# EVALUATE ENVIRONMENTAL SUSTAINABILITY OF CONCRETE COMPOSITE FLOOR-PLATES

**ANG MIN YUAN**

**A project report submitted in partial fulfilment of the**
**requirements for the award of Bachelor of Engineering**
**(Honours) Civil Engineering**

**Lee Kong Chian Faculty of Engineering and Science**
**Universiti Tunku Abdul Rahman**

**September 2020**

# DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : Ang

Name : Ang Min Yuan

ID No. : 16UEB07419

Date : 11th Oct 2020

# APPROVAL FOR SUBMISSION

I certify that this project report entitled **"EVALUATE ENVIRONMENTAL SUSTAINABILITY OF CONCRETE COMPOSITE FLOOR-PLATES"** was prepared by **ANG MIN YUAN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature :

Supervisor : DR. ONG CHUAN FANG

Date : 11th Oct 2020

# ACKNOWLEDGEMENT

First of all, I am truly grateful to be given this opportunity by Universiti Tunku Abdul Rahman, Lee Kong Chian Faculty of Engineering and Science to work on this project. I would like to thank everyone who offered help and supported me on this research journey. My sincere gratitude to Dr Ong Chuan Fang for his invaluable advice, guidance and his enormous patience throughout the process of completing this project, I am truly fortunate to be under his supervision.

Moreover, I am also extremely thankful to my friends and seniors, especially Mr Felix Kwan and my boyfriend who brainstormed with me and taught me the correct ways to complete this project. They had shared their knowledge with me selflessly, and given me comments or suggestion whenever it is needed.

Last but not least, I would like to appreciate my loving parents that supported me financially and given me strong mental encouragement to do my best for the project. All the effort, help and support received from these people are gratefully acknowledged.

# ABSTRACT

It is no secret that the construction industry has brought a significant impact to the environment, especially in concrete production. Concrete composite floor-plates which are constructed by cast in-situ reinforced concrete on top of a steel decking is an alternative slab design that could replace conventional RC slab, and hence reduce the amount of concrete used.

The environmental impacts between these concrete composite floor-plates conventional reinforced concrete slabs are not thoroughly explored. Therefore, Life Cycle Assessment (LCA) is carried out to study the environmental impacts of both of the studied slabs by assessing the input and output of the slabs in a cradle-to-gate manner. OpenLCA software were used by adapting cut-off system model based on ReCiPe method as impact assessment method. The results have shown that concrete production contributed the greatest environmental impact, the most significant process is clicker production which is responsible for high global warming potential (GWP). The lesser the concrete required, the lower the environmental impact. Overall, concrete composite floor-plates give a lower environmental impact as compared to conventional reinforced concrete slabs in terms of climate change, fine particulate matter formation, human toxicity, freshwater eutrophication and photochemical oxidant formation.

LCA is an important tool for decision making in the construction industry to help choosing a construction material that is environmentally friendly, hence lower the carbon footprints.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

## 1.1 General Introduction

It is an indisputable fact that the building and construction industry is one of the main contributors to environmental problems by exhausting resources and consuming energy or production of waste. In this day and age, environmental issues are in the spotlight with the emerging environmental impact like water pollution and resources crisis, in fact, some of the environmental impacts are wholly or partially resulted from industry development. It goes without saying that the construction industry, especially manufacturing process of building materials, contribute a remarkable amount of waste and pollutants to the environment. To bring the numbers down, a few standards have been introduced to the construction industry to guide the industry towards being environmentally friendly. One of the most commonly used standards is LEED, namely Leadership in Energy and Environmental Design. It is a green building certification system that is known globally to determine the environmental sustainability of a building throughout the building lifecycle. Besides LEED standard, Intergovernmental Panel on Climate Change (IPCC) also provides similar and regular scientific valuation on future potential risk to the environment.

According to Daly (1990), environmental sustainability refers to the ability to continue a certain resource by reusing them, and not creating a noticeable amount of pollution to the environment. An action or a product is said to be not environmentally sustainable if it uses not renewable resources or creates an unacceptable amount of waste to the environment. We are now living in the civilization where it is consumerist, we consume loads of resources in the natural habitat on a daily basis, particularly in urban places where there are a lot of tall and futuristic buildings, which directly consumes more power and resources. Therefore, being environmentally sustainable means to find the balance in between the needs to be more civilised and modernised, and the needs to protect and give back to the environment. On the stand of construction industry, the least that the industry could do is to try to eliminate waste and pollution to the environment and try to adapt and implement a more sustainable method in civil engineering spectrum.

In order to assess the environmental impacts of a certain product, Life Cycle Assessment (LCA) is adapted. LCA is an environmental management and accounting approach that takes into consideration of all aspects of resources used and environmental emission. LCA is particularly beneficial and convenient for decision makers when a decision is made by relating and comparing all the major environmental impacts between different methods.

In this study, the life cycle assessment of concrete composite floor plates and conventional reinforced concrete slab are compared in the cradle-to-gate manner, which covers from the extraction of the material, through the manufacturing process of a product, to the factory gate of the production. The findings from this study could offer valuable information to government or private agencies with building professionals for their future development.

## 1.2 Research Background

Concrete is one of the most commonly used man-made materials way back in the construction in Ancient Roman times, alongside with other materials like wood, aggregates and metals. Concrete is a composite material made out of cement, aggregates and water, it gains strength when the mixture is hardened. The steps producing concrete seem simple but manufacturing its core material, cement, is an energy intensive work. In fact, 0.76 – 1.36 kg of carbon dioxide equivalent is released into the atmosphere every 1 kg of Portland cement is manufactured (Nisbet et al., 1997). According to Mehta (2002), the worldwide production of ordinary cement contributes 5-8 % of global anthropogenic greenhouse gas (GHG) emission, in the worst-case-scenario, the number could go up to 10-15 % by year 2020. All in all, reducing cement use or substitute it with an alternative material is vital for the construction industry for being environmentally sustainable.

A study comparing the conventional and alternative manufacturing process of Portland cement was done by Huntzinger and Eatmon (2009), due to the growing concerns by the public as it imposed risk to human health. Apart from the carbon dioxide emission from the manufacturing process of cement, an abundant amount of cement kiln dust (CKD) is also generated through the manufacturing process. CKD is a very fine particulate matter that does harm to human respiratory system as well as pollution to the environment. In conventional manufacturing process of cement, large portion of CKD collected is disposed in landfills or kept as a stockpile on site, creating waste in either way. According to Van Oss and Padovani (2003), 15-20 % of CKD formed are by clinker production, therefore, to eliminate CKD production, the usage of cement clinker must be brought down. To tackle this issue, supplementary cementitious materials like fly ask, slags, and natural pozzolans are used as clinker substitution. The substitution of these materials reduces the quantity of clinker needed by per ton of cement production, indirectly reducing the amount of CKD produced to scale down the environmental impact.

A study done by Brambilla et al. (2019) says that steel-concrete composite structures are the most competent and effective structural method for construction sector including buildings, bridges and infrastructures. This is in light of the fact that the composite action between the two elements, steel and concrete, is able to combine and enhance their structural integrity, with the fact that the two building materials are the most used and most impressive ones of all times. Nonetheless, due to the monolithic nature contributed by the shear connection practice nowadays, the deconstruction of a composite structure is complicated and certainly challenging, making the recyclability of composite structure complicated. However, it is believed that the use of steel-concrete composite structure in replacing the conventional concrete structure could bring down the environmental impacts caused by construction sector.

## 1.3 Problem Statement

The environmental impact of the conventional concrete is gaining attention with the advancement of building industry, which brings up the usage of concrete. However, production of concrete develops high level of carbon dioxide and causes harm to the most fertile and lush surface of the earth, the topsoil. Most of the construction industries are starting to take initiative on adapting and putting more emphasis on sustainable concrete production to unburden the environment, instead of developing high strength concrete (Nielsen and Glavind, 2007). Greenhouse gases emissions and climate changes are still the main focus while studying the environmental impact of a product, as the discharge of carbon dioxide from the concrete production contributes to the resulting pollutant in the air (Van den Heede and De Belie, 2012).

According to Helepciuc (2017), the idea of eco-friendly design and energy efficiency urges the necessity to look for alternative materials and technologies that impose minimum harm to the environment, so as to substitute the conventional materials for the building constructions industry. By doing so, the diminution of the environmental impact with regards to energy consumption and emissions causing greenhouse effect will be allowed. The trend in production of recycled materials is gaining importance day by day so that it is able to avert the environmental pollution from industrial and agricultural wastes. Cement is in need of searching for its substitution or lower the usage of it as the cement production is a vital context in representing the infrastructure construction industry. With the growth of world population from, among it is the 3 billion people who stay in or around the cities. The snowballing effect of ratio in population and urbanization in the developing countries is causing a significant hike in cement production (Shen et al., 2017).

Studies like Ferrante et al. (2019) and Derysz et al. (2017) that had been done on the environmental impact of concrete production in the past years showed that the impact of concrete composite floor plates to the environment had yet to be fully understood, given that the composite structures are extensively used in the construction industry nowadays. According to Martínez-Rocamora et al. (2016), the industry does not pay attention to the position of waste management of concrete in a life cycle of building construction. The industry needs to comprehend and recognize the importance of it, so that a significant revolution will happen in the process of solving the environmental impact caused by construction. This study focuses on the new technique of construction method such as the use of concrete composite floor plates to bring down the environmental impact to the natural environment in comparison with the conventional reinforced concrete slab.

## 1.4 Objectives

Life Cycle Assessment (LCA) used in this study is a systems analysis tool that aims to evaluate the impact caused by a product, or in this case, concrete composite floor plates. The burden caused by concrete is mainly material and energy associated that need to be evaluated. However, the use of concrete composite floor plates imposes different level of environmental impact than conventional reinforced concrete slab and it should be compared and discussed in a detailed manner. With the aid of LCA, the environmental characteristic of the two products can be analysed and studied.

This study has two main objectives:

i. To identify life cycle inventory of conventional reinforced concrete slab and concrete composite floor plates.
ii. To compare the environmental impacts resulted from the two different concrete slabs in a cradle-to-gate manner.

## 1.5 Scope of Work

Life cycle assessment (LCA) is a comprehensive method in comparing the environment impact in full range and throughout the product life cycle. In this study, the life cycle assessment of concrete composite floor plates and conventional reinforced concrete slabs are looked into in a cradle-to-gate manner. It is a partial product life cycle which comprises pre-use (extraction of raw material, material production and manufacturing process) to the factory gate. A system boundary is used in the LCA to limit the evaluation of the system. The life cycle of both studied slabs consists of a few major phases, that are, extraction of raw material, raw material transportation and manufacturing process. The result of LCA is highly dependable of the LCI, which is life cycle inventory. In this study, Ecoinvent database is adopted. It is a life cycle inventory database of common materials and processes which will be drawn by the LCA software to process and calculate a holistic picture of the possible impact of the specific product. Moving on, the Life Cycle Impact Assessment (LCIA) will be performed to evaluate the potential environmental impact of the studied product system. ReCiPe impact assessment method is adopted in this study.

A substantial amount of environmental wastes is contributed by transportation. In environmental aspects, transportation burns most of the world’s petroleum and creates major air pollution by producing carbon monoxide, carbon dioxide, nitrous oxides and particulate matter, not to mention other impacts like sound pollution. In the manufacturing process of conventional slabs and composite floor plates, they each require different raw materials and chances are the raw materials will be transported from different sources. With this difference, the delivery distances of the raw material from their sources are assumed to be standardized unless the transport sensitivity analysis is carried out.

## 1.6 Significance of Study

We are living in a modernized and globalized world where building industry contributes significantly to. In fact, there is an unstated global race between countries to build the tallest skyscraper or a symbolic architectural accomplishment. However, building structures like that imposes massive impact to the environment in terms of resources used and environmental emission, not forgetting buildings with normal height. One of the most evident wastes contributed by construction industry is wastes produced by concrete in manufacturing process. Manufacturing concrete gives out an abundant amount of greenhouse gases (GHGs), carbon dioxide, as well as particulates matter. Studies have shown that there are alternatives in reducing the concrete production by-products by having a substitution material. In this study, a comparison in terms of environmental impact of the life cycle of a conventional reinforced concrete slab and a concrete composite floor plate will be discussed.

With the aid of LCA, all the aspects of the life stages of concrete will be accessed by analysing the input and output data of the production. As a result, the decision maker in the industry could easily detect the source of waste and take necessary action or alternatives to tackle the issue.

## 1.7 Outline of the Report

Chapter 1 of the report includes the introduction and research background of this project study. Other than that, problem statements, aims and objectives, scopes and limitations of the study together with the significance of the study are highlighted. Literature review is done in Chapter 2 on the conventional reinforced concrete slab and concrete composite floor-plate. The frame work of the life cycle assessment and the software used in the assessment are also thoroughly discussed in this chapter. Chapter 3 explains the methodology of the project study where the goal and scope are defined with the input data used in the analysis. The life cycle impact assessment and interpretation are highlighted in Chapter 3 as well. Moving on to Chapter 4, results and discussions are shown in tables and graphs, then interpreted clearly. Comparison between both of the studied slabs are done. Lastly, conclusions have been made in Chapter 5 with limitation and recommendations for future study.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In Chapter 2, conventional reinforced concrete slab and concrete composite floor plate were thoroughly discussed including their composition, properties and environmental impact. The systematic analytic method, Life Cycle Assessment including its tools and database were also revealed in this section.

## 2.2 Conventional Reinforced Concrete Slab

Conventional concrete is a mixture of Ordinary Portland Cement (OPC), water and fine and coarse aggregates or rocks. The paste comprises Ordinary Portland Cement and water, coats the surface of the fine (small) and coarse (larger) aggregates. Hydration will then happen as a chemical reaction where the paste hardens and gains strength to form the rock-like mass, which is identified as concrete.

A conventional reinforced concrete slab is as shown in Figure 2.1. It is a concrete slab reinforced by steel bars in order to transfer the bending moment developed in the slab. Casting a reinforced concrete slab requires the aid of formwork which serves as a temporary mould. Traditional formwork is usually made up using timber, alternatively, it can also be fabricated from steel, glass fibre reinforced plastics and other materials. Then, steel reinforcing bars are placed into their positions with the predetermined spacings and size of concrete cover. Reinforced concrete slabs have been the most commonly used structural element in the construction industry for many years now.

As the construction industry developed, more types of concrete slabs have been introduced to suit for the required physical properties or other requirements like cost, material selection or environmental impact. However, according to the findings from Begum et al. (2013), it is more economic to use conventional reinforced concrete structure in low rise buildings below 15 stories as the dead load is comparatively lower than high rise buildings. Table 2.1 shows the comparison of cost (in Bangladeshi Taka) between reinforced concrete structure and composite structure at different story height taken from

Begum et al. (2013). Note that the usage of reinforced concrete structure for building storey of 6 and 12 resulted in a lower cost of construction as compared to the usage of composite structures.

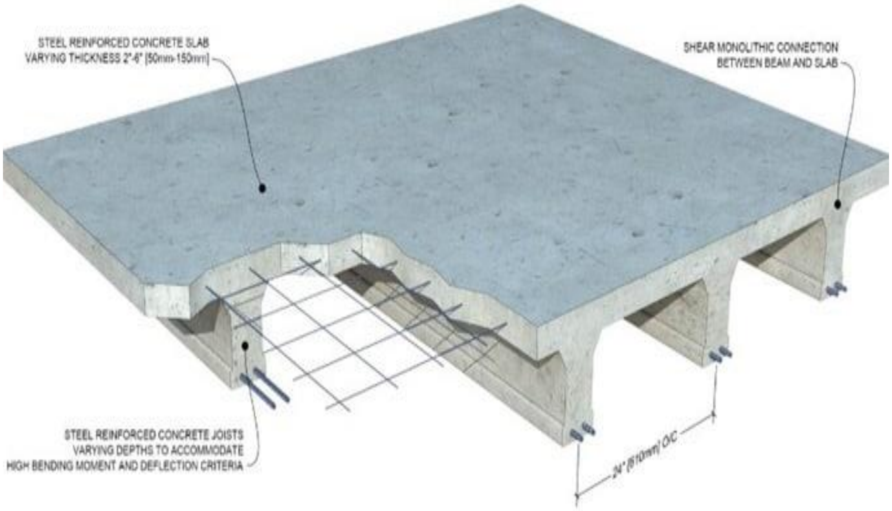


Figure 2.1: Conventional Reinforced Concrete Slab

Table 2.1: Comparison of Cost between Reinforced Concrete Structure and Composite Structure at Different Story Height (Begum et al., 2013)

| Story | Cost of RC Structure (Tk.) | Cost of Composite Structure (Tk.) | % different |
|---|---|---|---|
| 6 | 2,38,86,780 | 2,83,58,945 | 19 |
| 12 | 5,52,73,408 | 5,73,02,982 | 4 |
| 18 | 8,52,57,890 | 8,22,23,379 | -4 |
| 24 | 13,49,85,000 | 11,57,43,510 | -14 |

## 2.3 Concrete Composite Floor-plates

Nowadays, steel-concrete composite construction has gained wide acceptance as an alternative to pure steel and pure concrete construction. Concrete composite floor plates sometimes go by a more common name which is composite slab. Both names are understandable that they are commonly constructed from cast in-situ reinforced concrete on top of a steel decking or steel plate, and are connected to the steel beam by means of embedded welded studs as shown in Figure 2.2.

The steel plate acts as a long-lasting formwork and working area during the construction phase, it also acts as external malleable reinforcement during service life of the slab. The welded studs or shear studs are welded to the deck sheet to transfer the force between the steel section and the concrete part of a concrete composite floor plate, thus increases the stiffness and strength of the composite structure. The concrete slabs cast on top of the steel plate are like conventional reinforced concrete slab as the steel bars are placed into position as designed. In case of a fire, the steel bar embedded in the concrete slabs would prevent cracking and safeguards against degradation of decking.

In terms of physical properties, concrete composite floor plates outweigh conventional reinforced concrete slab as it has higher strength to weight ratio and a higher structural integrity. Structural integrity is the ability of a structure or an element to hold together under a loading including its own weight without deforming and breaking apart. Apart from that, composite structure also found to have better sound proofing properties, higher dimensional stability and a more long-lasting finish. These advantages have led to a big increase in the use of composite construction all over the world in recent years. On the other hand, the cost of construction with composite framing in high rise building is relatively lower as compared to the cost using conventional framing. This is due to the use of smaller cross-sectional element in high rise building, resulting in the lower usage of steel and formwork for concrete, and hence resulting in a lower labour cost. Therefore, steel-concrete composite system can also provide an effective and economic solution in medium to high-rise buildings.

All in all, concrete composite floor systems represent the most efficient structural solution for buildings and bridges, as the composite action combines and optimizes the structural properties of the two most used and impactful building materials, i.e. steel and concrete (Brambilla et al., 2019).

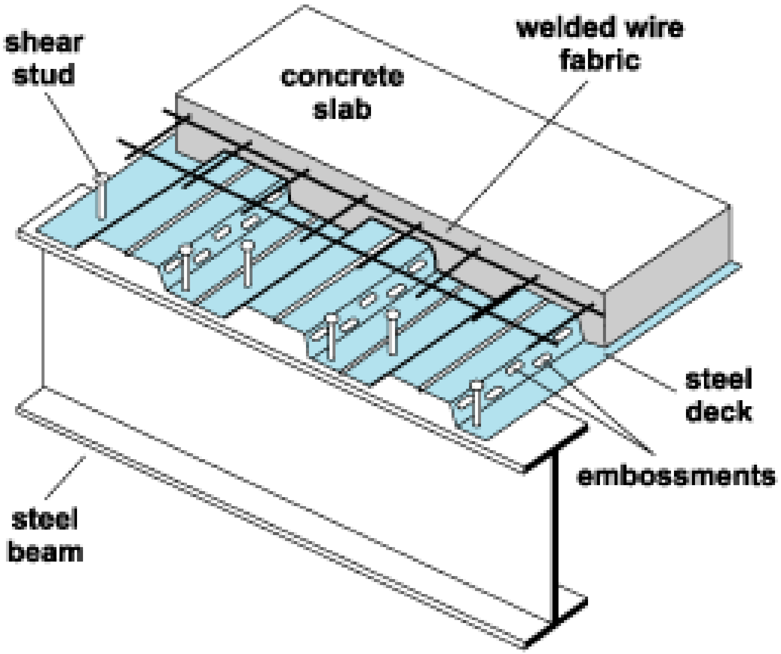


Figure 2.2: Composite Floor System (Begum et al., 2013)

### 2.4 Environmental Impact

The construction industry inevitably plays an important role in minimizing the environmental impact to take account for the considerable amount of resources it consumes and the amount of waste it produces. To minimize the environmental burdens of conventional reinforced concrete slabs and concrete composite floor plates, the impact caused by each composite material must be studied and understood. The main barrier in studying the environmental impact of composite structure is the difficulty in assembling and disassembling the structure as it is more complicated and takes more time. However, this study focuses on the environmental impact of concrete and steel separately.

#### 2.4.1 Concrete

Due to the vast urbanization and rapid growth in the construction industry, the usage of concrete became more and more extensive and demanding as it is versatile in a lot of civil works like buildings, bridges, roads and dams. In fact, concrete ranked as the most widely used substance on Earth besides water. However, the production of concrete brings significant and irreversible impact to the environment due to the cement consumption. Cement is the main ingredient in the making of concrete as it binds the material together and gives strength and other physical properties to concrete. Nonetheless, cement production placed the third ranking contributor of anthropogenic carbon dioxide in the world, ranking after transportation and energy generation.

Generally, there are three main processes in cement production, which includes the preparation of raw materials, production of cement clinker, and finally, manufacturing of cement. Other raw materials like limestone rock, chalk and clayey schist are extracted and transported to the factory where they are crushed to powder form. All the raw materials will then be mixed in the right ratio to reach the designed composition. After it goes through a pre-heater, the ready composition is then placed into a kiln with temperatures of about 14500 °C. This procedure induces physical and chemical changes that convert the raw mix into clinker, which consumes the largest amount of energy. Optionally, additives and other minerals like gypsum, slag, and fly ash are added in to achieve the desired properties of the end product (Salas et al., 2016).

According to Gursel et al. (2014), over 5% of anthropogenic carbon dioxide ($CO_2$) emission is contributed by the global concrete production, especially from the manufacturing process of cement clinker. It was also discovered that for every 3 Gt (Gross Tonnage) of Portland cement produced globally, 2.6 Gt of $CO_2$ will be emitted yearly in return for the average production circumstances. Part of the emissions are caused by the combustion of fossil fuels in the production of Portland cement, as it is an energy-intensive material, needing 4–5 GJ for every ton of Portland cement produced. The remaining half is due to the calcination of limestone. Likewise, according to Initiative (2009), for every one mt (metric ton) of Portland cement clinker produced, 0.87 t of $CO_2$ is freed into the atmosphere. Nevertheless, this figure may differ with the location, technology, production efficiency, mix of energy sources used in electricity generation, and the selection of kiln fuels. However, the production of concrete not only contributes to $CO_2$ emissions. The study and quantification of the complete environmental burden of concrete production need a comprehensive analytical method, which is life cycle assessment (Gursel et al., 2014).

Apart from $CO_2$ emission, the cement industry also takes up responsibility for the noteworthy emissions of carbon monoxide and heavy metals. The main sources of heavy metal pollution in the natural environment are events done by human for profiting purposes, like industrial processing and mining. Photochemical ozone formation, heavy metals and carcinogens values are resulted from the manufacturing process of cement because of the raw materials used and energy-intensive processes. Cement production also make great impact to land surfaces, as a consequence resulting from quarrying, waste dumping, and storage of unwanted materials. Lastly, $SO_2$ and $NO_x$ emissions are also the main contributor to acidification and eutrophication (Salas et al., 2016). Figure 2.3 illustrates the environmental impact of cement production.

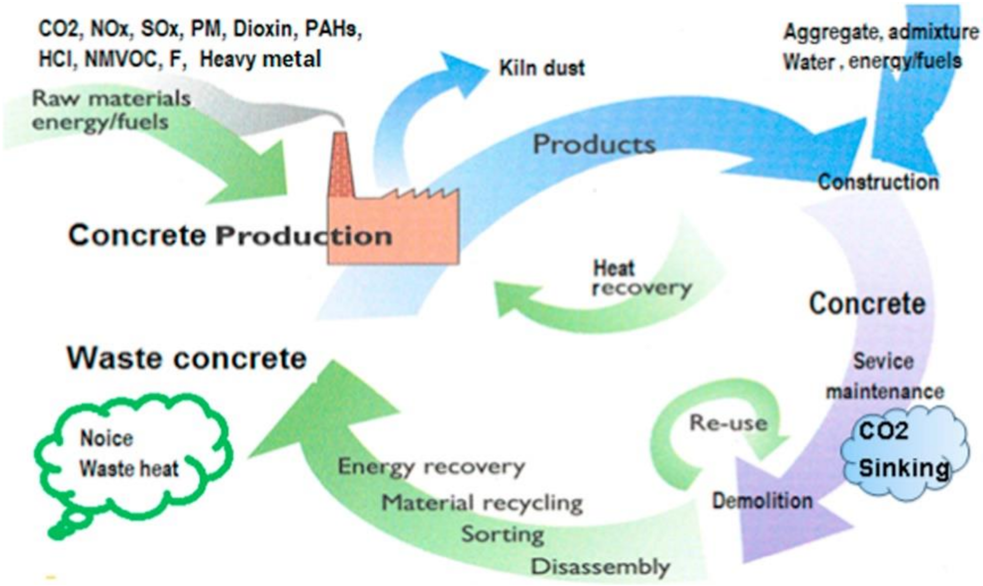


Figure 2.3: Environmental Impact from Cement Production (Shen et al., 2017)

### 2.4.2 Steel Plates and Steel Reinforcement

Steel is another key component in modern construction industry. In fact, steel is an alloying element made of iron, carbon, and chromium occasionally to give corrosion resistance. The utilization of steel in composite floor plate includes steel reinforcement and steel decking or steel plates. Besides, steel is also an essential raw material for other industries like manufacturing of car, furniture, building, and energy-used products as it has high tensile strength and is comparatively durable.

The steel elements can be categorized as three levels as shown in Figure 2.4, including crude steel, semi-finished steel, and finished steel. Crude steel is steel in its first solid form, it can then be further manufactured as slab, billet, bloom, beam, and bleak. Steel reinforcement, steel plate, and shear studs are in the third level in steel industry.

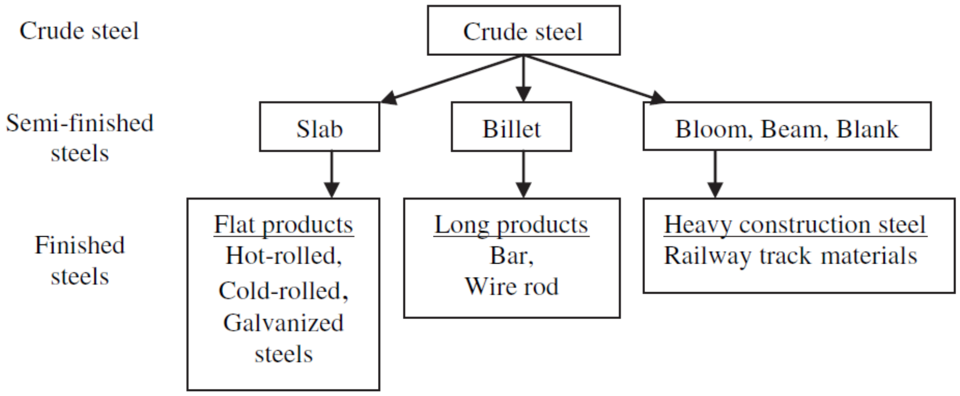


Figure 2.4: Category of Steel (Tongpool et al., 2010)

The environmental impact from steel is comparatively lower than cement in concrete production. However, the increment in energy consumption and greenhouse gas emission has also started to gain attention in steel industry. According to a study done by Tongpool et al. (2010), the steel industry in Japan takes up 15% of the total greenhouse gas emission of the country. Apart from the concern of greenhouse gas emission and energy consumption, the manufacturing of iron and steel are also draining the mineral resources in the natural environment. Moreover, emissions like CO, $NO_x$, $SO_x$, oil, and heavy metals from steel production could bring harm to biological community and human. For example, the production of galvanized steels needs zinc, while it produces toxic residue during the mining and refining processes of zinc, and subsequently polluting the industry. Moreover, zinc production also generates lead as a co-product and cadmium as a by-product, posing harm to the ecosystem. Cadmium, copper and zinc could also contaminate soil and reduce the sprouting rate of rice seeds and the growing process of root cells (Tongpool et al., 2010). Figure 2.5 demonstrates the environmental impact caused in the life cycle of steel production.

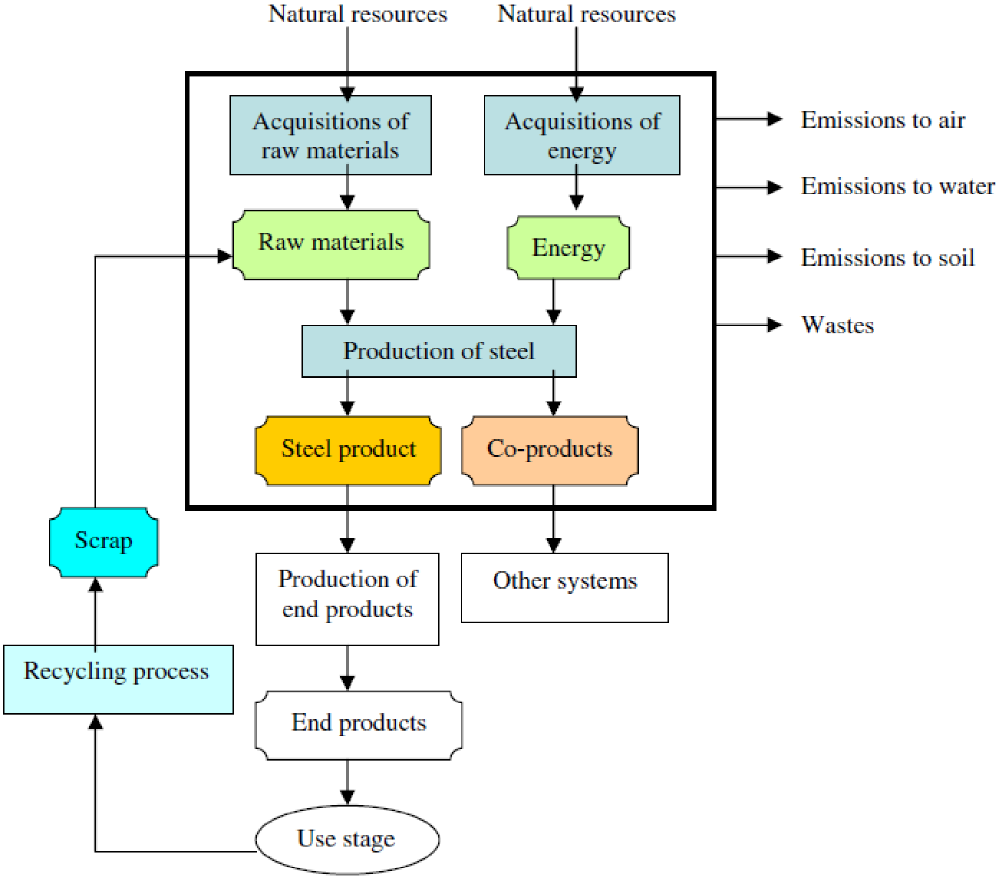


Figure 2.5: Steel Production and its Environmental Impact (Tongpool et al., 2010)

## 2.5 Life Cycle Assessment

Life cycle assessment (LCA) is an analytical approach to study and investigate the environmental performance of a variety of products or services throughout its full life-cycle. LCA contributes great help in construction sector, as the environmental issues aroused from construction activity are always of the interest to the public. The possible use of LCA in construction sector is shown in Table 2.2. LCA helps to understand and determine the best strategy to lower the environmental impact from the manufacturing process to the product’s end of life. In this case, the most environmentally friendly material can be selected based on the LCA analysis. At some level, LCA also helps building stakeholders to readily quantify the sustainability impact brought by the constructed building as it is significant to consider all stages in a building’s life cycle (Russell-Smith and Lepech, 2012).

Table 2.2: Possible Use of LCA in Construction Sector (Menoufi, 2011)

| **Type of user** | **Stage of the process** | **Aim of using LCA at this stage** |
|---|---|---|
| Consultants advising municipalities, urban designers | Preliminary phases | - Setting targets at municipal level.<br>- Defining zones where residential/ office building is encouraged or prohibited.<br>- Setting targets for development areas. |
| Property developers and clients | Preliminary phases | - Choosing a building site.<br>- Sizing a project.<br>- Setting environmental targets in a program. |
| Architects, Engineers and Consultants | - Early and detailed design (Product development)<br>- Design of a renovation project<br>(product improvement) | Comparing design options<br>(Geometry, orientation and technical choices) |

Generally, there are 5 main stages in the entire life cycle of a product or services, which starts from the sourcing stage of raw material needed for a product or service, then to the production point where the raw material is converted into an actual product. Furthermore, the third stage is the distribution of product to the end user, followed by the usage of product by the user. Lastly, is the act done by the user when the product has come to the end of its life. The five main stages in the life cycle of a product is illustrated in Figure 2.6.

Figure 2.6: Five Main Stages in the Life Cycle of a Product

The International Standard 14040 (ISO, 2006) describes the principle and framework for the life cycle assessment (LCA) as four phases: definition of the goal and scope, the life cycle inventory analysis (LCIA), the life cycle impact assessment (LCIA) and the life cycle interpretation. LCA is an iterative approach where the four phases stated above relies on the outputs of the other phases. Figure 2.7 shows the framework of life cycle assessment.

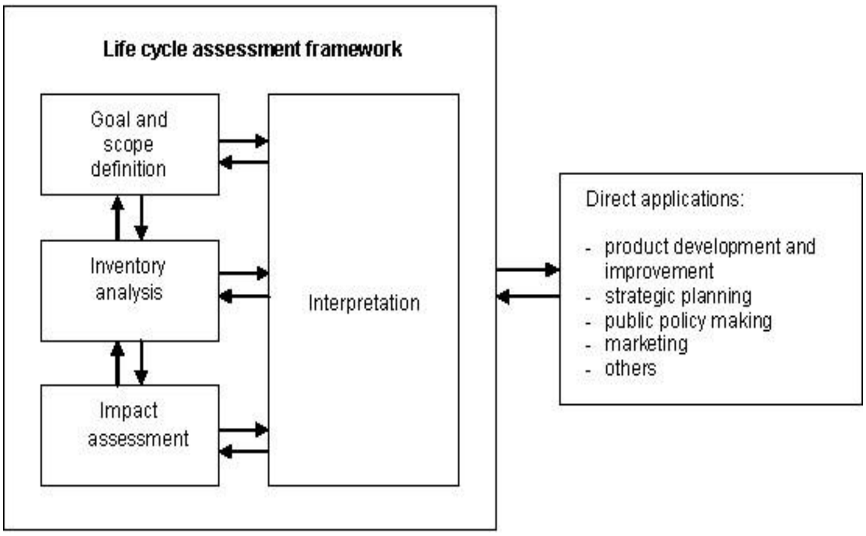


Figure 2.7: LCA Frame Work according to ISO 14040 Standard (Menoufi, 2011)

This iterative approach is significant in order to make sure that the results of the analysis are consistent and flexible. The four phases are discussed in the following sub-sections.

### 2.5.1 Definition of the Goal and Scope

The first step of a Life Cycle Assessment is the definition of the goal and scope. It is undoubtedly the most essential phase as it determines the exact approach to be followed in the process and defines the product to be assessed.

According to Finkbeiner et al. (2006), parameters are identified so that the purpose of impact assessment can be achieved. The wide variety of parameters includes the time and resources needed, the purpose of the study, the intended application, the system boundaries, the assessment methodology, and the general assumptions and limitations. In this way, definition of the goal and scope will act as a guiding light to the complete LCA process to achieve the most relevant and accurate results.

### 2.5.2 Life Cycle Inventory (LCI)

Life cycle inventory (LCI) is the second step involved in the LCA. LCI involves the process of data collection and calculation procedures based on the inputs and outputs of a product system defined in the first step. It contains the amount of energy and material involved in the process throughout all stages in the life cycle of a product.

Figure 2.8 shows the flow diagram depicting the common inputs and outputs of a product system. The LCI analysis is reliant on the variety types and different quantities of natural resources like water, energy and air. The material used, method of transportation which emits unwanted air and water, and the way of disposal when the product has come to the end of life, are all the factors affecting the LCI analysis. However, the consideration and consequences of these factors vary depending on the region. For instance, a region may be more dependent on renewable energy resources or fossil fuels, which makes the transportation of product less harmful to the environment. These variances may result in the difference in assumptions and limitations of the study of LCA.

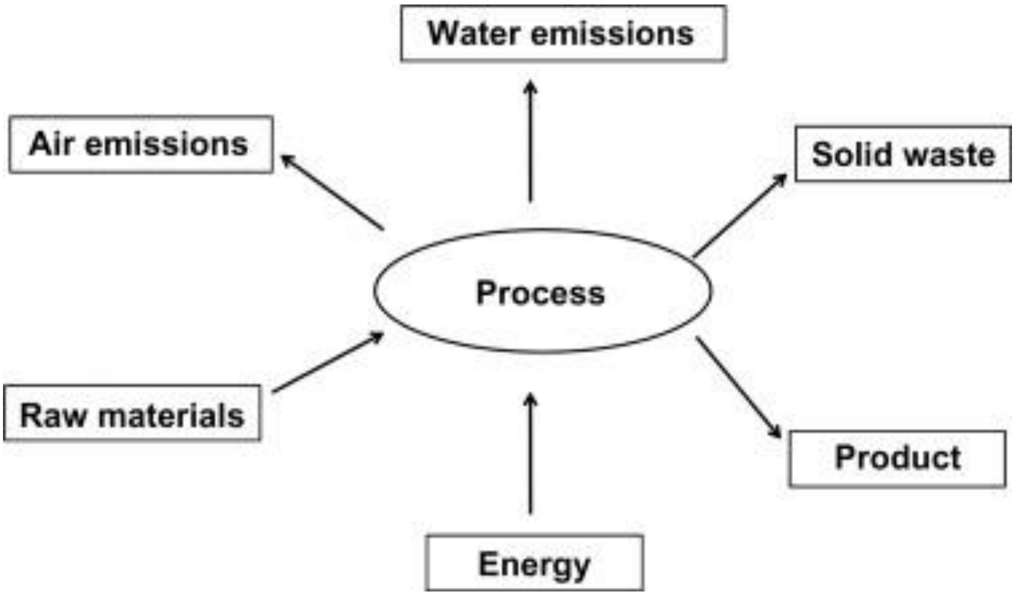


Figure 2.8: Flow Diagram of the Inputs and Outputs of a Product System (ul Islam and Kumar, 2019)

### 2.5.3 Life Cycle Impact Assessment (LCIA)

In the third phase of LCA, Life Cycle Impact Assessment (LCIA) is practised to estimate and comprehend the quantity and importance of the potential environmental impact of a product or service by converting the result obtained from LCI phase. The results will then be grouped into relevant environmental impacts categories, for instance, the impacts on natural environment, resources, and human health (Lehtinen et al., 2011).

#### 2.5.3.1 Definition and classification of impact categories

Midpoint and endpoint are quite different from one and another, where defining endpoint indicators are targeted at the level of the areas of protection, like natural environment, human health, and natural resources. However, midpoint indicators are defined at impacts between the point of emission and the endpoint (Capaz and Seabra, 2016). The point that makes midpoint and endpoint method distinctive is how the environmental relevance of category indicators is taken into consideration (Bare et al., 2000). Figure 2.9 shows the schematic presentation of the difference between midpoint and endpoint.

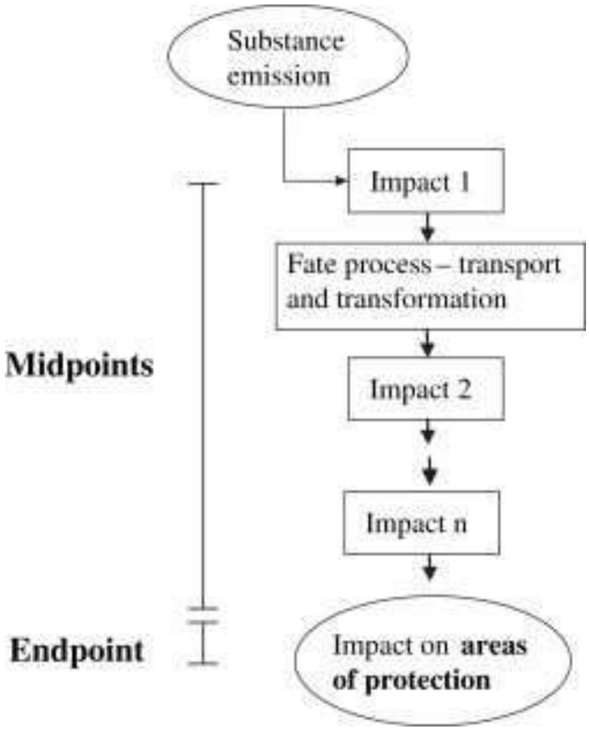


Figure 2.9: Difference Between Midpoint and Endpoint Along a Mechanism

According to Capaz and Seabra (2016), accessing and grouping the possible environmental impacts caused by the product or service can be studied and evaluated by categorization and characterization of the flow. In categorization, goals are defined at the first place, then the environmental impact categories are selected, such as global warming, ozone layer depletion, and acidification. The potential effect will be calculated by each category involved due to the flow identified in the product system. The potential impacts are assessed at the midpoint or endpoint levels by taking the characterization factors into account.

#### 2.5.3.2 ReCiPe Method

ReCiPe method is one of the most widely used methods for the life cycle impact assessment (LCIA), as it converts the long list of result obtained from Life Cycle Inventory, into a variety of indicators. These indicators show the related consequences on an environmental impact category as shown in Figure 2.10. ReCiPe method evaluates indicators at two level, which are the eighteen midpoint indicators and three endpoint indicators. According to Sustainability (2011), both midpoint and endpoint method include aspects according to three cultural perspectives where a combination of alternatives or choices on matters like time or expectations are characterized. Among the three perspectives, individualistic perspective is based on the consideration of short-term interest, and technological optimism pertaining to human adaptation. Secondly. the hierarchist perspective is built on scientific consensus with regard to the time frame, which commonly considered as the default model. Lastly, egalitarian perspective is based on the consideration of long-term interest in precautionary principle thinking.

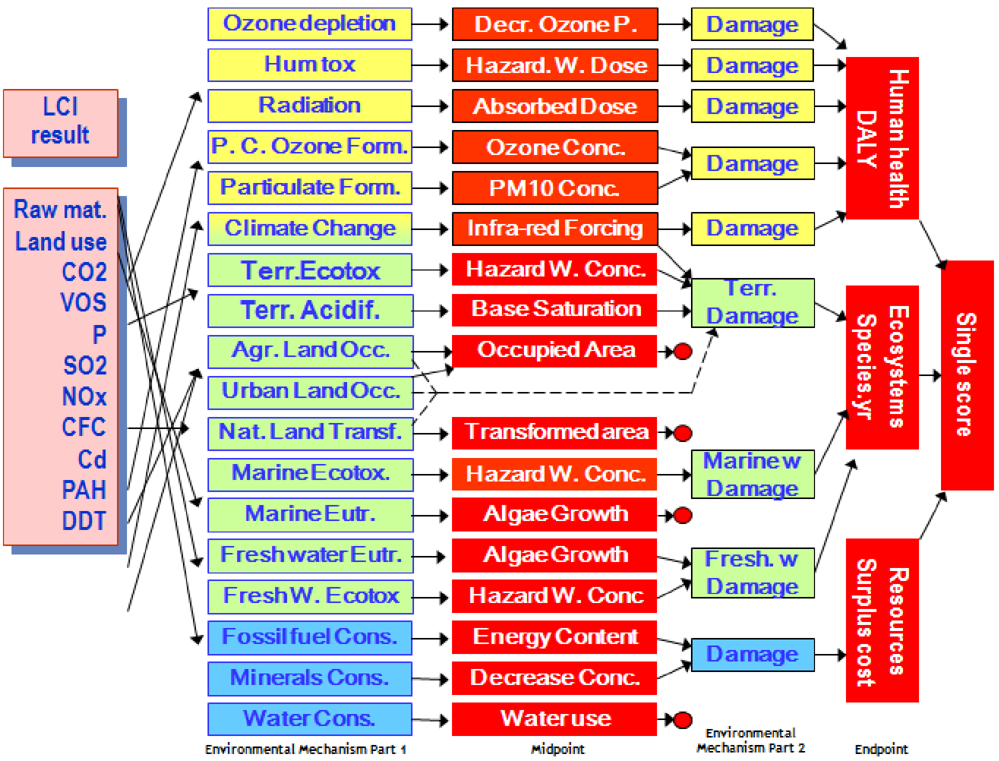


Figure 2.10: Relationship between LCI Parameters (Left), Midpoint Indicator (middle) and Endpoint Indicator (Right) in ReCiPe((LCIA), 2009)

### 2.5.4 Life Cycle Interpretation

The final stage in a life cycle assessment is the interpretation of the results. This stage in LCA comprises merging the findings from Life Cycle Inventory (LCI) with the Life Cycle Impact Assessment (LCIA). It analysed the most viable inputs, outputs and possible environmental effects of a creation onto the system. The data from the LCI and LCIA is examined and assessed. Then, deductions can be made. By finding the areas for enhancements, commendations can be made especially on the precise problems. This period in LCA is called improvement analysis. There are five main stages in the period. Firstly, finding vital problem of the system. Secondly, the result is assessed. Thirdly, based on the result, a related conclusion is made. Fourthly, Limitation of the system is explained. Finally, suggestion is given based on the result of previous phases (Crawford, 2011b).

## 2.6 LCA Tools and Database

To carry out the study using LCA, there is a lot of data needed for every stage in the life cycle framework, whether it is in cradle-to-grave or cradle-to-gate manner. For example, the data needed consists of the inputs and outputs from the production of concrete which includes the raw materials until the waste is produced. Selecting an appropriate tool and database before starting the study on the life cycle assessment is considerably important (Finnveden, 2000). Table 2.3 shows the list of LCA tools. Table 2.4 shows the free LCA database available in the market, and Table 2.5 shows the commercial LCA database.

Table 2.3: List of LCA Tools (Lehtinen et al., 2011)

| Tool name | Supplier | Supports LCI and/or LCIA* | Supports full LCA* | Language | Main database | Special area if any | Free? |
|---|---|---|---|---|---|---|---|
| AIST-LCA Ver.4 | National Institute of Advanced Industrial Science and Technology (AIST) | | Yes | Japanese | AIST-LCA database | | No |
| BEES 4.0 | National Institute of Standards and Technology (NIST) | | Yes | English | Bees database | Construction industry | Yes |
| CCaLC Tool | The University of Manchester | | Yes | English | CCaLC | | Yes |
| Eco-Bat 2.1 | Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud | Yes | | French, Italian, English | Eco-Bat database | Construction industry | No |
| Ecoinvent waste disposal inventory tools v1.0 | Doka Life Cycle Assessments (Doka Okobilanzen) | Yes | | English | Ecoinvent database | Waste management | No |
| EIME V3.0 | CODDE | | Yes | English | EIME database | Electrical, mechanical and electronic products | No |
| Environmental Impact Estimator V3.0.2 | Athena Sustainable Materials Institute | | Yes | English | Own database | Construction industry | No |

Table 2.3 (Continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| eVerdEE v.2.0 | ENEA - Italian National Agency for New Technology, Energy and the Environment | | Yes | Italian, English | ENEA database | | Yes |
| GaBi 4 | PE International GmbH University of Stuttgart, LBP-GaBi | | Yes | English | Gabi database | | No |
| GEMIS version 4.4 | Oeko-Institut (Institute for applied Ecology), Darmstadt Office | Yes | | Spanish, Czech, | | Energy, transport, | No |
| KCL-ECO 4.1 | VTT | | Yes | English | | | No |
| LEGEP 1.2 | LEGEP Software GmbH | | Yes | English, German | LEGEP database | Construction industry | No |
| LTE OGIP; Version 5.0; Build-Number 2092; 2005/12/12 | t.h.e. Software GmbH | | Yes | German | | Construction | No |
| OpenLCA | GreenDeltaTC GmbH | | Yes | English | | | Yes |
| Qantis suite 2.0 | Quantis | | Yes | English | Qantis database | | No |
| REGIS 2.3 | sinum AG | | Yes | Japanese,<br>Spanish,<br>German,<br>English | ecoinvent Data v1.3: | | No |
| SALCA-tools | Agroscope Reckenholz-Tänikon Research Station ART | Yes | | German | | Agriculture | |

Table 2.3 (Continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SankeyEditor 3.0 | STENUM GmbH | Yes | | English | | | No |
| SimaPro 7 | PRé Consultants B.V. | | Yes | Spanish, French, Italian, German, English | SimaPro | | No |
| TEAMTM 4.5 | Ecobilan - PricewaterhouseCoopers | | Yes | English | | | (Yes) |
| The Boustead Model 5.0.12 | Boustead Consulting Limited | | Yes | English | The Boustead Model database | | No |
| Umberto 5.5 | ifu Hamburg GmbH | | Yes | English | Umberto Library | | No |
| USES-LCA | Radboud University, Nijmegen | Yes | | English | | Toxic impacts between substances | Yes |
| WRATE | UK Environment Agency | | Yes | English | | Municipal waste management systems | No |

Table 2.4: Free LCA Databases (Lehtinen et al., 2011)

| **Database name** | **Supplier** | **Languages** | **Special area, if any** |
|---|---|---|---|
| CCaLC database | The University of Manchester | English | |
| CPM LCA Database | Centre for Environmental Assessment of Product and Material Systems - CPM | English | |
| Eurofer data sets | EUROFER | English | Steel industry |
| GEMIS 4.4 | Oeko-Institut (Institute for applied Ecology), Darmstadt Office | Spanish<br>Czech<br>German<br>English | Energy, transport, recycling and waste treatment |
| Franklin Associates' Case examples | Franklin Associates | English | |
| ILCD | European Commission | English | |
| LC Data | Forschungszentrum Karlsruhe | German<br>English | Energy, transport and end of life |
| LCA_sostenipra_v.1.0 | Universitat Autònoma de Barcelona (UAB) | Spanish,<br>Catalan,<br>English | biomass production (energy crops and forest biomass), wood use and recycling (energy and products), ecodesign, sustainable architecture, service systems and green chemistry |
| MFA_sostenipra_v.1.0 | Universitat Autònoma de Barcelona (UAB) | Spanish<br>Catalan<br>English | |
| PlasticsEurope Eco-profiles | PlasticsEurope | English | Polymers (main) and their intermediates |
| ProBas | Umweltbundesat | German | |

Table 2.5: Commercial LCA Databases (Lehtinen et al., 2011)

| **Database name** | **Supplier** | **Languages** | **Special area, if any** |
|---|---|---|---|
| DEAMTM | Ecobilan - PricewaterhouseCoopers | English | |
| Ecoinvent Data v1.3 | EcoInvent Centre | Japanese, English | |
| EIME V11.0 | CODDE | Spanish, French, English | Selection of products |
| esu- services database v1 | ESU- services Ltd. | German, English | |
| GaBi databases 2006 | PE International GmbH | Japanese, German, English | |
| Option data pack | National Institute of Advanced Industrial Science and Technology (AIST) | Japanese | Chemical production, iron & steel and waste management processes |
| Sabento library 1.1 | ifu Hamburg GmbH | German, English | Enzymatic processes, cell cultures, and microbiological systems |
| SALCA 071 | Agroscope Reckenholz-Tänikon Research Station ART | German, English | Agriculture |
| SimaPro database | PRé Consultants B.V. | English | |
| sirAdos 1.2. | LEGEP Software GmbH | German | Construction |
| The Boustead Model 5.0.12 | Boustead Consulting Limited | English | Fuels, materials |
| Umberto library 5.5 | ifu Hamburg GmbH | German, English | |

### 2.6.1 OpenLCA

In this study, openLCA version 1.7.4 will be used to conduct the life cycle assessment of concrete composite floor plate and conventional reinforced concrete slab. OpenLCA is a free and open source software used for Life Cycle Assessment (LCA) and sustainability assessment with graphical modelling. Free databases are made available on the openLCA website such as exiobase, ARVI, NEEDS, ELCD, Agribalyse, USDA, and bioenergiedat.

### 2.6.2 Ecoinvent 3.4 Database

Out of the many databases available in the market, Ecoinvent 3.4 is selected to aid the research of this study. Ecoinvent is the world’s largest transparent life cycle inventory database consist of 10,000 over datasets which cover large variety of sectors including agriculture, energy and manufacture. Examples of industries the database covers are computer production, fatty acid production, electricity production, benzene production, palm oil mill operation, concrete production, transportation, and many more. All the data are supplied by dependable and consistent sources by independent professionals so that it is presented in a transparent way. Ecoinvent is made conveniently for construction purposes, as every type of construction material is involved and established with a vast diversity of products (Martínez-Rocamora et al., 2016). Figure 2.11 depicts the basic structure of Ecoinvent database.

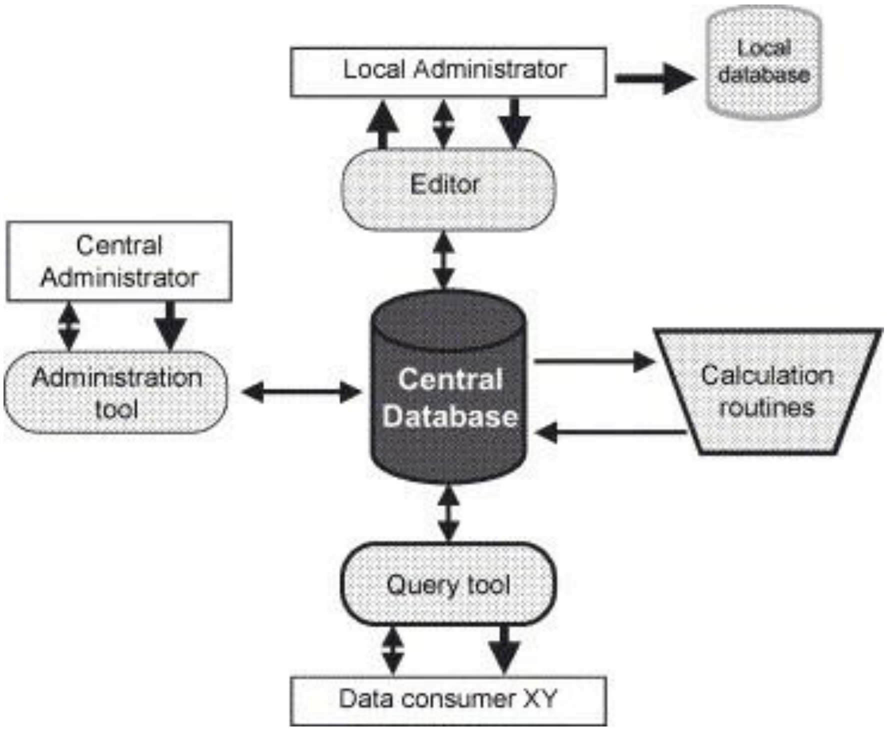


Figure 2.11: The Basic Structure of Ecoinvent Database System (Frischknecht and Rebitzer, 2005)

Ecoinvent provides three system models based on the same fundamental data of real-world processes to choose from, which is cut-off system model, allocation at the point of substitution (APOS) system model and consequential system model (Ecoinvent, 2013). In cut-off system model, all the exchanges are classified into either allocatable by-products recyclable material, or waste. It was assumed that all recyclable materials are cut off from the product producing system, making no impacts or benefits to the producing activity. Thus, secondary material only bears the burden of recycling process without having burden from the primary processes. However, there exists an underlying rule that a producer is responsible for the disposal of the waste from the production or service. Furthermore, APOS system model is performed on a ground that all treatment processes required for any by products are included as an expansion of the allocation system. It is based on the attributional approach in which burdens are assigned proportionally to particular processes. Lastly, consequential system model evaluates the result of a change in a system by adopting different fundamental assumptions. All in all, cut-off system model is the most often adopted system model in most of the LCA in construction industry due to its simplicity and easier understanding for the users.

## 2.7 Limitation of LCA

These days, LCA has been widely used as a standard and tool to compare and evaluate the environment impacts of a product or service, however, it does have its imperfection and shortcomings. According to Lehtinen et al. (2011), the result of LCA is said to be insufficient in transparency, which makes LCA a less reliable source of information and less suitable for comparison. Moreover, the social and economic aspects have been acknowledged by most of the contemporary theories to be a critical aspect in long term sustainability. LCA is also said to be unable to account for economic and social data.

Impact category separates different emissions into one effect on the environment by converting the different emissions into one different unit during the Life Cycle Impact Assessment (LCIA) of LCA. In recent years, some impact categories of LCA have gained importance and attention because of climate change, which are global warming potential and water pollution or water usage. In fact, the life cycle of concrete production foreseeably contributes to a considerable amount of greenhouse gas (GHG) which leads to global warming and the hard surfaces created by concrete will cause surface runoff, and subsequently result in water pollution. Global warming is generally known as ‘carbon footprint’, which depicts the amount of GHG emission caused by a product’s life cycle. The studies on global warming is well supported by various methodologies and guidance, for instance, PAS 2050:2008 (Publicly Available Specification) was developed to provide community and industry a consistent method for assessing the life cycle GHG emission of goods and services. (Specification, 2008). On the contrary, water usage or water pollution, which is commonly known as ‘water footprint’ is on the spotlight of environmental issues but has no agreed methodology about water foot print and relevant data is limited. As a result, studying the specific impact category is difficult as the studies on the subject is comparatively limited (Lehtinen et al., 2011).

# CHAPTER 3

# METHODOLOGY AND WORK PLAN

## 3.1 Introduction

As mentioned in the previous chapter, life cycle assessments are performed in accordance to the guideline given by ISO 14040 series in order to study the environmental impacts of processes and products throughout their life cycle. The methodology of the study is stated in this chapter, including four main stages in the life cycle assessment framework which are definition of the goal and scope, life cycle inventory, life cycle impact assessment and life cycle interpretation. A few assumptions have been made in this study due to the limitation of data in the production process.

## 3.2 Goal and Scope definition

The objective of this life cycle assessment study is to determine the environmental impact from the productions of conventional reinforced concrete slab and concrete composite floor plates, and to study the difference of both productions. Besides, this study aims to evaluate the energy inputs associated with the two types of slabs and their embodied energy. The intended audience of the study is the construction industry which targets to reduce the environmental impact of the production of concrete.

The system boundaries of the production process need to be set up for the assessment. In this study, the system boundary was limited to cradle-to-gate, where only processes from raw material extraction, to manufacturing of material until the transportation to construction site are taken into consideration. Moreover, Only the energy inputs related with the building construction in the initial stage were evaluated, where energy needed for on-going component replacement, end-of-life restoration, disposal and possible reuse and recycling of materials were excluded (Crawford, 2011a). The amount of fuel might differ in different concrete mixing plants (Dahmen et al., 2018), therefore assumption had been made such that the energy consumption for the production of different concrete in different plants are the same.

The system boundary of conventional reinforced concrete slab and concrete composite floor plates are shown in Figure 3.1. The making of both slabs requires the productions of concrete and steel. Concrete and steel bars are needed for a conventional reinforced concrete slab, whereas steel plates, steel bar and concrete are needed for a concrete composite floor plate. The product system of steel includes the attainments of raw materials like iron or steel input, scrap and the production of the steel product. The scope of the project is not a complete life-cycle assessment, where the use and disposal stages of products are excluded as shown. Each of the products assessed has a life cycle, starting with raw material extraction, then packaging and shipment of the product to the construction site.

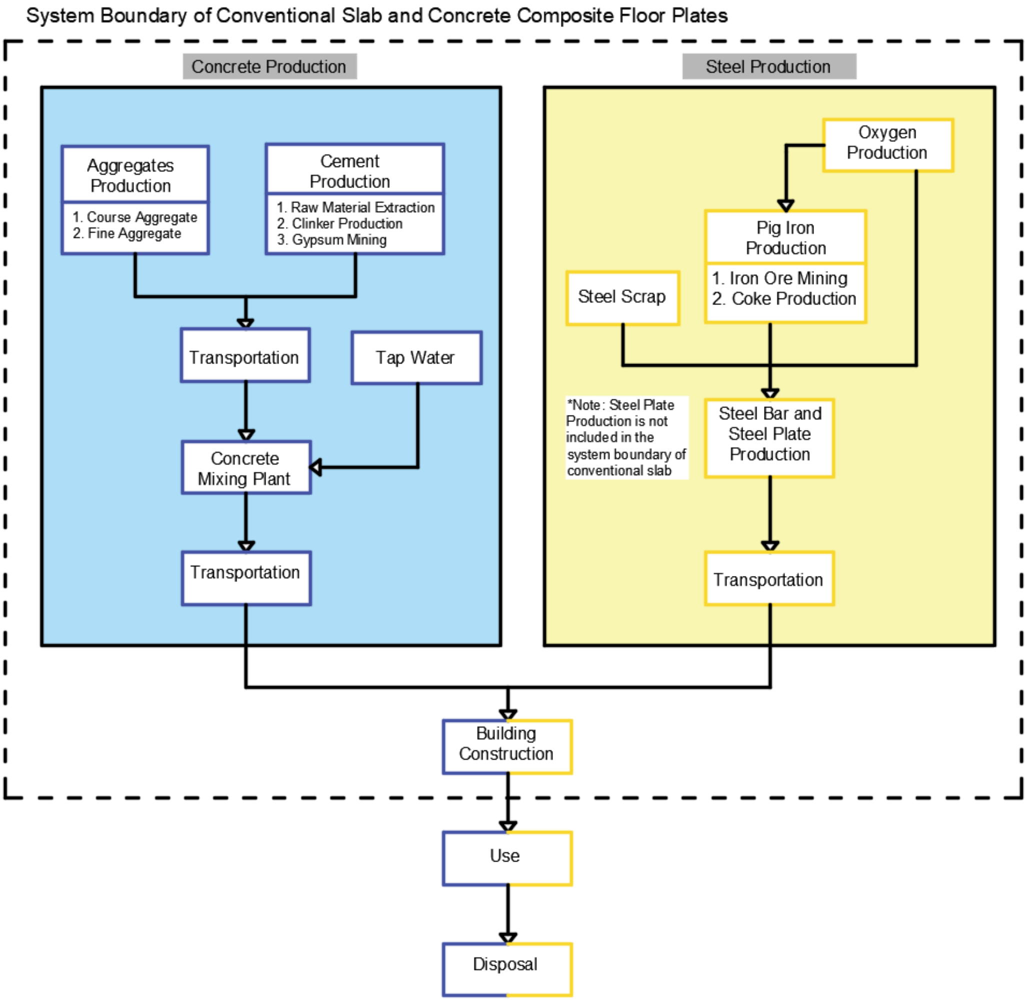


Figure 3.1: System Boundary of Conventional Reinforced Concrete Slab and Concrete Composite Floor-plates

The amount of fuel might differ in different concrete mixing plants (Dahmen et al., 2018), therefore assumption had been made such that the energy consumption for the production of different concretes in different plants are the same. In addition, referring to the study by Nisbet et al. (1997), assumption on the total distance of transportation of cement to the concrete mixing plant was 100 km, while the distance for coarse and fine aggregate to concrete mixing plant is 50 km. Besides, the transportation radius of steel including reinforcing steel and steel decking was set to 50 km.

### 3.2.1 Evaluated Slabs

Both conventional reinforced concrete slabs and concrete composite slabs adopted in this study are with the dimension of 2m x 2m in size and 200 mm thickness in depth. The cut sections of studied slabs are as shown in Figure 3.2 and Figure 3.3. The type of slab design used in this study is the flat slab, which is a type of reinforced concrete slab supported directly and only by concrete columns without the use of beams. According to the guideline given by Mosley et al. (2012) in Eurocode 2, the lifespan of a flat slab is 50 years.

A reference unit or the functional unit is where the environmental impact of the product system will be assessed, including the input and outputs related. In this study, the floor system is the focus, and both the studied floor system are designed to carry the same carrying capacity for a given live load of 5 $kN/m^2$, and dead loads of screed, ceiling, service and finishes with 1.8, 0.55 and 0.2 $kN/m^2$, respectively (Wang et al., 2018). All floor systems in this study are designed in accordance with Eurocode 2 to meet the load requirements.

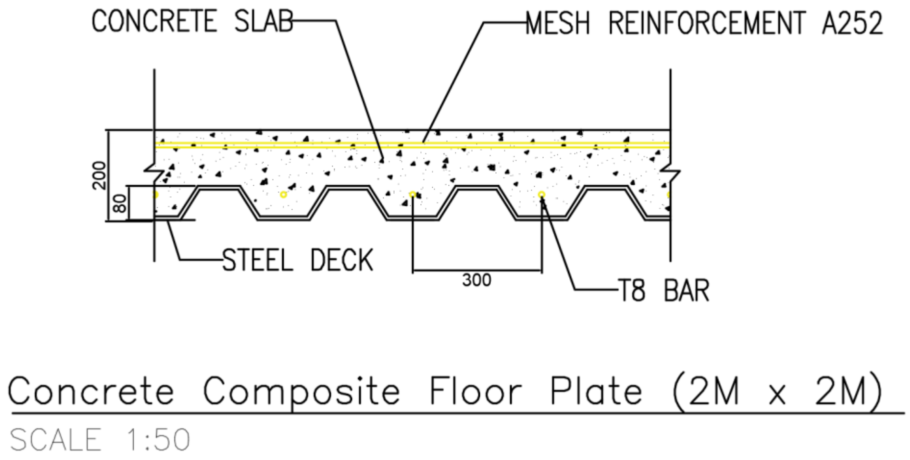


Figure 3.2: Geometry of Concrete Composite Floor-plates

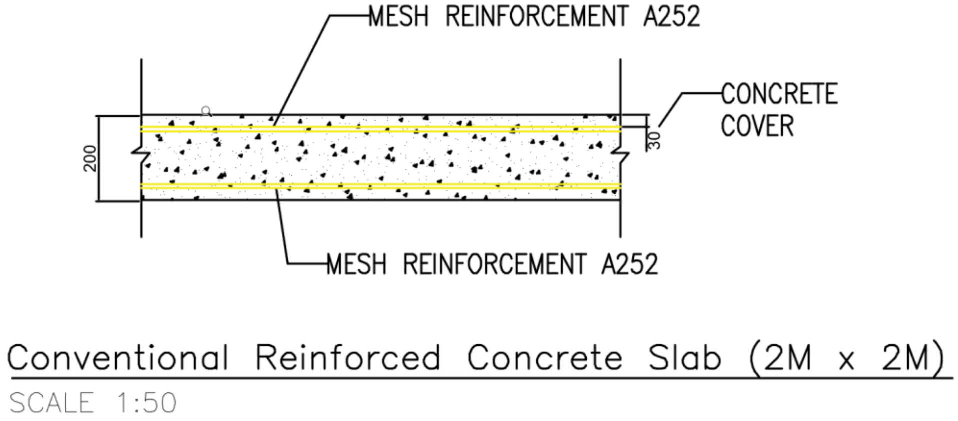


Figure 3.3: Geometry of Conventional Reinforced Concrete Slab

#### 3.2.1.1 Properties of materials involved

The main construction materials involved in the manufacturing process of conventional reinforced concrete slab and concrete composite floor plate are concrete, steel plate, reinforcing steel bar and water. The water used in the study is assumed to be obtained from the tap water supply network. The properties of materials involved need to be specified for the convenience of input process in OpenLCA software.

ASTM Type 1 Portland Cement is used as the main binding material in the making of concrete. The mix design for the concrete used in this study is in favour to achieve Grade 30 concrete, which consist of ASTM Type 1 Portland

Cement, fine aggregate, coarse aggregate and water, with the mass ratio of 1:3:2.1:0.55. The mix design ratio of concrete and density of materials are obtained from Cheah and Ramli (2013) and are specified in Table 3.1. The concrete mix was targeted to have a slump value of 50 mm in its fresh state and a design characteristic cube compressive strength of 31.15 MPa at the age of 28 days.

Table 3.1: Mix Design Ratio of Concrete and Density of Materials (Cheah and Ramli, 2013)

| **Raw Materials** | **Mix Design Ratio** | **Density** |
|---|---|---|
| Cement | 1 | 350 kg/m$^3$ |
| Fine aggregates | 3 | 1050 kg/m$^3$ |
| Coarse aggregate | 2.1 | 740 kg/m$^3$ |
| Water | 0.55 | 193 kg/m$^3$ |

Steel also plays an important role in the manufacturing process of reinforced concrete as well as concrete composite floor plate, as it involves the use of longitudinal steel bar, square wire mesh and steel decking. The longitudinal reinforcing steel bar used in concrete composite slab is 7H8-300, that is 7 steel bars with the diameter of 8 mm with 300 mm spacing in the span of 2 meters. Next, the steel decking adopted in this study is trapezoidal corrugated steel sheet with 1 mm thickness. The mesh reinforcement used in the both slabs of this study is A252 with the reinforcement properties as shown in Table 3.2. Note that the bar size is 8 mm in diameter with 200 mm spacing. The weight of the mesh reinforcement is able to obtain by using the weight given, 3.95 kg/m$^2$. According to Institution (2006), the weight of solid steel and corrugated steel sheet per mm thick is given 7850 kg/m$^3$ and 10 kg/m$^2$, with that, the weight of steel bar and steel decking are able to be computed. Table 3.3 summarizes the properties of steel bar, mesh reinforcement and steel decking used in reinforced concrete slab and concrete composite floor plates as well as their total steel weight.

Table 3.2: Properties of Mesh Reinforcement (Specialist Construction Supplies)

| **BS REF** | **Mesh Size Nominal Pitch of Wire (mm)** | | **Wire Sized (mm)** | | **Cross Sectional Area Per Metre Width (mm)** | | **Weight (Kg/m$^2$)** |
|---|---|---|---|---|---|---|---|
| | **Main** | **Cross** | **Main** | **Cross** | **Main** | **Cross** | |
| A252 | 200 | 200 | 8.0 | 8.0 | 252.0 | 252.0 | 3.95 |

Table 3.3: Summary of Properties of Material Used and Total Steel Weight

| | **Steel Bar** | **Mesh Reinforcement** | **Steel Decking** | **Total Steel Weight** |
|---|---|---|---|---|
| Reinforced Concrete Slab (2mx2m) | - | A252<br>$(2 \times 2m \times 2m)$ | - | 31.6 kg |
| Composite Floor Plates (2m x 2m) | 7H8-300 | A252<br>$(1 \times 2m \times 2m)$ | 1mm thickness | 61.32kg |

The manufacturing processes of the materials involved in the studied slabs are subjected to an embodied energy coefficient, which is the energy consumed by the material during its production stage. The energy usage in the production of material especially at concrete mixing plant and steel production is of great interest in this study. Table 3.4 shows the embodied energy consumption by various types of material involved in this study. This data is then be utilised to calculate the electricity for the inputs of both of the studied slabs.

Table 3.4: Embodied Energy Consumption for the Production of Materials (Ahmed and Tsavdaridis, 2018)

| **Material** | **Embodied energy coefficient (MJ/kg)** |
|---|---|
| Cement | 5.5 |
| Sand | 0.081 |
| Gravel | 0.083 |
| Water | 0.01 |
| Reinforcing steel bar | 17.4 |
| Metal Deck | 22.6 |

## 3.3 Life Cycle Inventory

After defining the goal and scope, LCA methodology involves the conception of the life cycle inventory of the environmental impacts caused by a certain product or process. A life cycle inventory entails a thorough tracing of all the flows, input and output of the system (Dahmen et al., 2018). The input data consisted of the acquisition of raw materials, energy, water and transportation, whereby the output included the waste, emission to air, water and land. The mix design of concrete and properties of steel adopted in this study was elaborated in section 3.2.1.1, the data is then utilised and inputted into the openLCA software.

All data was taken from Ecoinvent 3.4 database. The model system selected in this study is the cut-off model. Table 3.5 shows the details of input of raw materials involved in both conventional reinforced concrete slab and concrete composite floor plates productions. Table 3.6 entails the selected origin of datasets. Figure 3.4 and Figure 3.5 shows the input data in openLCA software for conventional reinforced concrete slab and concrete composite floor plates respectively.

Table 3.5: Input for Raw Material Production

| Material | LCI Data Source | Data Quality Assessment |
|---|---|---|
| Cement, Portland | cement production, Portland \| cement, Portland \| Cutoff, U | • The dataset describes the production of cement (CEM I) in Switzerland and covers the representative production mix of CEM I 42.5 und CEM I 52.5 R as defined in EN 197-1.<br>• The activity starts with the clinker in the silo to be used for cement production and with the additional ingredients of the cement at the gate of the cement plant.<br>• The activity includes also the electricity used for the grinding of the clinker, grinding aids, heat for the drying of additions etc. and ends with the cement produced in the cement mill. The dataset does not include packaging and administration. |
| Energy usage at concrete mixing plant | electricity, high voltage, production mix \| electricity, high voltage \| Cutoff, U | • The shares of electricity technologies on this market are valid for the year 2014.<br>• They have been implemented by the software layer and don't represent the production volumes in the unlinked datasets valid for the year 2012. These shares have been calculated based on statistics from 2014.<br>• Basic source is from IEA. 2017. IEA World Energy Statistics and Balances. |

Table 3.3 (Continue)

| | | |
|---|---|---|
| Gravel, crushed | gravel production, crushed \| gravel, crushed \| Cutoff, U | • This dataset represents the production of 1 kg of crushed gravel. From the total amount (100%) of mined gravel round, crushed and sand, about 15% is crushed gravel. From gravel at ground, unexcavated.<br>• This activity ends with the crushed gravel produced and the recultivation process done. This dataset includes the whole manufacturing process, internal processes (transport, etc.) and infrastructure.<br>• This dataset doesn't include the administration and wastewater wasn't considered because it has been assumed that the content is mainly superfine sand which has no negative effect on the ground water and soil. |
| Sand | gravel and sand quarry operation \| sand \| Cutoff, U | • This dataset corresponds to the production of 1 kg of sand (35%) and gravel (65 %). From the total sectoral production volume (100 %) of mined gravel round, crushed and sand, about 85 % is gravel round and sand This activity ends with the gravel and sand dogged and the recultivation process done.<br>• The dataset includes the whole manufacturing process for digging of gravel round and sand (no crushed gravel), internal processes (transport, etc.), infrastructure for the operation (machinery) and land-use of the mine (incl. unpaved roads). |

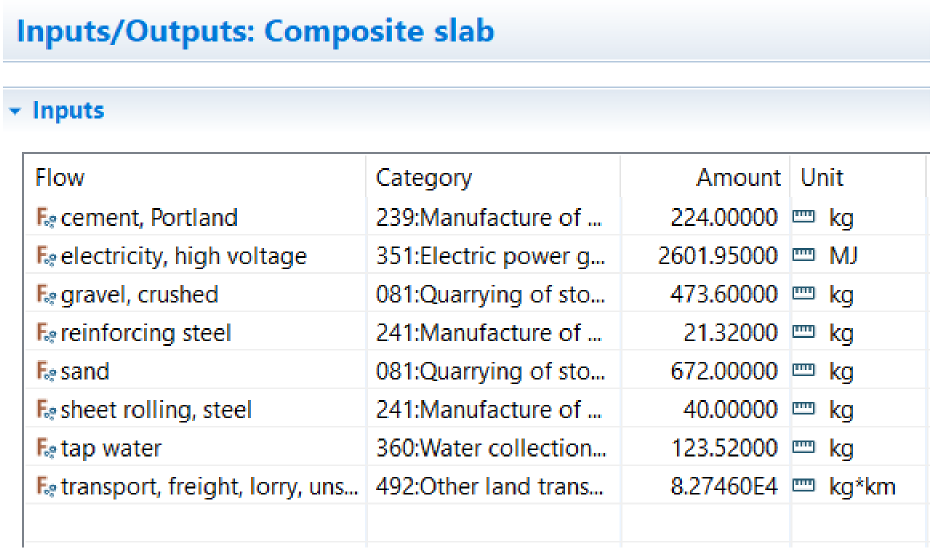
Table 3.3 (Continue)

| | | |
|---|---|---|
| Tap water | tap water production, conventional treatment \| tap water \| Cutoff, U | • This dataset represents production of 1 kg of tap water under pressure at facility gate, ready for distribution in network. It represents average operation of conventional treatment for production tap water. Conventional treatment includes coagulation and decantation, filtration and disinfection. Other treatment such as oxidation (ultraviolet radiation, ozone) and other adjustment (pH, alkalinity, etc.) can be present in some plant. |
| Reinforcing steel | reinforcing steel production \| reinforcing steel \| Cutoff, U | • This dataset represents Average of World and European production mix. This is assumed to correspond to the consumption mix in Europe, and the results of the central updates were reviewed extensively.<br>• Mix of differently produced steels and hot rolling |
| Sheet rolling steel | sheet rolling, steel \| sheet rolling, steel \| Cutoff, U | • This process is to be used only for un- and low-alloyed steel. For many applications, the products of hot rolling are unsatisfactory, e.g., with respect to cross section, surface quality, dimensional accuracy, and general finish, so that cold rolling is necessary.<br>• Cold rolled products are mainly strips and sheets with high quality surface finish and precise metallurgical properties for use in high specification products. |

| | | |
|---|---|---|
| | | • This dataset includes the process steps continuous pickling line, cold rolling, annealing, tempering, inspecting and finishing, packing coils or sheets, roll maintenance.<br>• Does not include the material being rolled. |
| Transportation | market for transport, freight, lorry, unspecified \| transport, freight, lorry, unspecified \| Cutoff, | • This dataset represents the transportation of lorry on the road.<br>• The path of transportation distance is assumed according to relative research which is 100 km for cement, 50 km for coarse and fine aggregates, 50 km for reinforcing steel and steel decking. |

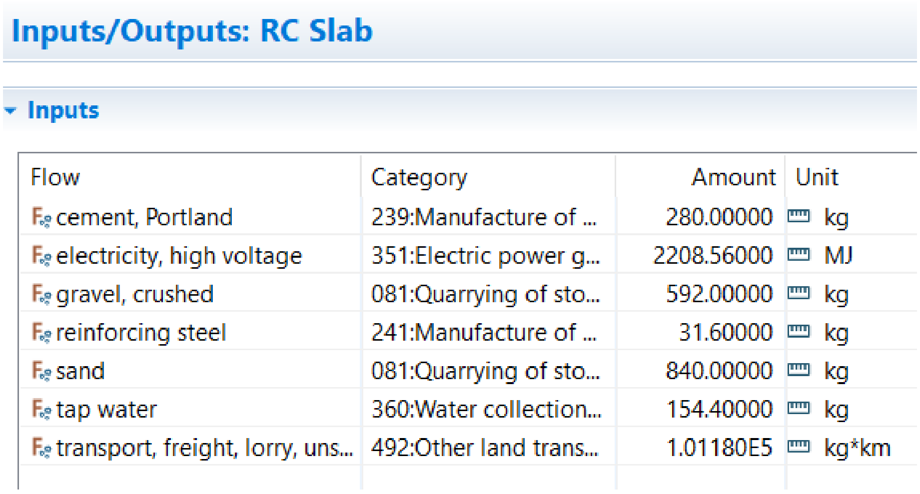
Table 3.6: Origin of Datasets

| Dataset | Origin |
|---|---|
| Cement | Switzerland |
| Fine/Coarse aggregate | Switzerland |
| Tap water | Switzerland |
| Energy usage | Switzerland |
| Reinforcing steel & steel deck | Rest of World (RoW) |
| Transportation | Rest of World (RoW) |



| Flow | Category | Amount | Unit |
|---|---|---|---|
| cement, Portland | 239:Manufacture of ... | 224.00000 | kg |
| electricity, high voltage | 351:Electric power g... | 2601.95000 | MJ |
| gravel, crushed | 081:Quarrying of sto... | 473.60000 | kg |
| reinforcing steel | 241:Manufacture of ... | 21.32000 | kg |
| sand | 081:Quarrying of sto... | 672.00000 | kg |
| sheet rolling, steel | 241:Manufacture of ... | 40.00000 | kg |
| tap water | 360:Water collection... | 123.52000 | kg |
| transport, freight, lorry, uns... | 492:Other land trans... | 8.27460E4 | kg*km |

Figure 3.4: Input Data of Concrete Composite Floor-plates



| Flow | Category | Amount | Unit |
|---|---|---|---|
| cement, Portland | 239:Manufacture of ... | 280.00000 | kg |
| electricity, high voltage | 351:Electric power g... | 2208.56000 | MJ |
| gravel, crushed | 081:Quarrying of sto... | 592.00000 | kg |
| reinforcing steel | 241:Manufacture of ... | 31.60000 | kg |
| sand | 081:Quarrying of sto... | 840.00000 | kg |
| tap water | 360:Water collection... | 154.40000 | kg |
| transport, freight, lorry, uns... | 492:Other land trans... | 1.01180E5 | kg*km |

Figure 3.5: Input Data of Conventional Reinforced Concrete Slab

### 3.4 Life Cycle Impact Assessment

In the life cycle impact assessment stage, it is targeted to further evaluate the potential impact on the environment from the results of the LCI. The important steps involved in the LCIA is the selection and definition of impact categories, classification, characterization and normalization (Crawford, 2011c).

The impact categories selected and defined in this study is climate change, ozone depletion, human toxicity, particulate matter and eutrophication. Classification is about assigning results in LCI to the impact categories chosen. The influence of each impact to each impact category is evaluated by multiplying it by a characterization factor. Lastly, the final step was the normalization where the characterized LCI results was to give an idea by expressing them in the way that allows the comparison of the impact categories.

The impact assessment method adopted in this study is ReCiPe method established in 2008 through collaboration between RIVM, Radboud University Nijmegen, Leiden University and PRé Sustainability. In this study, the characterisation factor will be derived at midpoint level. Choosing a different impact assessment method may diverge across area and could result in a different LCIA result. ReCiPe model was used as it is a more comprehensive and holistic method to gauge the environmental impact of the studied slabs in the construction industry.

### 3.5 Life Cycle Interpretation

The environmental impact of the conventional reinforced concrete slab and concrete composite floor plate are compared according to the selected and concerning impact categories, which are climate change, fine particulate matter formation, human toxicity, freshwater eutrophication and photochemical oxidant formation. The results of impact categories selected for both of the studied slabs are interpreted based on their characterization factors. Lastly, the product among the two kinds of slab with lesser emission or lesser environmental impact was recommended.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

This chapter focuses and compares on the results of the life cycle impact assessment of concrete composite floor-plates and conventional reinforced concrete slab. The environmental impacts under the impact category of ReCiPe method using cut-off method is thoroughly discussed. The focused environmental impacts are climate change, fine particulate matter formation, human toxicity, freshwater eutrophication and photochemical oxidant formation.

All the results are taken from openLCA by analysing the environmental impact contributed by every meter cube ($m^3$) of the two studied slabs. Each impact category result is supported by its own impact indicator and characterization factor. The LCIA results of two studied slabs are compared and presented in tables and bar charts generated from Excel, the relative percentages and values in the bar charts indicate the environmental impact contributed by the slab with different processes.

## 4.2 Environmental Impacts of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

### 4.2.1 Climate Change

Climate change is a long-term variation in average weather conditions, and often linked with global warming. Global warming is a phenomenon which describes the rising of average surface temperature on Earth, mostly due to the increasing level of greenhouse gases (GHG) emissions. The most direct and possible effect of climate change is extreme weather and polar ice melting. Polar ice melting would result in sea level rising, subsequently affecting the coastline as well as the terrestrial and aquatic ecosystem.

According to Huijbregts et al. (2016), climate change parameter in LCA adopting ReCiPe method is measured by the increment of infrared radiative forcing, which is a factor altering the balance between the inbound solar radiation and outbound IR radiation inside of the Earth’s surfaces. (Pulselli and Marchi, 2015) The main greenhouse gases on the earth’s atmosphere are carbon dioxide ($CO_2$), water vapour ($H_2O$), methane ($CH_4$), nitrous oxide ($N_2O$) and ozone ($O_3$). In this study, the global warming potential is accessed by per kg $CO_2$ produced by each studied slab. For every kg emission of greenhouse gas would cause an expansion in atmospheric concentration of greenhouse gases. As a consequence, the radiative forcing capacity would rise, ensuing the increase of global mean temperature or global warming potential.

The fact that production of construction material takes up responsibility in environmental issue is mainly because of the $CO_2$ emission in cement production. The global warming potential (GWP) measured by per kg $CO_2$ equivalent of the two types of slabs are illustrated in Figure 4.1. It is shown that a cubic meter of conventional reinforced concrete slab contributed a higher GWP than a concrete composite floor plate by 19 %, which are 300.27 kg $CO_2$ and 251.82 kg $CO_2$ in total, respectively. Similarly, the GWP of both of the studied slabs are dominated by clinker production, which is the main process in manufacturing cement.

The clinker production released $CO_2$ from the calcination process that involved burning of limestone into calcium oxide which is the main ingredient to produce clinker. Besides, the burning process combines carbon (C) with oxygen ($O_2$) in the air to make $CO_2$. The manufacturing process of cement contributed 62 % and 65 % of GWP to concrete composite floor plates and conventional reinforced concrete slab, respectively. The sinter production and pig iron production are both under the manufacturing process of reinforcing steel, which gives the same weightage of 9% in GWP but with different amount of kg $CO_2$. Other processes like hard coal mine operation, market for hard coal and anaerobic digestion of manure gave 29 % and 26 % of GWP in concrete composite floor plates and conventional reinforced concrete slab respectively.

Moreover, by looking from a bigger picture, not just cement, but other materials contributed a fair amount of GWP as well. Table 4.1 shows that, the production of steel gives 24.48 % and 22.25 % of GWP to concrete composite floor-plates and reinforced conventional concrete slab respectively, the higher percentage contribution is resulted from the higher amount of steel used in concrete composite floor-plates. Successively, transportation and electricity contributed 4.32 % and 3.80 % of GWP to concrete composite floor-plates as well as 4.43 % and 2.71 % to reinforced concrete slab. Furthermore, the impacts of coarse and fine aggregates as well as water is relatively low as it all contributed less than 1% of the total GWP.

This phenomenon is reflected from the usage of cement in both of the studied slabs. The production of a cubic meter of conventional reinforced concrete slab requires 280 kg of cement whereas a concrete composite floor plates requires mere 224 kg, which is 20 % lesser usage in cement. From this, it revealed that the usage of cement is the main reason for the high GWP and climate change. The production of concrete composite floor-plates gives a lower GWP as it requires a lesser amount of concrete.

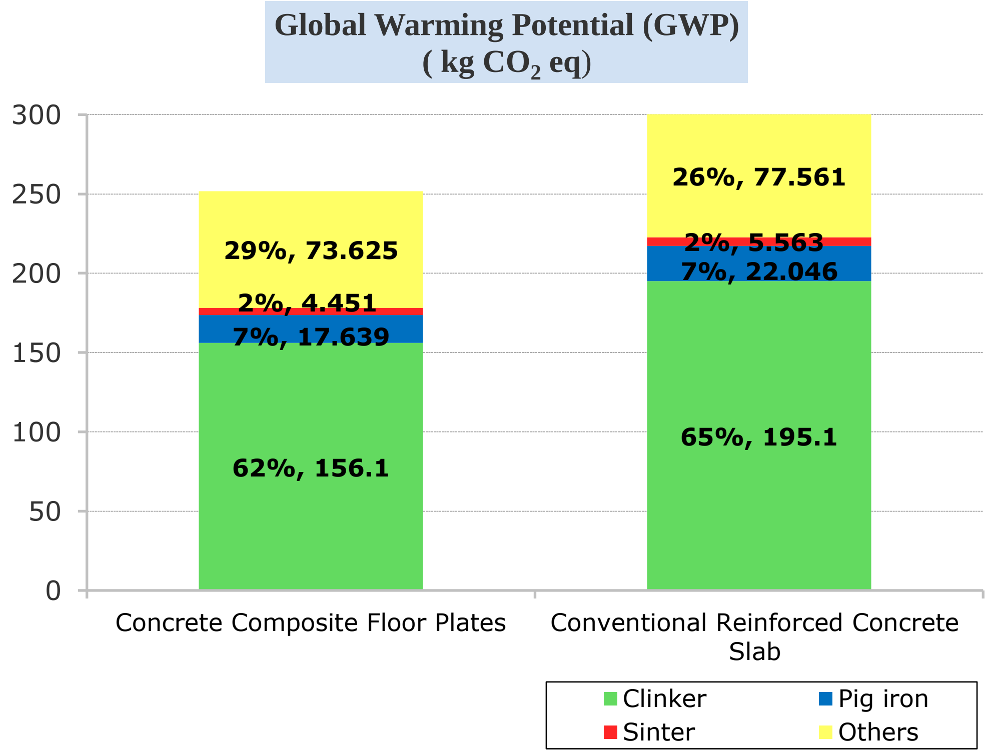


Figure 4.1: Global Warming Potential (GWP) Of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

Table 4.1: Contribution of Materials to GWP of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

| Materials | CCFP (kg CO$_2$) | | RC SLAB (kg CO$_2$) | |
|---|---|---|---|---|
| Cement | 166.24 | 66.08% | 207.80 | 69.23% |
| Steel Reinforcement | 45.06 | 17.91% | 66.79 | 22.25% |
| Steel Decking | 16.52 | 6.57% | - | - |
| Transportation | 10.88 | 4.32% | 13.30 | 4.43% |
| Electricity | 9.56 | 3.80% | 8.12 | 2.71% |
| Coarse Aggregates | 1.76 | 0.70% | 2.20 | 0.73% |
| Fine Aggregates | 1.54 | 0.61% | 1.93 | 0.64% |
| Water | 0.016 | 0.01% | 0.02 | 0.01% |
| Total Contribution | 251.576 | | 300.16 | |

### 4.2.2 Fine Particulate Matter Formation

Fine particulate matter generally refers to the extremely small solid particles and liquid particles suspended in air, which is also known as particle pollution or PM. Particulate matter 2.5 is generally termed as PM$_{2.5}$, which means the tiny particles are less than or equal to two and a half microns or 2.5 μm. PM$_{2.5}$ are very fine that it cannot be seen by human eyes, as it is at least 30 times finer than a human hair. However, it brings significant concern to human health as it causes air pollution, reduction in visibility and haziness when the concentration of PM$_{2.5}$ is levelled, consequently bringing risk to human health.

Human respiratory system allows the size range of PM$_{2.5}$ to travel deeply inside of the respiratory tract and even into the lungs, influencing lung function and triggering asthma and heart diseases. Besides, it also causes eye, nose and throat irritation which would consequently result in coughing, sneezing, runny nose and shortness of breath. When the concentration of PM$_{2.5}$ in outdoor elevated, the reduction in visibility or blurriness could cause car accident.

In this study, the particulate matter formation potential (PMFP) is measured by per kg PM$_{2.5}$ produced by the usage of every cubic meter of concrete composite floor-plates and conventional reinforced concrete slab. As demonstrated in Figure 4.2, this study found that conventional reinforced concrete slab generated 0.330 kg PM$_{2.5}$ equivalent to the environment, which is also 7.5 % more of PM$_{2.5}$ as compared to concrete composite floor-plates, which generated 0.307 kg $PM_{2.5}$ equivalent. As found in prior studies and literature about environmental impacts of Portland cement production, it is commonly known that particulate matters are produced as a by-product in all major stages in the manufacturing process. For instance, raw meal preparation, pyro processing and finish grinding are the processes that generate vast amounts of fine dust and particles. However, in this study, it was found that the $PM_{2.5}$ generation from anaerobic digestion of manure is 22 % and 18 % of the total emission in concrete composite floor-plates and conventional reinforced concrete slab, more than that in clinker production which are 15 % and 17 %.

Anaerobic digestion of manure is a process where bacteria breaks down organic matter like manure, which is excrement of animals for land fertilizing purpose. After the organic matters in waste and wastewater are broken down, it would then be transformed into biogas, which is a composition of methane, carbon dioxide and sludge that is full of nutrients. In the manufacturing process of both the concrete composite floor-plates and conventional reinforced concrete slab, anaerobic digestion of manure is needed for water and wastewater treatment to cope with the water supply. Other than anaerobic digestion and clinker production, other processes contributed to the generation of $PM_{2.5}$ are coking, sinter production, transportation, electricity production, etc., which takes up a high portion of 57% and 58% in total PMFP of concrete composite floor-plates and conventional reinforced concrete slab respectively. Coking and sinter production are both the processes of manufacturing of cement, whereas sinter production is accountable for the manufacturing of reinforcing steel. Besides, combustion also gives vast amount of $PM_{2.5}$, that includes the combustion chamber in car engines and burning of fossil fuels to generate electricity.

Table 4.2 illustrates the amount of PMFP generated by the materials required by productions of concrete composite floor-plates and conventional reinforced concrete slab. It shows that the production of steel forms the most particulate matter, which is 42.16 % to concrete composite floor-plates and 43.03% to conventional reinforced concrete slab. The other contributing factor came next in line after steel production is electricity, and then cement production.

Transportation, fine and coarse aggregates contributed 5.13 %, 1.29 % and 1.24 % of total PMFP to concrete composite floor-plates, whereas conventional reinforced concrete slab received 5.83%, 1.50 % and 1.44 %. Lastly, the impact from water is seemingly negligible as it gives 0.01 % to PMFP. Even though the difference in PMFP of both of the studied slabs are not very significant, but the higher amount of $PM_{2.5}$ generated from conventional reinforced concrete slab could be introduced by the higher amount of reinforcing steel required. Furthermore, a big part of the PMFP is made up of many other minor processes, thus, it implies that the contribution to PMFP of both of the studied slabs are fairly fragmented.

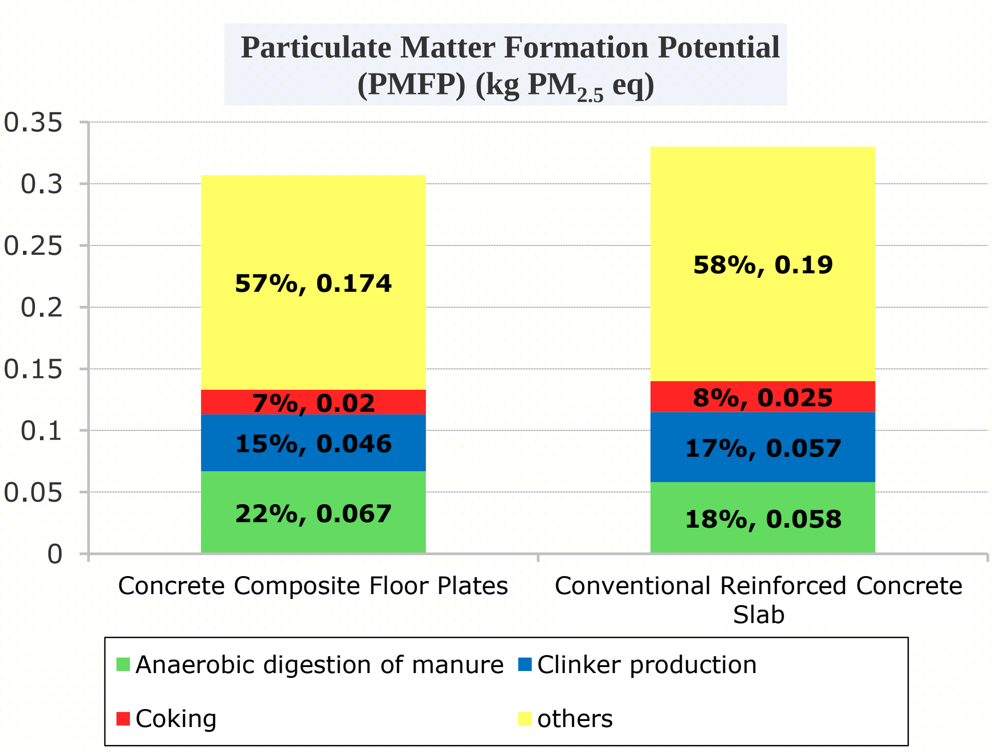


Figure 4.2: Particulate Matter Formation Potential (PMFP) of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

Table 4.2: Contribution of Materials to PMFP of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

| **Materials** | **CCFP (kg $PM_{2.5}$)** | | **RC SLAB (kg $PM_{2.5}$)** | |
|---|---|---|---|---|
| Steel reinforcement | 0.096 | 31.27% | 0.142 | 43.03% |
| Electricity | 0.082 | 26.87% | 0.089 | 27.03% |
| Cement | 0.071 | 23.30% | 0.070 | 21.17% |
| Steel decking | 0.033 | 10.89% | - | - |
| Transportation | 0.016 | 5.13% | 0.019 | 5.83% |
| Coarse aggregates | 0.004 | 1.29% | 0.005 | 1.50% |
| Fine aggregates | 0.0038 | 1.24% | 0.005 | 1.44% |
| Water | 0.000033 | 0.01% | 0.000041 | 0.01% |
| Total Contribution | 0.306 | | 0.330 | |

### 4.2.3 Human Toxicity

Freshwater ecotoxicity, marine ecotoxicity, terrestrial ecotoxicity, human cancer and non-cancer toxicity are all fell under the impact category of toxicity in the impact assessment method adopted in this study. According to the World Health Organization (2018), cancer is the second disease that cause the most deaths globally, with roughly 9.6 million deaths due to cancer in 2018. Cancer is a group of diseases involving abnormal cell growth with the potential to invade or spread to other parts of the body. Commonly, the substances or chemicals that lead to cancer are called carcinogen or carcinogenic substances, while the term ‘carcinogenic’ means to have the potential to cause cancer. In this study, human carcinogenic toxicity potentials (HTPc) of concrete composite floor-plates and conventional reinforced concrete slab are explored and measured by per kg 1,4-DCB equivalent produced. 1,4-DCB is an organic compound with the chemical formula of $C_6H_4Cl_2$ (para-dichlorobenzene), often used as the reference unit of human toxicity potential.

As displayed in Figure 4.3, the concrete composite floor-plates presented a lower HTPc of 27.47 kg 1,4-DCB, whereas a conventional reinforced concrete slab produced 29.40 kg 1,4-DCB of HTPc, with the percentage difference of 7%. The activities that contributed to the high HTPc are mostly from the waste treatment of raw materials and hazardous waste. The major and key treatments are the treatments of slag, sludge from steel rolling, oxygen furnace waste and spoil from hard coal mining as well as lignite mining. Steel slag is a by-product of steel making which is produced during the separation of the molten steel from impurities in steel-making furnaces. It can be seen that the process of treating slags emitted the highest amount of HTPc, and prominently contributed 44 % of the total HTPc in a conventional reinforced concrete slab. On the other hand, the HTPc caused by treatment of slag in concrete composite floor-plate weighted 8.883 kg 1,4-DCB equivalent, which is 45% lesser than conventional reinforced concrete slab. However, the treatment of basic oxygen furnace waste gives a larger HTPc to concrete composite floor-plates than to conventional reinforced concrete slab, which are 5.58 kg 1,4-DCB and 3.11 kg 1,4-DCB respectively. Oxygen furnace waste are typically found during basic oxygen steelmaking process, where it converts molten pig iron into steel by blowing oxygen through a lance over the molten pig iron inside the converter. This finding could be explained by the fact that concrete composite floor-plates required a higher amount of steel, which includes reinforcing steel and steel decking.

Additionally, Table 4.3 depicts the contribution of materials to HTPc of studied slabs. It is shown evidently that the production of steel is highly responsible for the carcinogenic toxicity to human, with 89.28 % and 88.60 % of percentage contribution from concrete composite floor-plates and conventional reinforced concrete slab. Dissimilar to the impacts discussed earlier, cement production gives a much lower amount of HTPc, which are 5.35 % and 6.27 %.

At any rate, the treatment and disposal of waste is severely important as it keeps the environment hygienic and drives sustainability as well as the health of human beings. However, according to Rushton (2003), waste management options like sewerage treatment, incineration, composting and landfill give off a large amount of substances in imperceptible quantities and exceptionally low levels. In fact, carcinogens are found to be emitted from the air pollution from anaerobic decomposition of organic matters.

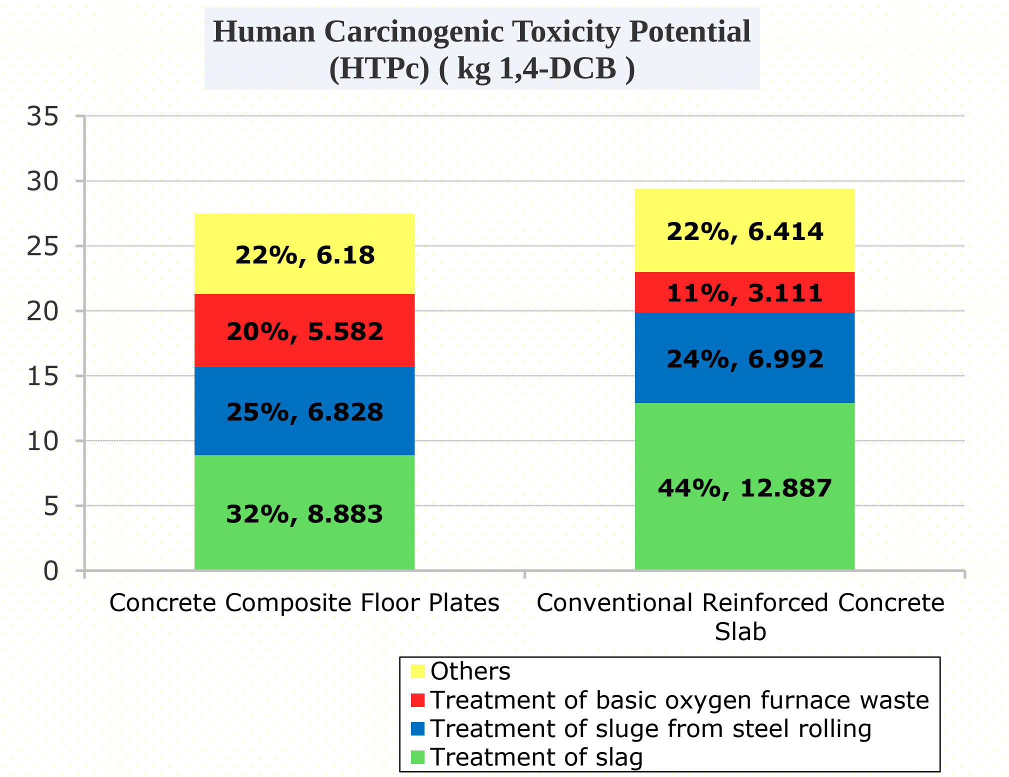


Figure 4.3: Human Carcinogenic Toxicity Potential (HTPc) of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

Table 4.3: Contribution of Materials to HTPc of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

| **Materials** | **CCFP (kg 1,4-DCB)** | | **RC SLAB (kg 1,4-DCB)** | |
|---|---|---|---|---|
| Steel reinforcement | 17.53 | 63.83% | 25.98 | 88.60% |
| Steel Decking | 6.99 | 25.45% | - | - |
| Cement | 1.47 | 5.35% | 1.84 | 6.27% |
| Electricity | 0.85 | 3.10% | 0.72 | 2.46% |
| Coarse aggregates | 0.25 | 0.91% | 0.31 | 1.06% |
| Transportation | 0.22 | 0.80% | 0.28 | 0.95% |
| Fine aggregates | 0.15 | 0.55% | 0.19 | 0.65% |
| Water | 0.0025 | 0.01% | 0.0031 | 0.01% |
| Total Contribution | 27.4625 | | 29.3231 | |

### 4.2.4 Freshwater Eutrophication

Freshwater eutrophication happens when the nutrients and minerals in freshwater become exceedingly enriched, resulting in the overgrowth of aquatic plants or algae. Just like any other plants, algae under the water gives off oxygen by photosynthesis, but consumes high amount of oxygen, especially at night during respiration. In case of algae bloom, where the number of algae accumulate too fast under freshwater, the oxygen depletion of the water body may happen. As a consequence, the under-water ecosystem may be severely impacted, as an instance, fisheries and recreation will be affected as well as decreasing the clarity of water. Usually, eutrophication happens because of the overly discharge of detergents or fertilizers that contains nitrate or phosphate into the aquatic system. In this LCA, the Freshwater Eutrophication Potential (FEP) is measured by per kg P (phosphate) equivalent produced.

Figure 4.4 shows the FEP generated by concrete composite floor-plates and conventional reinforced concrete slab. It shows that the treatment of spoils from lignite mining and hard coal resulted into more than half of the FEP, which is 54 % and 51 % to the concrete composite floor-plates and conventional reinforced concrete slab. Hard coal and lignite are essential raw material in manufacturing process of steel in oxygen furnace, where 70% of steel production uses coal. Moreover, spoils are the excavated topsoil or subsoils that have been removed in order to obtain the raw materials underneath. The volume of soils that have been excavated will expand to three times of the volume before it was excavated, therefore, treatment of spoil is necessary but the process if rather extensive. Pit lakes that have been discarded after lignite mine operation has been one of the issues to the problem of eutrophication. Moreover, the filling of groundwater into the pit lake may contain high concentration of phosphorus due to the geographic location (Lessmann et al., 2003). The filling river water rich in nutrients also causes the blossom of algae. It is followed by the release of nitrogen from fossil fuel burning that seeps into the water.

All in all, the results shown in Table 4.4 tells that the conventional reinforced concrete slab has higher environmental impact, with FEP of 0.075 kg P, as compared to concrete composite floor-plates which contributed to FEP that is 16% lesser, which is 0.063 kg P. The materials that caused more FEP are steel and cement production, which gives 55.42 % and 36.32 % to concrete composite floor-plates as well as 54.49 % and 38.54 % to conventional reinforced concrete slab.

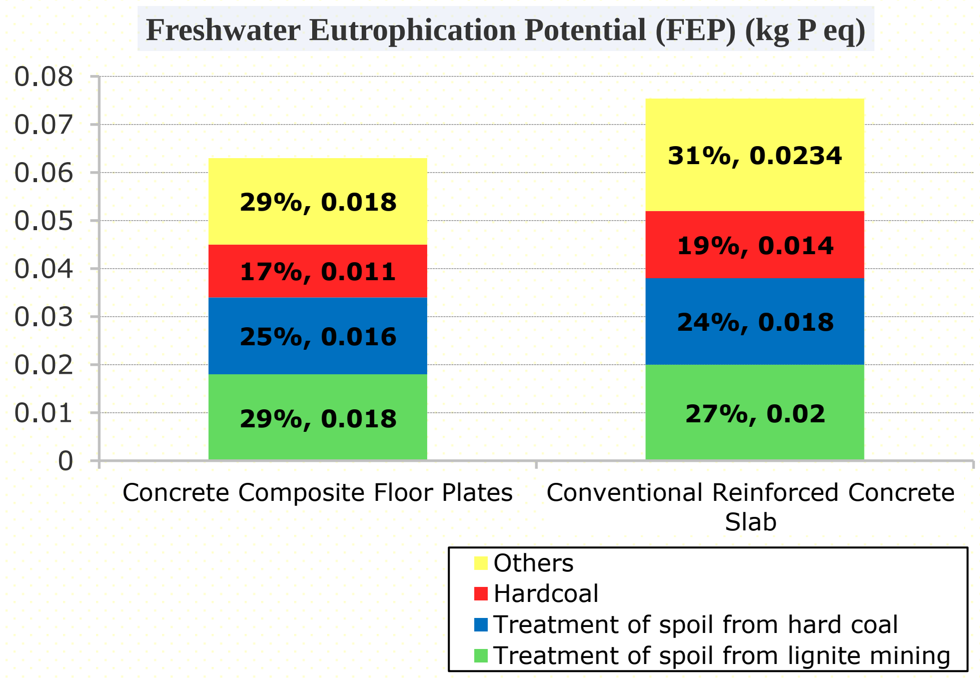


Figure 4.4: Freshwater Eutrophication Potential (FEP) of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

Table 4.4: Contribution of Materials to FEP of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

| **Materials** | **CCFP (kg P)** | | **RC SLAB (kg P)** | |
|---|---|---|---|---|
| Steel reinforcement | 0.028 | 44.21% | 0.041 | 54.49% |
| Cement | 0.023 | 36.32% | 0.029 | 38.54% |
| Steel decking | 0.0071 | 11.21% | - | - |
| Electricity | 0.0031 | 4.89% | 0.0026 | 3.46% |
| Transportation | 0.0009 | 1.42% | 0.0011 | 1.46% |
| Coarse aggregates | 0.00071 | 1.12% | 0.00089 | 1.18% |
| Fine aggregates | 0.00051 | 0.81% | 0.00064 | 0.85% |
| Water | 0.000013 | 0.02% | 0.000016 | 0.02% |
| Total Contribution | 0.063 | | 0.075 | |

### 4.2.5 Photochemical Oxidant Formation: Human Health

Photochemical oxidants are better and commonly known as ozone, it is a secondary air pollutant formed as a result of the concentration of various highly reactive gases in the air (Potential, 2019). The effect of photochemical oxidants is photochemical smog, which is an intense air pollution where it damages crops as well as degrading art works. Smog formation relies on both primary and secondary pollutants. Primary pollutants are emitted directly from a source, such as emissions of sulphur dioxide from coal combustion. On the other hand, secondary pollutants are formed when primary pollutants undergo chemical reactions in the atmosphere. In fact, photochemical smog is made up by a mixture of ozone, nitrogen dioxide and fine particulate matter. In this study, the Photochemical Oxidant Formation Potential: Humans (HOFP) are measured by per kg $NO_x$ equivalent formed by 1 $m^3$ of the studied slabs.

Photochemical oxidants could cause impairment in human eyes, nose and throat. Under long term exposure, it could even cause lung cancer or heart disease. Figure 4.5 shows that a clinker production is main the process that contribute to the high HOFP, which gives 37 % and 39% of the total HOFP to concrete composite floor-plates and conventional reinforced concrete slab respectively. This could be explained by the formation of $NO_x$ in a high temperature cement kilns during fuel combustion (Neuffer, 1994). Additionally, other processes like transportation and burning of diesel in machines also generated photochemical oxidants.

Table 4.5 gives an overall picture for the contributions of HOFP. It reveals concrete composite floor-plates emit 17.4% lesser photochemical oxidants than a conventional reinforced concrete slab. The main material responsible for the number of HOFP is cement production, followed by steel production which is 32.59% and 29.90% of HOFP emission by concrete composite floor-plates and conventional reinforced concrete slab respectively. The higher percentage contribution reflected on concrete composite floor-plates are because of the higher amount of steel required. The emission of photochemical oxidants from transportation is notably high, which is 11.47% and 11.79% to composite floor-plates and conventional reinforced concrete slab, as a substantial amount of $NO_x$ is given off during the combustion of fuel.

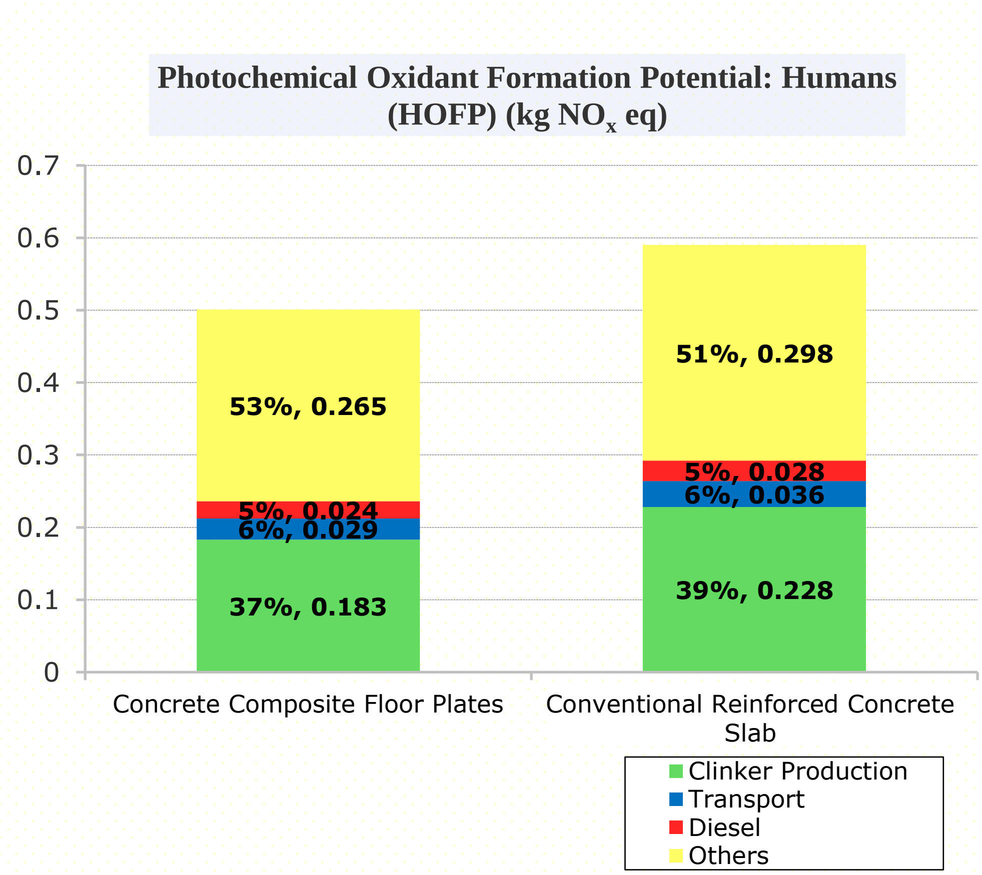


Figure 4.5: Photochemical Oxidant Formation Potential: Humans (HOFP) of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

Table 4.5: Contribution of Materials to HOFP of Concrete Composite Floor-plates and Conventional Reinforced Concrete Slab

| **Materials** | **CCFP (kg NO$_x$)** | | **RC SLAB (kg NO$_x$)** | |
|---|---|---|---|---|
| Cement | 0.23 | 46.27% | 0.3 | 49.83% |
| Steel reinforcement | 0.12 | 24.14% | 0.18 | 29.90% |
| Transportation | 0.057 | 11.47% | 0.071 | 11.79% |
| Steel decking | 0.042 | 8.45% | - | - |
| Electricity | 0.026 | 5.23% | 0.022 | 3.65% |
| Fine aggregates | 0.012 | 2.41% | 0.016 | 2.66% |
| Coarse aggregates | 0.01 | 2.01% | 0.013 | 2.16% |
| Water | 0.000035 | 0.01% | 0.000043 | 0.01% |
| Total Contribution | 0.497 | | 0.602 | |

## 4.3 Comparison of Concrete Composite Floor-Plates and Conventional Reinforced Concrete Slab

In this study, five impact categories are chosen to evaluate and compare the environmental impacts resulted from the life cycle of the studied slabs, concrete composite floor-plates and conventional reinforced concrete slab. Apparently, concrete composite floor-plates are proven to give lesser impact to the environment. The environmental impacts caused by the studied slabs are mainly subjected to the amount of cement, steel, electricity and transportation, whereas the use of water as well as coarse and fine aggregates contributed to an insignificant impact. Concrete production brings many negative impacts on the environment especially in terms of carbon dioxide emissions, photochemical oxidants formation as well as causing the depletion of fossil energy resources at high rate. Noticeably, clinker production is the process that caused the most environmental impact.

Other than the higher amount of cement used which mentioned earlier, a higher amount of steel reinforcement used is also another key factor affecting the sustainability of a conventional reinforced concrete slab. In fact, manufacturing process of steel decking gives lesser environmental impact than steel reinforcement as it is easier to be recycled. Therefore, the adoption of steel decking to replace the number of steel reinforcement in concrete composite floor-plates is a good alternative to unburden the environment.

Despite a concrete composite floor-plate being more environmentally friendly than a conventional reinforced concrete slab, a conventional reinforced concrete slab is still more widely used and adopted generally in the construction industry. This is because there are a few concerns with composite building materials, one of which is that steel is very temperature sensitive as it expands and contracts with change in temperature, which makes it unpredictable and hence safety issues raised from there. Besides, painting of surfaces must be timely maintained to prevent rusting, which could cause an amount of expenses (Stewart, 2020). Moreover, a cost comparison between reinforced concrete structure and composite structure done by Begum et al. (2013) shows that the cost of composite structure for mid-rise building could cost up to 19% higher than reinforced concrete structures. Therefore, with the reasons laid down, a conventional reinforced concrete slab is a safer and more economical slab to use in a building.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

In this study, the life cycle assessment of concrete composite floor-plates and conventional reinforced concrete slabs has been conducted and compared. The two objectives of this study had been fulfilled, which are the identification of life cycle inventory of conventional reinforced concrete slab and concrete composite floor-plates as well as the comparison of the environmental impacts resulted from the two different concrete slabs in a cradle-to-gate manner. The life cycle inventory of both the studied slabs are determined using Ecoinvent 3.4 software and input data origin are based on the Rest of the World (RoW) setting. The input data used for the production of the slabs included cement production, sand mining, coarse aggregate mining, tap water usage, transportation, manufacturing of steel decking and reinforcing steel as well as electricity usage, which is based on the Rest of the World (RoW) origin. Furthermore, the environmental impact analysis was done using the ReCiPe method in the openLCA software.

The results from the analysis have shown that the production of concrete composite floor-plates have the potential to significantly lower the environmental impacts in comparison with the production of a conventional reinforced concrete slab. This statement is made by looking at the five impact categories accessed in this study, which are climate change, fine particulate matter formation, human toxicity, freshwater eutrophication and photochemical oxidant formation. The contributing processes to the impact categories are shown in the graphs. Among the many processes, the process of manufacturing cement, especially clinker production, gives the most impact to the environment. It is also noticed that concrete composite floor-plates with the lesser amount of concrete in the input gives out lower environmental impacts. Aside from that, manufacturing of steel reinforcement is also found to be one of the main contributors to the impact categories chosen, succeeding concrete production. Conventional reinforced concrete slab generally comprises concrete and steel reinforcement, therefore the noteworthy environmental impact. Electricity generates a fair amount of environmental impact as it involves combustion of fuel which generates greenhouse gases and air pollutants. Transportation is found to be rather significant in the problem of photochemical oxidant formation by the studied slabs, as the combustion in engines form $NO_x$. On the contrary, water usage and mining of coarse and fine aggregates contribute to very little impacts on both of the studied slabs.

In a nutshell, this assessment has concluded that concrete composite floor-plates are a good alternative in replacing conventional reinforced concrete slab in the construction industry, as it is more environmentally friendly. Life cycle assessment is also found to be a useful tool to analyse the life cycle of a construction material in term of environmental impacts. This study can act as a guideline to choose a slab that is environmentally friendly. Despite the fact that replacing a conventional slab to concrete composite floor-plates might not make a very significant decrement in environmental impact made by the construction industry, but it will definitely make a difference in the long run.

## 5.2 Limitations of Study

In this study, the life cycle assessment is limited to cradle-to-gate assessment, where it is only covered from the raw materials extraction until the production of concrete at the concrete mixing plant, without considering the construction, occupancy and demolition stage of the structure. Besides, the assumption of the transportation covered in this study are subjected to discrepancy with the actual distance as the paths of different hauling truck may not be the same. The distance of transportation is critical in computation of the impact assessment especially for some impact categories emphasize on the vehicle’s emissions and fuel consumption. Moreover, the lack of local input and environmental information needed for the life cycle assessment is one of the challenges to conduct the study and most of the impact analysis are done based on the sources from Switzerland and rest of the world (ROW).

Furthermore, cut-off method was adopted in this assessment, which places a cut-off when recyclable material leaves the product system, then contributes to zero burden from the point. The usage of this method does not include the consequential environmental impacts. Realistically, the consequential environmental impacts are also significant and should be taken into account for a more accurate life cycle assessment.

## 5.3 Recommendations

In this study, it is concluded that the volume of concrete and steel reinforcement is the main issue to the environmental problems from the production of slabs. Therefore, it is recommended to adopt the usage of concrete composite floor-plates in replacement of conventional reinforced concrete slab to reduce the environmental impact from the construction industry.

Based on the limitation of this study, there are some recommendations for the future research:

(i) More data collection should be carried out in local production of concrete as the existing data source of concrete industry in Malaysia is insufficient.

(ii) Data and information on the consumption of electricity and other energy at the landfill site that is considered in the avoided process should be studied and included.

(iii) The transportation detail is an important factor in this study, as the transportation for every factory and mining site are different. Hence, the study should be targeted at specific road and at specific destinations.

(iv) Sensitivity analysis on transportation in traffic and fuel can be done to increase the accuracy of results.

(v) Expansion of study can be done in a cradle-to-grave manner which is more holistic as a life cycle assessment.

(vi) Other impact assessment methods like CML method and Eco-indicator 99 can be adopted to make comparison and give another perception.

(vii) More refined analysis such as adding the exergetic life cycle assessment (ELCA) which include energy analysis in the individual production process or as secondary boundary to specify the energy involved for the waste-to-energy content.

# REFERENCES

*The Constructor* [Online]. Available: https://theconstructor.org/practical-guide/concrete-slab-construction-cost/28153/ [Accessed 14 March 2020].

(LCIA), R. m. f. L. C. I. A. 2009. *Quick introduction into ReCiPe LCIA Methodology* [Online]. Available: https://sites.google.com/site/lciarecipe/project-definition [Accessed 9th April 2020].

Ahmed, I. M. & Tsavdaridis, K. D. 2018. Life cycle assessment (LCA) and cost (LCC) studies of lightweight composite flooring systems. *Journal of Building Engineering,* 20**,** 624-633.

Bare, J. C., Hofstetter, P., Pennington, D. W. & De Haes, H. A. U. 2000. Midpoints versus endpoints: the sacrifices and benefits. *The International Journal of Life Cycle Assessment,* 5**,** 319.

Begum, M., SERAJUS, S. M., TAUHID, B. K. N. & Ahmed, W. 2013. Cost analysis of steel concrete composite structures in Bangladesh.

Brambilla, G., Lavagna, M., Vasdravellis, G. & Castiglioni, C. A. 2019. Environmental benefits arising from demountable steel-concrete composite floor systems in buildings. *Resources, Conservation and Recycling,* 141**,** 133-142.

Capaz, R. & Seabra, J. 2016. Life cycle assessment of biojet fuels. *Biofuels for Aviation.* Elsevier.

Cheah, C. B. & Ramli, M. 2013. The structural behaviour of HCWA ferrocement–reinforced concrete composite slabs. *Composites Part B: Engineering,* 51**,** 68-78.

Crawford, R. 2011a. *Life cycle assessment in the built environment*, Taylor & Francis.

Crawford, R. 2011b. *Life Cycle Assessment in the Built Environment*.

Crawford, R. H. 2011c. *Life Cycle Assessment in The Built Environment,* London and New York, Spon Press.

Dahmen, J., Kim, J. & Ouellet-Plamondon, C. M. 2018. Life cycle assessment of emergent masonry blocks. *Journal of Cleaner Production,* 171**,** 1622-1637.

Daly, H. E. 1990. Toward some operational principles of sustainable development. *Ecological economics,* 2**,** 1-6.

Derysz, J., Lewiński, P. M. & Więch, P. P. 2017. New concept of composite steel-reinforced concrete floor slab in the light of computational model and experimental research. *Procedia Engineering,* 193**,** 168-175.

Ecoinvent. 2013. *System Models in ecoinvent 3* [Online]. Available: https://www.ecoinvent.org/database/system-models-in-ecoinvent-3/system-models-in-ecoinvent-3.html [Accessed 22 March 2020].

Ferrante, C. d. O., de Andrade, S., de Lima, L. & Vellasco, P. d. S. 2019. Analytical study and experimental tests on innovative steel-concrete composite floorings. *Journal of Constructional Steel Research***,** 105868.

Finkbeiner, M., Inaba, A., Tan, R., Christiansen, K. & Klüppel, H.-J. 2006. The new international standards for life cycle assessment: ISO 14040 and ISO 14044. *The international journal of life cycle assessment,* 11**,** 80-85.

Finnveden, G. 2000. On the limitations of life cycle assessment and environmental systems analysis tools in general. *The International Journal of Life Cycle Assessment,* 5**,** 229-238.

Frischknecht, R. & Rebitzer, G. 2005. The ecoinvent database system: a comprehensive web-based LCA database. *Journal of Cleaner Production,* 13**,** 1337-1343.

Gursel, A. P., Masanet, E., Horvath, A. & Stadel, A. 2014. Life-cycle inventory analysis of concrete production: A critical review. *Cement and Concrete Composites,* 51**,** 38-48.

Helepciuc, C. M. 2017. The Environmental Impact of Concrete Production and the Necessity of Its Greening. *Resilient Society***,** 81.

Huijbregts, M., Steinmann, Z., Elshout, P., Stam, G., Verones, F., Vieira, M., Hollander, A., Zijp, M. & Van Zelm, R. 2016. ReCiPe 2016: a harmonized life cycle impact assessment method at midpoint and endpoint level report I: characterization.

Huntzinger, D. N. & Eatmon, T. D. 2009. A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. *Journal of Cleaner Production,* 17**,** 668-675.

Initiative, C. S. 2009. Cement industry energy and CO2 performance: getting the numbers right. *World Business Council for Sustainable Development*.

Institution, B. S. 2006. BS 648:1964 Schedule of weights of building materials. *Appendix A, Table A1.* British Standards Institution.

ISO 2006. International Standard ISO 14040. Switzerland: ISO copyright office.

Lehtinen, H., Saarentaus, A., Rouhiainen, J., Pitts, M. & Azapagic, A. 2011. A review of LCA methods and tools and their suitability for SMEs. *Europe Innova Eco-Innovation Bio Chem. ,* 17**,** 2014.

Lessmann, D., Fyson, A. & Nixdorf, B. 2003. Experimental eutrophication of a shallow acidic mining lake and effects on the phytoplankton. *Hydrobiologia,* 506**,** 753-758.

Martínez-Rocamora, A., Solís-Guzmán, J. & Marrero, M. 2016. LCA databases focused on construction materials: A review. *Renewable and Sustainable Energy Reviews,* 58**,** 565-573.

Mehta, P. K. 2002. Greening of the concrete industry for sustainable development. *Concrete international,* 24**,** 23-28.

Menoufi, K. A. I. 2011. Life cycle analysis and life cyle impact assessment methodologies: a state of the art.

Mosley, W. H., Hulse, R. & Bungey, J. H. 2012. *Reinforced concrete design: to Eurocode 2,* Macmillan International Higher Education.

Neuffer, W. J. 1994. Alternative Control Techniques Document: NOx Emissions from Cement Manufacturing.

Nielsen, C. V. & Glavind, M. 2007. Danish experiences with a decade of green concrete. *Journal of Advanced Concrete Technology,* 5**,** 3-12.

Nisbet, M., Van Geem, M. G., Gajda, J. & Marceau, M. 1997. Environmental life cycle inventory of Portland cement and concrete. *World Cement,* 28**,** 3.

Organization, W. H. 2018. *Cancer* [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/cancer [Accessed 6 August 2020].

Potential, T. E. o. W. P. H. 2019. *Photochemical oxidant formation* [Online]. Available: http://encyclopedia.uia.org/en/problem/134677 [Accessed 10 August 2020].

Pulselli, F. & Marchi, M. 2015. Global Warming Potential and the Net Carbon Balance.

Rushton, L. 2003. Health hazards and waste management. *British medical bulletin,* 68**,** 183-197.

Russell-Smith, S. & Lepech, M. Activity-based methodology for life cycle assessment of building construction. CIBSE ASHRAE Technical Symposium, 2012. 1-13.

Salas, D. A., Ramirez, A. D., Rodriguez, C. R., Petroche, D. M., Boero, A. J. & Duque-Rivera, J. 2016. Environmental impacts, life cycle assessment and potential improvement measures for cement production: a literature review. *Journal of Cleaner Production,* 113**,** 114-122.

Shen, W., Liu, Y., Yan, B., Wang, J., He, P., Zhou, C., Huo, X., Zhang, W., Xu, G. & Ding, Q. 2017. Cement industry of China: driving force, environment impact and sustainable development. *Renewable and sustainable energy Reviews,* 75**,** 618-628.

Specification, P. A. 2008. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. *Bsi Br. Stand. Isbn,* 978**,** 580.

Stewart, M. 2020. *Pros and Cons of Three Concrete Struture Methods* [Online]. Stewart Perry. Available: https://stewartperry.com/tips-from-the-field/pros-and-cons-of-three-concrete-structure-methods/ [Accessed].

Sustainability, Q. 2011. *ReCiPe* [Online]. Available: https://www.pre-sustainability.com/recipe [Accessed 9th April 2020].

Tongpool, R., Jirajariyavech, A., Yuvaniyama, C. & Mungcharoen, T. 2010. Analysis of steel production in Thailand: Environmental impacts and solutions. *Energy,* 35**,** 4192-4200.

ul Islam, S. & Kumar, A. 2019. Life Cycle Assessment of Rubber Dam. *Hydraulic Rubber Dam.* Elsevier.

Van den Heede, P. & De Belie, N. 2012. Environmental impact and life cycle assessment (LCA) of traditional and ‘green’ concretes: Literature review and theoretical calculations. *Cement and Concrete Composites,* 34**,** 431-442.

Van Oss, H. G. & Padovani, A. C. 2003. Cement manufacture and the environment part II: environmental challenges and opportunities. *Journal of Industrial ecology,* 7**,** 93-126.

Wang, J., Tingley, D. D., Mayfield, M. & Wang, Y. 2018. Life cycle impact comparison of different concrete floor slabs considering uncertainty and sensitivity analysis. *Journal of Cleaner Production,* 189**,** 374-385.