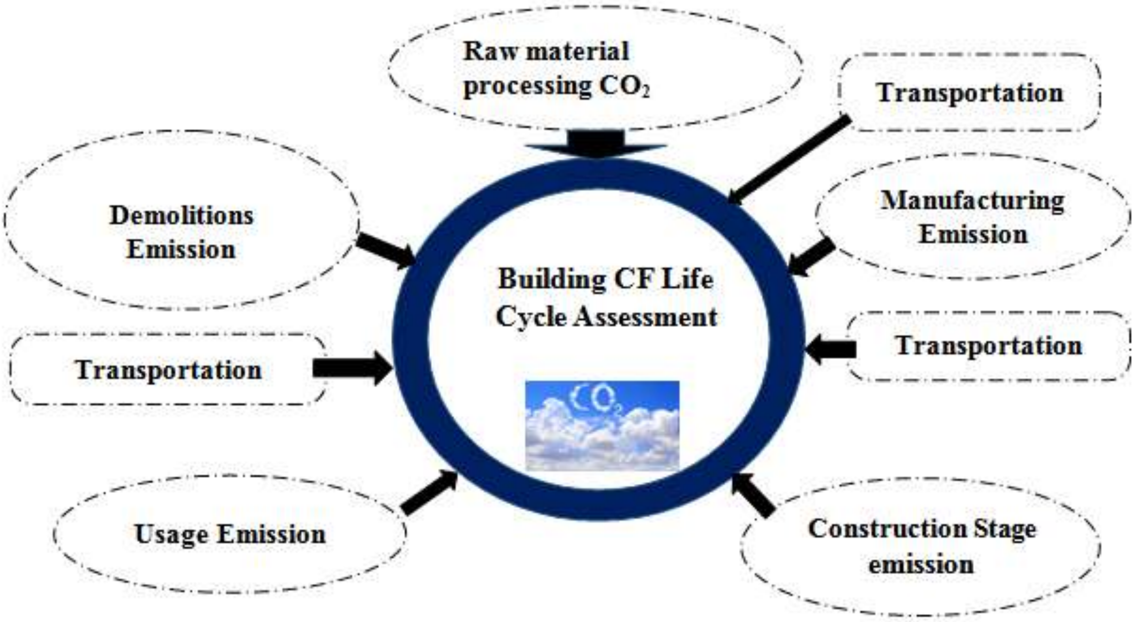

Fig. 3.0 b: Building Carbon Footprint Life Cycle Stages

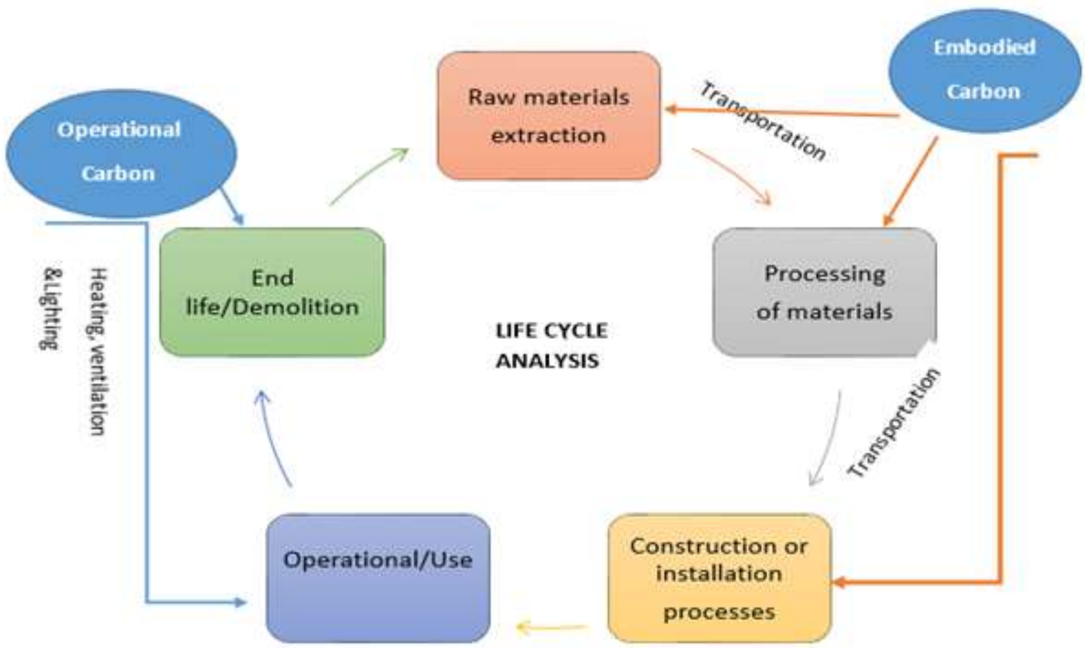

Fig.3. 0 c: Carbon Footprint Life Cycle Stages

3.1 Case Study Description

The case study building is a two storeys building with cast in place reinforced concrete pile foundation. The floor slab is designed with concrete, glue laminated wood materials, columns, beams were designed with cast in place concrete, some of the columns material is glulam timber, and the beams were designed with glulam timber. The roof material consists of steel frame truss members and lattelement for roof deck respectively.

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Prefabricated lattelement (Sandwich) wood materials were used for the wall and roof deck. Fig 3.1 depicts the major structural elements in the case study.

The major structural elements subjected to carbon footprint analysis are; Concrete materials which includes foundation piling, slab, concrete columns and beams, the steel materials includes roof steel structural member and steel column while the wood materials include floor wood, timberand column. The study focused on the embodied carbon of steel, concrete, and wood with respect to the quantity of each of the materials used.

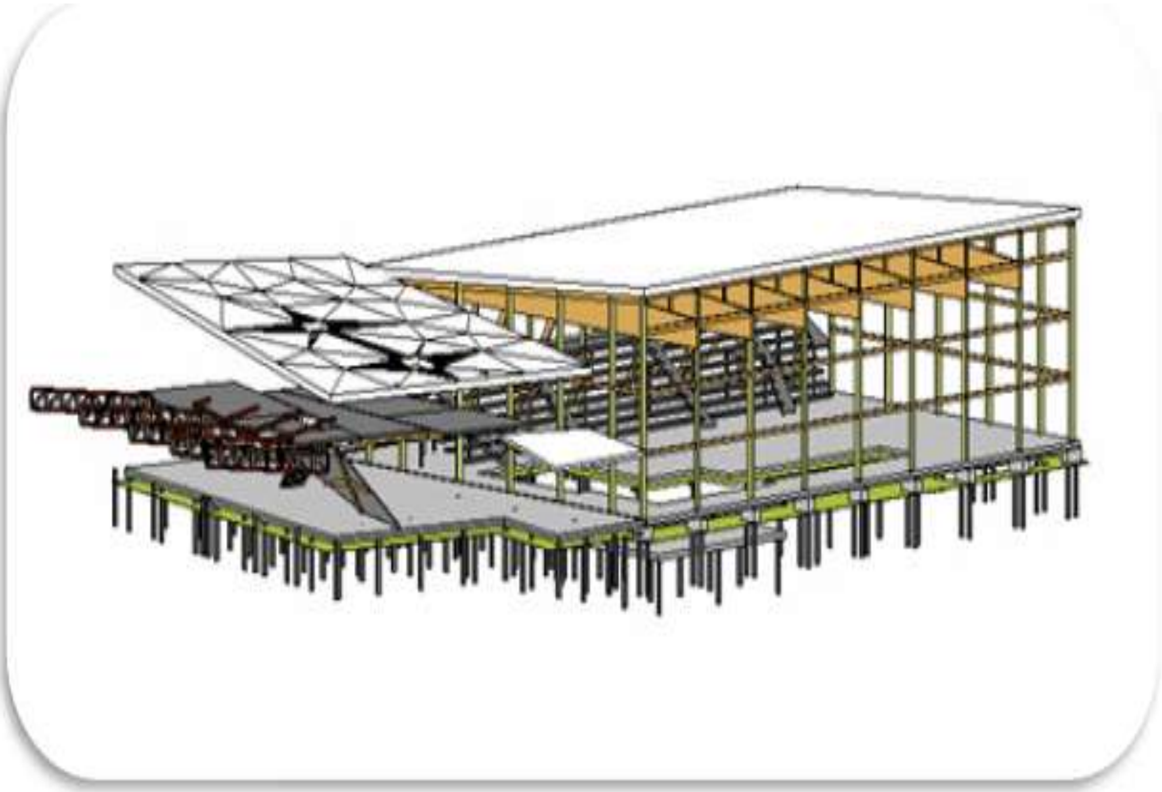

Fig.3. 1: Case study showing building components: (Data from Sweco Company, Sweden

3.2 Case Study Input Data

Calculation of carbon footprint of the selected municipal building designed by SWECO at Trosa, Sweden, was carried out using Revit Autodesk and One Click LCA software [16]. The below assumptions were input into One Click LCA software for the carbon footprint analysis:

Materials Product life: Technical service life.

Materials localization: Poznan, Poland.

Building service life: 60 years.

Case study building analysis: The scope includesextraction stage (A1 – A3), transportation stage construction stage (A4-A5), Operation stage (B6) as shown in Fig 3.2

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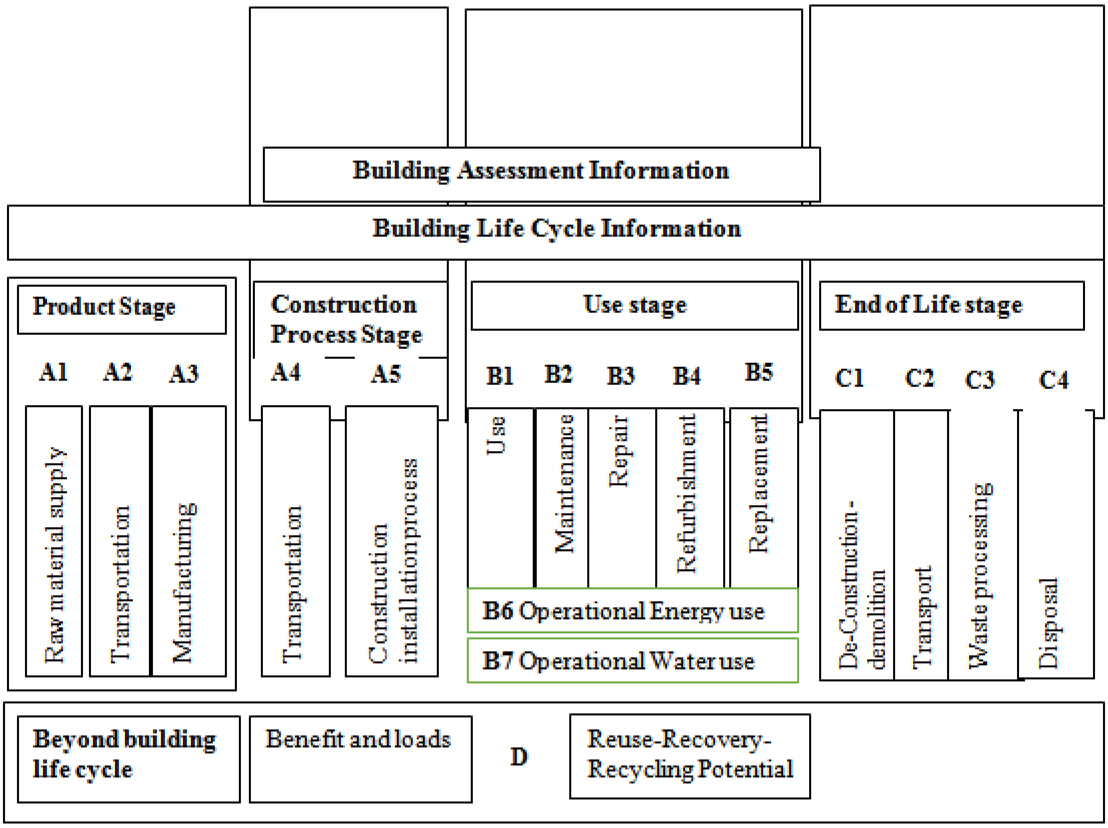

Fig. 3.2: Life Cycle Assessment Information according to EN 15804; 2012 [18]

This analysis excluded use stages (BI – B5), B7 and end of life stages (C1- C4) stages of the life cycle analysis. The excluded parts would be included in the further study.

3.3 BIM-Based Material Quantity Take-Off

Building Information Modelling (BIM) is a database having different categories of engineering information that can provide detailed material quantity information [4]

BIM model is a vital tool for extracting the bill of quantities of a building. BIM tool was usedto get the quantity take off for each of the building elements. The approach of BIM-based material take-off was used in this study to estimate the quantity of each of the components.The case study has a gross floor area (GFA) of 1308.551 m^2. The building has a concrete pile foundation and isolated footing. The wall and roof were designed of lattelement wood material.

3.4 Life - Cycle Analysis

This is connected to all the stages of a project's life. The life cycle assessment method was used to analyse the carbon footprint by studying the embodied carbon of all the major structural elements, its operation processes, transportation, and construction activities.

OneclickCLA software was used to calculate the carbon footprint connected to the product life cycle, the analysis is restricted to embodied carbon of structural components from A1 – A5 (Cradle to Gate), B6, C1-C4 as displayed in fig. 3.2. The study focuses on the analysis of product's life cycle which taking into consideration the direct and indirect CO_2 emission as a result of construction materials. As shown in Fig. 3.3

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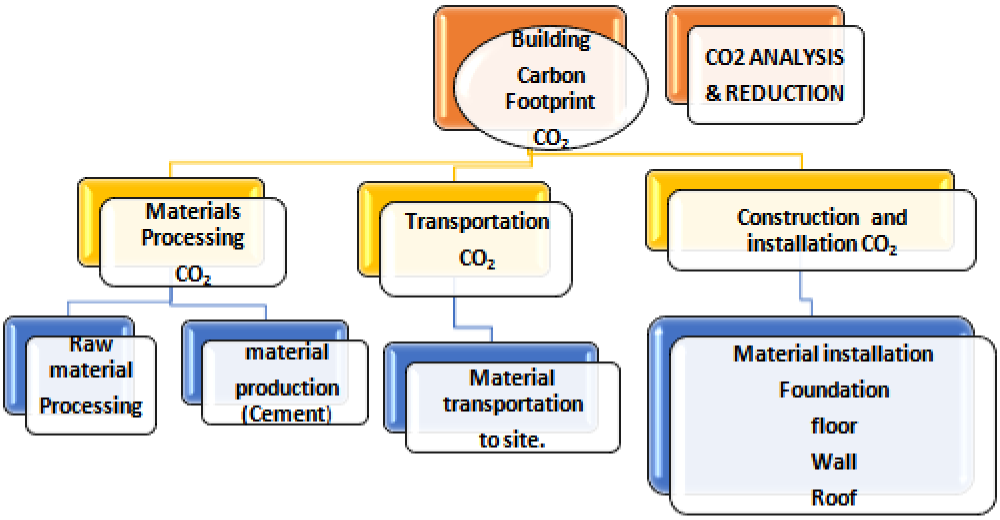

Fig.3.3: Diagram showing material CO_2 emission

3.3 BIM Model (Revit Autodesk software)

The BIM method was used to collect building data, the data was imported into Revit Autodesk BIM software via IFC format, the quantity of the selected materials were estimated to determine the quantity of carbon footprint in each of the material.Carbon footprint calculation was performed using the One-Click LCA methodology.

The Extracted quantity of materials from the Revit model imported into one-clickLCA, follow by input of the design data and building information. The materials EPD used throughout the analysis were virtually one-clickLCA generic data. The EPD of the materials were selected based on the materials proximity to the location of the project and amount of carbon in Kg/CO_2e as declared by the products manufacturers. The carbon footprint analysis andprocedure to determine the amount of Carbon in each of the building components and in the whole building model was represented with aid of flowchart in Fig.3.4.

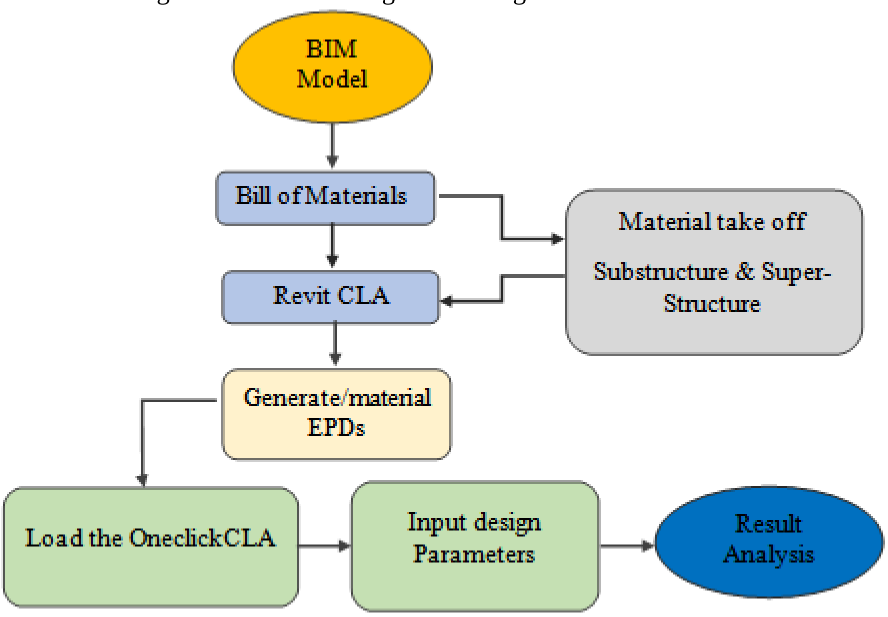

Fig. 3.4: Carbon footprint Analysis Flowchart

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IV. RESULT AND DISCUSSIONS

Two different analyses were carried out the first analysis was on building materials carbon footprint estimation which covers from cradle to gate (material extraction, transportation, and construction stage), gate to gate. The second analysis focused mainly on material CO_2 emission reduction as the results were discussed below.

Materials Carbon Footprint Life Cycle Analysis. The life cycle assessment for CO_2ein the construction materials. Tab. 4.1 below shows the amount of greenhouse gasesemission for different categories in the life cycle assessment result analysed from One-clickLCA software.

The result from the analysis as depicted in Tab.4.1 shows the amount of CO_2 equivalents emission in kilogramme, which includes the following greenhouse gases; global warming (CO2e), acidification (SO2e), eutrophication (PO4e), ozone depletion potential (CFC11e).

The result shows the amountof the greenhouse gases

The result of kg CO_2e from the life cycle assessment was estimated to be 830 tons with a gross internal area of 1308.25m^2.

In order to determine the kilogramme of carbon dioxide per square meter (kg CO_2 /m^2) the total CO_2e, which is 830 tons is divided by Gross Internals Floor Area (1308.23m^2) gives the 629 Kg CO_2e/m^2. The amount of kg CO_2/m^2 is used to determine the carbon heroes benchmark which is use to classify the building types across different countries and to help set the reduction target.

Tab.4. 1: Graph showing Building Life Cycle Stages (Life cycle stages global warming)

Item		Value	Unit	Percentage %
A1-A3 Materials		730 000	kg CO_2e	88.38 %
A4 Transportation		21 000	kg CO_2e	2.56 %
A5 Construction		470	kg CO_2e	0.06 %
B6 Energy		6 200	kg CO_2e	0.74 %
C1-C4 End of life		69 000	kg CO_2e	8.26 %

4.1 Materials Classification

The analysisresult shows global warming in KgCO_2e, based on the material classification. The types of materials used for external wall and façade in this project contributed significantly to the CO_2 emission also the materials selected for the floor slab, and ceiling has high CO_2 emission based on the selected EPD.Tab. 4.2 below display how different material types have a major effect on CO_2e emission.

Tab.4. 2: Global warming kg CO_2e – Classifications based on material

Item	Value	Unit	Percentage %
External walls and façade	320 000	kg CO_2e	38.93 %
Floor slabs, ceilings, roofing decks, beams and roof	290 000	kg CO_2e	35.43 %
Other structures and materials	130 000	kg CO_2e	15.38 %
Columns and load-bearing vertical structures	52 000	kg CO_2e	6.32 %
Foundation, sub-surface, basement and retaining walls	26 000	kg CO_2e	3.15 %
Electricity use	6 200	kg CO_2e	0.74 %

Site electricity consumption	470	kg CO_2e	0.06 %
Construction waste	4,8	kg CO_2e	0.0 %

4.2 Resources Types (Global Warming Kg CO_2e)

The type of resources selects for construction also plays major roles in CO_2e emissions. Tab. 4.3 revealed different type of materials used in this study. The major structural elements used are concrete, steel and wood. The results obtained after the analysis shows that concrete and steel have a high carbon footprint compare to wood material. In order to achieve maximum reduction in materials carbon emission, wood materialusage should beincreased in construction i.e. Glulam and CLT are best materials for reducing building carbon footprint. In Tab. 4.4 the percentage of each of the items with their quantities, from Tab. 4.3shows that ready mix concrete has highest percentage CO_2emission, follow by steel, the quantity of material used is directly proportional to the carbon emission.

Tab.4. 3: Global warming kg CO_2e - Resource types

Item	Value	Unit	Percentage %
Ready-mix	330 000	kg CO_2e	39.27 %
Metals	260 000	kg CO_2e	31.21 %
Wood	240 000	kg CO_2e	28.71 %
Utilities	6 600	kg CO_2e	0.8 %
Waste treatment	4,8	kg CO_2e	0.0 %

4.4 CO_2 Emission Based On Material Quantity

Material quantity was also considered in this carbon footprint analysis. The materials quantity by mass were evaluated based on material usage, floor slab, Ceiling, roofing decks and structural beam used in this design is 62.02%, while external wall and façade is 16.83%, Other structure and material has 8.63, column and load-bearing vertical structures has 7.48% while the foundation material has 5.03%.

The results shown in Fig. 4.4 show that material quantity contributed more to construction carbon emission. Material quantity use in the construction should have considerable mass so as to reduce the amount of CO_2 e emission.

Tab.4. 4: Material Quantity Usage (Mass kg) - Classifications

Item	Value	Unit	Percentage %
Floor slabs, ceilings, roofing decks, beams and roof	1 600 000	Kg	62.04 %
External walls and façade	430 000	Kg	16.83 %
Other structures and materials	220 000	Kg	8.63 %
Columns and load-bearing vertical structures	190 000	Kg	7.48 %

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Foundation, sub-surface, basement and retaining walls	130 000	Kg	5.03 %

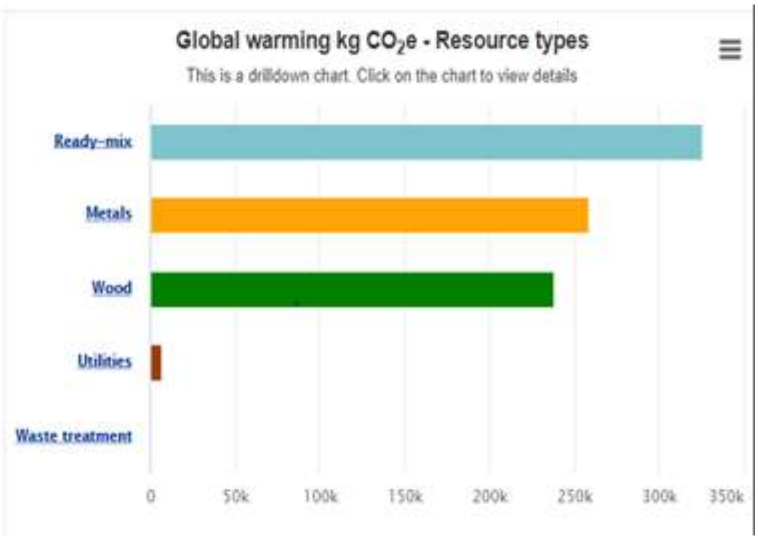

Fig.4. 1 Life Cycle Analysis result showing Quantity of the materials used

4.5 Embodied Carbon Benchmark

The embodied carbon benchmark is the fundamental stage of achieving low carbon building, in an attempt to assess CO_2e emission in buildingmaterials, the study demonstratesthe use Carbon heroes' benchmark to set a reduction target for the building carbon emissions. Carbon Heroes benchmarks were compared withtwo different analyses. According to One-clickLCA software, the building embodied carbon was calculated for 60 years for all of the materials in this study.

4.6 Material Carbon Footprint Reduction

In this study, two (2) different analyses were performed; the first analysis focuses on calculating materials carbon footprintwhile the second analysis focused on material CO_2 emission reduction.

The analysis was carried out to substitute materials with high carbon content for materials with low carbon emission. In the second analysis, the following assumptions were used; the quantity of concrete used was reduced, wood materials were mostly used, material EPD with low CO_2 emission were used. While others design input data such transportation distances, building service life and assumed unit of electricity used during construction process remain the same. The result in Fig 4.3 below shows carbon footprintanalysis and Fig 4.4 displayed significant reduction in amount of CO_2e emission.

From the firstanalysis, the result of global warming (kg CO_2e) from the life cycle assessment was estimated to be 830 tons with abuilding of gross internal area of 1308.25m^2. To determine the kilogramme of carbon dioxide per square meter (kg CO_2 /m^2),total CO_2e which is 830 tons is divided by Gross Internals Floor Area (1308.23m^2) gives approximately 629 Kg CO_2e/m^2(global warming).

This resultassist in determining the amount of CO_2 emission per year by dividing the total CO_2 emission by (629 Kg CO_2e) by building service life, which was taking as 60 years and it is equivalent to 10.57 kg CO2e/m^2/ year.

The amount of global warming (kg CO_2/m^2)was used to determine the carbon hero benchmark, which help to classify the building types in different countries and to set the CO_2 emission reduction target.

Second analysiswas performed to reduce the amount ofCO_2 emission obtained from the first analysis;some of the materials were replacedwith sustainable materials. I.e.use of low carbon emission ready mix concrete, reduction in building aesthetics and reduction in volume of concrete by replacing itwith wooden materials the quantity of CO_2eemissionwas drastically reduced from 830 tons to 663 tons, and the CO_2 emission change from629 kg CO_2e/m^2 to501 kg CO_2 e/m^2 as show in the figure below.

To achieve Optimum carbon emissions reduction more iterations are needed to perform toachieve absolute carbon emission.

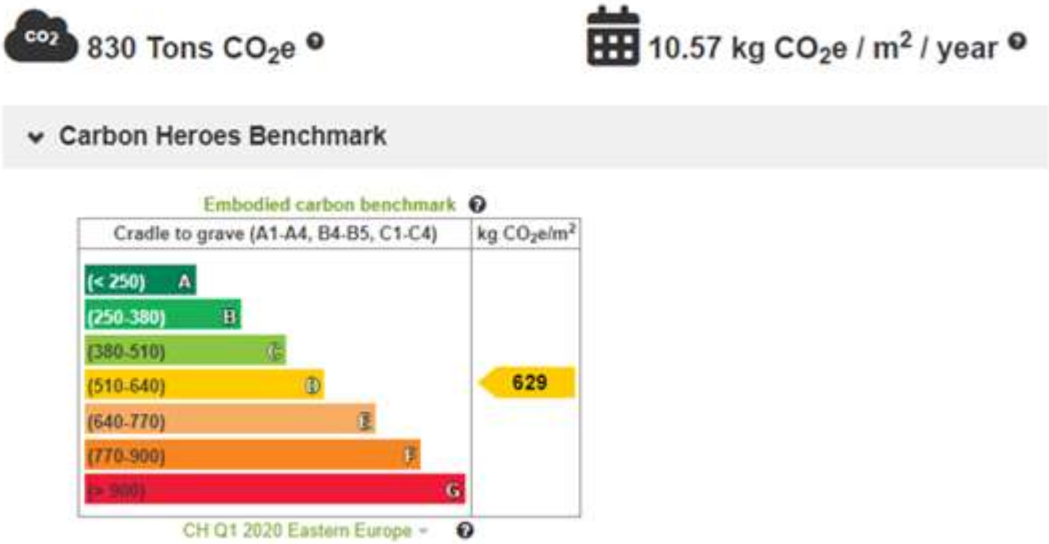

Fig.4. 4 Carbon Heroes Benchmark after Carbon FootprintAnalysis

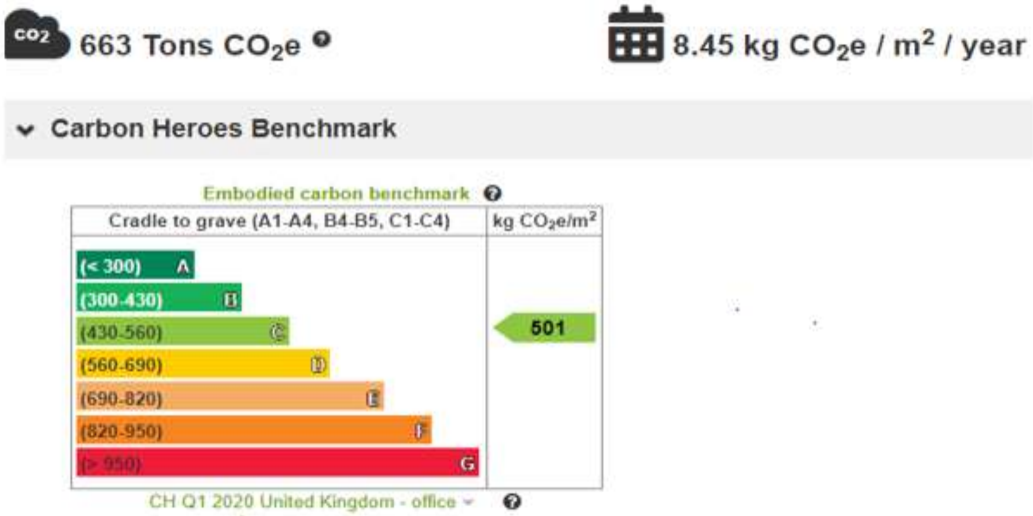

Fig.4. 5 Carbon Heroes Benchmark after Carbon Reduction Analysis

V. CONCLUSION

This study concluded that using Life cycle assessment method, BIM approach and carbon analysis software play a crucial roles in selecting sustainable building materials and achieving a zero emission environment. Using generic or manufacturer's environmental product declaration wouldhelp in evaluating amount of carbon footprint in the building materials also in each of the construction stages.

The use of One-clickLCA BIM login with building Life Cycle Assessment (LCA) approach play a crucial role in reducing the embodied carbon and the operational carbon of each of the construction materials from cradle to site and during the construction stage. The results from this study demonstrated and assessed how to estimate the embodied carbon from material extraction to construction stages and during construction process.

The study shows that using more wood materials, low carbon concrete carbon and less quantity of materials of cast in place concrete will play a significant role in achieving zero CO_2 emission in accordance with IPCC and European Union targets.

VI. RECOMMENDATION

If we think seriously on achieving a sustainable and healthy environment, some importantregulations have to be introduced, in particular, standards for engineers should be obliged to check the carbon footprint and if the amount of carbon footprint is high, the design should be changed.

Future studies should focus on analysis and reduction of construction materials waste; this would also help us in achieving the sustainability and reduce cost and energy usage for transportation to the dumping site.

Acknowledgment

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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