Design of a low carbon building
Case study of an architectural competition project
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Abstract

Greenhouse gases (GHGs) emissions due to human activities have considerably increased in the past decades which are the main contributors of global warming. In order to limit the consequences of the global climate change happening, all sectors must reduce their carbon emissions and especially the building industry which represents 19% of the carbon footprint of human activities. This paper is giving methods to help reduce the carbon footprint of a building when designing it such as life cycle assessment which allow project teams to compare the global warming potential of all building materials. Those methods are used and challenged in a case study of an architectural competition project named quai d’Issy in Paris, France. Using biobased materials help reduce the carbon footprint of a building, a structure made of timber and concrete elements can emit less than 21% of GHGs than a classic concrete structure. By sourcing reused and recycled building materials, by using geothermal heat pump as heating and cooling systems for example, we have been able to reach for the quai d’Issy project a carbon footprint of 930kgCO₂eq/m² of floor area, which is less than level needed for the highest French environmental certification. However, these results can be obtained only if the building materials companies continue their work to develop low-carbon materials and promote recycled and reused materials. This study emphasises the need to spread knowledge of the tools to design low-carbon building to all the actors of the building industry in order to promote behaviours that will limit the consequences of climate change.
Sammanfattning

Utsläpplen av växthusgaser (GHGs) har ökat avsevärt under de senaste decennierna till följd av mänskliga faktorer, vilket resulterar i en allt mer omfattande grad av global uppvärmning. Med detta som grund fordras att samtliga sektorer bör sträva efter reducerade koldioxidutsläpp, i synnerhet byggnadsindustrin som motsvarar hela 19% av de totala utsläppen. Uppsatsen ämnar att presentera och redogöra tillvägagångssätt för reducierung av byggnadens koldioxidavtryck vid utformning av dessa så väl som avtrycken under byggnadens livstid, exempelvis livscykelbedömning vilket möjliggör för projektgrupper att jämföra varje enskilt materials påverkan på den globala uppvärmningen. Dessa metoder används och utmanas i en fallstudie av ett arkitektoniskt tävlings projekt vid namn Quai d’Issy i Paris, Frankrike. Användningen av biobaserade material hjälper till att minska koldioxidavtrycket i en byggnad, med hjälp av en struktur gjord på trä och betongelement som har visat att avge en minskning av 21% av GHGs, detta jämfört med en klassisk betongkonstruktion. Genom användningen av återanvända och återvunna byggnadsmaterial samt en geotermisk värmepump med värme- och kylsystem, har Quai d’Issy projektet gett ett koldioxidavtryck av 930kgCO₂eq/m² golvyta, vilket är mindre än den begärda nivån an fransk miljöcertifiering. Dessa resultat kan emellertid endast erhållas om företagen till byggnadsmaterialen fortsätter arbetet med att fortgå arbetet med minskningen av koldioxidhalten i material samt främja återvunna och återanvända material. Denna uppsats har avsikten att understryka behovet av kunskap angående byggande med lite koldioxidutsläpp till alla aktörer inom byggn industri, därtill uppmuntra till begränsningar och minska konsekvenserna av klimatförändringar.
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1 Introduction

Carbon emissions have become one of the major concerns in our society due to its impact on global warming and especially in the construction industry where it represents 19% of the global carbon emissions (IPCC, 2014). The challenge of cities across the world is to find means, methods and to promote behaviours that will reduce carbon emissions in all sectors.

This paper will first take great care of presenting different methods that can be used to assess the carbon impact of buildings and develop means to reduce the emissions due to the choice of building materials and the architectural conception. The aim of this thesis is to confront known methods to reduce the carbon footprint to a project that I have been working on within an architectural firm in Paris during the spring semester 2019. It was designed for a competition which values innovation in the architectural, engineering and programmatic answer. Like all real projects, the one studied has its own context which limits the scope for actions and implied to adjust existing solutions. The site studied has a very restrictive context by the shape of its parcel, by the local urbanism laws and by the nuisances around its location. Those constraints have implied to combine different methodologies to attain the goal to design a low-carbon building. Being able to understand the complexity and the specificities of a project allows project teams to answer highly demanding objective, such as in the case studied to design the building with the lowest carbon footprint in Paris, France.

By confronting the carbon impact of different structural and facade designs, it has been possible to develop a high-quality project answering the same needs of comfort as a regular project but with way lower environmental impact.
2 Background

The earth’s temperature has increased at alarming rates over the last 50 years. This phenomenon, known as global warming, can be defined as an increment in the standard global temperature which in turn causes climate change. The emission of global warming causing gases commonly known as greenhouse gases (GHGs) such as carbon dioxide (CO₂), HFC and methane (CH₄) into the atmosphere is the main cause of the rise in international temperature levels. The emission of these gases is caused by a wide range of human activities among them construction (Wen, Siong, and Noor, 2015). In order to compare the global warming potential (GWP) effect of these different gases, it is more convenient to use the equivalent carbon dioxide (CO₂eq) value. The following table gives the GWP for given time horizon of the different gases:

Table 1: Lifetimes and direct GWPs relative to CO₂ (Foster et al., 2007)

<table>
<thead>
<tr>
<th>Gas</th>
<th>Lifetime (years)</th>
<th>20 years</th>
<th>100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>100</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>12</td>
<td>72</td>
<td>25</td>
</tr>
<tr>
<td>HFCs</td>
<td>1 to 270</td>
<td>437 to 12 000</td>
<td>124 to 14 800</td>
</tr>
</tbody>
</table>

Buildings and constructions amount for 19% of the global carbon emission (IPCC, 2014). The largest growth in the carbon emissions over the previous decades comes from the generation of electricity, transport and mainly building operations. The construction and subsequent operation of a building contributes to the GHGs’ emission. In the construction process, large amounts of energy are necessary in order to sustain the process. Energy used to fulfil these construction needs consequently emits CO₂ into the atmosphere (Wen, Siong, and Noor, 2015). For instance, energy used to warm up buildings during the winter season and to cool them down during summer is in most cases generated by the high energy burning of fossil fuels which in turn results in the emanation of heavy CO₂ volumes into the atmosphere. Furthermore, embodied energy, which is the energy used in the construction and manufacture of building material such as cement and steel also results in the release of CO₂ and other harmful gases into the atmosphere (Hammond and Jones, 2008).
2.1 Methods of Carbon Impact Assessment

With the rising international concern for global warming and the effects of the construction industry on the same, different assessment methods have been used to evaluate the carbon footprint for buildings. The carbon impact of a building is the total quantity of CO$_2$ released into the atmosphere by the activities of the building. Reducing the carbon footprints in efforts to reduce CO$_2$ emission is therefore increasingly important in the designing of a building (Wang et al, 2010). The reduction in carbon impact decreases the structure’s operation costs as well as raises property value. These methods for carbon accounting include the life cycle assessment method and the basic ratio calculation model.

2.1.1 Basic Ratio Calculation

In the construction of smaller buildings and structures, basic ratio calculation of the carbon impact of different building materials and different structural designs can be calculated by using known estimates of carbon footprints and emissions caused by these materials. Furthermore, the ratio can be calculated for different structural decisions using known impact on the environment for each decision. An analysis is carried out to determine the carbon footprint reduction potential of using different types of materials and also for using different types of designs for the same structural purposes. Data concerning different carbon emission levels of different building materials can be obtained from previous research materials or inventories containing information on the same. The ratio of carbon footprint per unit of material to the mass of the whole building is done to analyse the impact that could subsequently be caused by the total mass of the material in the whole building (Krygiel and Nies, 2008).

This method is, however, not efficient in its parameters to analyse different scenarios caused by different decisions made in the designing of a building throughout the entire life cycle. Its simple model of operations is insufficient in analysing the many varying inputs, outputs, processes and decisions related to the carbon footprint of a building (Krygiel and Nies, 2008). Apart from the building materials’ impact, various processes and decisions are associated with the total carbon emissions caused by a building increasing the need for increased complexity of analysis by adding the number of inputs and applying parallel models of analysis. This results in the need for more complex models of carbon impact evaluation especially for larger buildings.
2.1.2 Life Cycle Assessment

Life cycle assessment is a useful apparatus for assessing the potential ecological load of a product or service during their lifecycle. It attempts to calculate the environmental effects of a service or product throughout all stages of its life cycle. In a life cycle assessment, the energy and materials used together with the pollutants produced from the activities involved are quantified over the full life cycle. The processes involved in life cycle assessment from cradle to cradle are raw materials acquisition, manufacturing, operation/use and waste management respectively (Curran, 1996).

![Figure 1: Life cycle stages of a building material](image)

There exist four steps in a typical Life cycle assessment. These are:

a. Goal definition: Here the goals, scope and limitations of the analyses are defined.

b. Inventory compilation of the environmental inputs and outputs relevant to the subject. In this case the inputs comprise of energy and the initial materials while outputs include waterborne, solid and gas emissions.

c. Evaluation of potential ecological effects in reference to the inputs and outputs in the inventory.

d. Interpretation of the inventory and impact phases.

In the first stage of the life cycle assessment, the goals of the study are stated together with the limitations or scope the analyses. Adequate knowledge of the purposes intended for the results of the study is useful to the person conducting the study when making decisions on the direction of the assessment. Defining the scope of the evaluations is also important in making decisions on data to be collected and the types of analysis and frameworks to be used in the study. When the goals and limitations of the study are efficiently and substantially stated, the results found are not affected by the various simplifications that are made in a life cycle assessment (Curran, 1996).
The second stage of the assessment, inventory analysis, involves the evaluation of the environmental inputs and outputs that are associated with the total impact related to the subject. In the case of low-carbon buildings, inputs would include raw materials and the energy involved in their production, emissions and disposal mechanisms. The full scope of the study is demonstrated in this stage. The different impacts on the environment related to the collected data are stated and analysed (Rebitzer et al., 2004).

Thirdly, in the life-cycle impact assessment, the data is grouped and the environmental impacts evaluated. Conclusions made from this stage are useful in the making of better and more sustainable business decisions. The classification of data is done according to the relationships among the items therein (Rebitzer et al., 2004). For instance, in the case of building materials, products used for the same structural purposes are classified in the same category. In this section the reader is made to understand the detailed results of the study.

Lastly, the credibility of the results found from the assessment is evaluated. Several evaluation models and instructions are contained in the ISO 140144 standard for the efficient evaluation of the conclusions made in line with the methods used. This is an important stage in the assessment as it assures confidence in the results of your study therefore increasing credibility (Chou and Yeh, 2015).

In recent years conducting a life cycle assessment has been made easier and more efficient by the development of several technological tools that are conveniently put into use (Unger, Beigl and Wassermann, 2004). These include life cycle assessment software such as SimaPro and GaBi; and online inventories for data on carbon footprints and global warming potential for various metals (Speck et al., 2016). The effective use of a good life cycle assessment utilizes these tools in producing accurate findings. Knowledge on the running, operation and use of the various tools is therefore essential for relevant and accurate results. In France, the data base INIES contains all the LCAs that have been checked by an third party and also gives some by default data for elements where data are missing.

The life cycle assessment method provides a model for examining different materials from cradle to gate (Chou and Yeh, 2015). However, life cycle assessment as a method of evaluating carbon emissions has several limitations. Most of these are associated with uncertainties at different points in the analysis. The uncertainties that arise in the conducting of a life cycle assessment have an impact on the accuracy of the results. There exist three categories in the uncertainties in a life cycle assessment namely: parameters, scenario and model uncertainty. Parameter uncertainty occurs with analytically evaluated data or data assessed through imitation. Scenario uncertainty in a life cycle assessment is associated with
the variation in decisions made. This type of uncertainty can cause significant differences in the results (Huijbregts, 1998).

2.2 Common Practices for Low Carbon Construction

In the building of a low carbon structure, various practices are applied in construction in efforts to reduce the discharge of CO$_2$ and other greenhouse gases into the environment. Early evaluation of a building’s carbon footprint increases opportunities for reduction of carbon impact in buildings. Measuring the carbon footprint of the various building material is an effective way of controlling the building’s eventual carbon impact. In this stage of the process, alternative materials and layouts that could help reduce the accumulative carbon impact can be considered. A life cycle assessment can be conducted to determine the carbon footprint of individual materials by giving a set of inventory data which gives information on the environmental impact per unit of the material (Pitt et al, 2009). Alternatively, data obtained from previous research and various databases can be used in determining the types of materials that can affect a low-carbon building plan and also different design decisions that can be made to reduce the carbon impact in regard to building materials. The latter is mostly possible in the construction of small structures. The various practices that can be commonly used in the construction of a low-carbon building include:

a. Use of Low Carbon Concrete.
b. Use of low carbon insulation material e.g. cellulose and modern energy efficient insulation designs.
c. Use of unfired clay bricks in place of primary clay bricks.
d. Using hardwood flooring system.
e. Natural ventilation.

2.2.1 Use of Low Carbon Concrete

Cement is the main constituent in the making of concrete. Low carbon cement is used in construction in the effort to minimise the large amount of carbon emission that occurs during the manufacture of conventional cement (Cabeza et al, 2013). In recent years, various types of low carbon cement have been developed. A common practice in the reduction of carbon emission by cement is the fractional substitution of normal cement with other by materials such as ground granulated blast furnace slag (GGBLC) and natural components in the concrete mix. According to previous studies, it would amount in an estimated 3.8% (10.5 kg CO$_2$eq) carbon content reduction in the mix from 44.089 kg CO$_2$eq to 33.50 kg CO$_2$eq. The use of bio-cement is also a rising practice in the building of a low-carbon building. An example is bioZEment (where the capital letters ‘ZE’ stand for ‘zero emission’) which is manufactured by the use of
biotechnology. Different species of bacteria are used in the precipitation of calcium carbonate materials through metabolic processes. Besides significantly reducing the amount of carbon emission commonly associated with the manufacture of cement, the use of bioZEment significantly reduces a building’s embodied carbon content (Whiffin, 2004).

2.2.2 Use of Low Carbon Insulation Material

Low carbon insulation material such as assessed cellulose is used in place of traditional insulation material such as expanded polystyrene (EPS) to reduce the building’s overall carbon emissions. Compared to normal insulation materials (EPS) whose carbon content can be estimated at 2.92 kg CO$_2$eq per functional unit, the use of cellulose insulator leads to a much lesser estimated total carbon content of 0.73 kg CO$_2$eq per functional unit. The decrease is due to the low carbon production scenario of cellulose which involves the grounding of wood fibres, recycled paper and several chemical composites. The substitution of traditional insulation material with cellulose thus contributes significantly to reduce overall carbon emissions by up to 0.8%. A building’s carbon footprint is also minimised by use of continuous insulation which refers to insulation that is done continuously across all structural members of a building with fasteners and service openings as the only thermal bridges (Blengini and Di Carlo, 2010). This type of insulation is installed either in the interior or exterior surface of the building thus allowing the building to save large amounts of energy through its lifetime therefore reducing the overall carbon footprint. Continuous insulation provides thermal, water, vapour and air control layers in one system thus simplifying the construction process. This is achieved by increasing thermal performance and forestalling thermal bridging (Kneifel, 2010).

2.2.3 Using Unfired Clay Bricks

Unlike conventional clay bricks which involve intense heating in their manufacture, unfired clay bricks are manufactured using natural or earth materials. The units of the masonry in unfired bricks are air dried for minimum shrinkage and to enhance strength. Most traditional forms of unfired clay bricks are made by hand. This creates a large saving in the amount of energy usage reduction and a consequent reduction in carbon emissions. In conventional clay construction, the bricks are held together by the use of mortar. As a result, walls built using unfired clay bricks are thicker than normal brick walls therefore increasing stability (Oti, Kinuthia and Bai, 2009). However, it is advisable to reduce the thickness for the reduction of environmental costs. Modern unfired bricks are produced in similar clay making plants to fired clay but do not undergo the firing process. This makes their use in building more
environmentally sustainable as compared to the use of regular fired clay bricks (El Fgaier et al, 2015).

Partial substitution of primary clay bricks with unfired clay bricks is another common practice in the reduction of carbon emissions. In the making of bricks, clay building materials play a key role in the reduction embodied carbon (Oti, Kinuthia and Bai, 2009). A mixed composition of cement, primary clay and ground granulated blast-furnace slag (GGBS) is used in the making of unfired bricks which have a higher potential for CO₂eq reduction. The carbon emissions resulting from the use of primary clay bricks are estimated at 12.02 Kg CO₂eq while those resulting from unfired clay bricks stand at 9.96 Kg CO₂eq per functional unit; indicating a 3.6% reduction in embodied carbon per functional unit (Padilla-Rivera, Amor and Blanchet, 2018). The high levels of CO₂ emissions resulting from the manufacture of primary clay can be attributed to the high temperature heating process with the requirements ranging from 900 to 1200 Celsius (Padilla-Rivera, Amor and Blanchet, 2018). Consequently, several greenhouse gases are released into the atmosphere. The substitution of primary clay building bricks with low carbon unfired bricks is therefore an important practice in the construction of a low carbon building.

2.2.4 Using Hardwood for Flooring Systems

The use of hardwood in the place of conventional flooring systems is another common method in the reduction of the amount of carbon content of a building. This environmental benefit can be credited to the amount of CO₂ mitigated by wood during its extraction, transportation and installation. This amount exceeds the total carbon emissions therefore offsetting the emissions throughout the building’s life cycle. According to previous research through a life cycle assessment, the overall carbon emission saving brought about by the use of hardwood flooring systems as a replacement for conventional systems is approximately 3.1% (Lippke, 2010). The use hardwood for floors is mainly sustainable when applied in the construction of intermediate floors in a storied building.

The main contribution of the use of hardwood flooring systems in the place of conventional ones is the sustainability that is provided by the use of wood over other components for construction such as concrete (Cabeza et al, 2013). Two main features of wood as a building material, carbon absorption and low energy requirement credit the preference over other materials.
2.2.5 Natural ventilation

The use of natural ventilation for the cooling of a building in place of mechanical systems is a recent design practice in reducing the building's energy demand. Natural ventilation systems utilize pressure differences in supplying and removing air from a building and thus require no mechanical input. Naturally ventilated buildings are also known as breathing buildings since the temperature differences are often created by natural processes (Allard, 1998). In most cases, strategically placed openings are used to allow the movement of air in and out of the building. Wind-driven and buoyancy-driven ventilation are the two forms used in natural ventilation.

Wind-driven ventilation is actualized by the use of strategic openings in a building that permit the easy flow of air in and out of the building. This type of natural ventilation is determined by wind behaviours, the building's envelope and openings such as chimneys. Buoyancy-driven ventilation occurs when air is moved in and out of a structure due to directional buoyancy force which is a result of temperature differences between the inside of a building and the exterior (Rai et al, 2011). By minimizing the use of mechanical systems in ventilation, the given building saves large amounts of energy thus reducing the global warming potential of the structure (Allard, 1998). There exist several design options for maximizing natural ventilation in buildings. These include:

a. Narrow building designs: The distribution of wind in all areas in wide buildings is a difficult and, in most instances, non-sustainable task. Effective natural ventilation occurs in buildings with widths of about 14 meters.

b. Building supply and exhaust openings in each room in a building are also an effective practice for natural ventilation. The exhaust opening should be positioned higher up on the wall than the supply opening to facilitate stack effect.

c. Maximizing internal airflow: Besides the movement of air in and out of a building, internal aeration is also a design option that serves to effect natural ventilation. Doors
located inside a building are built in open designs to assist whole building ventilation (Layfield and Strawmen, 2006).

d. Use of ventilated skylights or roof lights is a common practice in construction that serves not only to increase natural ventilation but also natural lighting in a building. Stale or warm air can escape through open roof lights through the buoyancy process (Rai et al., 2011).

2.3 Case Study: Quai d’Issy Competition

2.3.1 Introduction

As presented briefly in the parts above, there are several levers that can be put in place to limit the carbon footprint of a building when designing it and it is essential to have them in mind in the design steps of the project. The case study is based on a project that have been done by the architectural firm PCA-Stream in Paris, for the competition Inventons la Métropole du Grand Paris 2. The project was presented to the jury as a really low-carbon building which could be a model and an experimentation to put in place engineering and architectural method to reduce at the lowest possible the global carbon footprint of the building. PCA-Stream wanted to design a project that had the best level in the E+C- certifications, i.e. less than 980kgCO₂eq/m² of floor area.

2.3.2 Context

The construction site where the project was designed is located in the south-west of Paris, France, in between the 15th district and the city of Issy-les-Moulineaux. The site is actually an urban wasteland used to store railroad materials. Moreover, the site is in the middle of two high traffic car roads and a high frequency rail road. The air pollution and the noise surrounding the site are already two constraints that will affect the design of the building. This architectural competition searches to promote innovative, high value and sustainable project.

The figure below shows where is the project site located and the nuisances around it, the plot concerned by the project is highlighted in yellow.
The plot area is about 2,000 m$^2$ and the local urbanism law restricts the volume in which the building must be in. Moreover, at least 500 m$^2$ has to be empty of all kinds of constructions to respect urbanism laws. The possibilities in the shape of the building are quite limited. Especially, if the design proposed wants to have the highest surface possible and therefore, the highest profitability. The following figure shows the largest volume that can be constructed, the red form is the volume envelope in which the building must be contained.

2.3.3 Building studied

The architectural work has ended up by designing the shape below where no decision on the building materials, the percentage of glazing, the on-site energy production have been made. The shape below was the easiest to work with and could be the most suitable to be an office building.
The project proposed is seven floors high and has 17 500 m$^2$ of floor area, it will mostly be used by offices. The orientation and the exposition to daylight and wind is given in the figure below.
3 Methods

There exist a range of methods that could be used in the construction of a low-carbon building. The methods discussed herein will aid the design team in making the best decisions in choosing building materials. These methods are:

a. Life Cycle Assessment of all building materials.
b. Sourcing reusable and recycled building materials.
c. Increasing the use of carbon sink building materials where applicable.
d. Natural light building design.

3.1 Early Life Cycle Assessment of All Building Materials

The life cycle assessment method has grown to be an increasingly important tool for valuable decision support in evaluating ecological effects of products and services throughout their life cycles (Chou and Yeh, 2015). Government policies are gradually moving in the direction of life cycle accountability: the impression that a manufacturer is responsible for the environmental impacts made by their product as well as direct impacts of the product on the consumer. This model of evaluation is therefore suitable in evaluating the carbon impact for this subject (Huberman and Pearlmutter, 2008).

The purpose of this assessment is to find out the carbon impact of various building materials in order to make the most suitable selections for building products with the aim of reducing the general carbon impact of a given building. In this assessment, the procedural regulation standards adopted are ISO 14040:2006 and ISO 14044:2006 with several specifications which have been listed below. The impact classes selected in this assessment (except for cements) are:

a. Primary energy demand in MJeq done in line with to the CED method.
b. Global Warming Potential (GWP) in kg CO$_2$eq in accordance with the IPPC 2007 factors of characterization.
c. Density in m$^3$.
d. Thermal conductivity.

The cumulative energy demand (CED) method is used to distinguish between non-renewable and renewable energy use that arises from the manufacture, usage and disposal of a given building product. The GWP expresses the anthropogenic greenhouse effect that the carbon emissions by a given building material cause (Bribián, Capilla and Usón, 2011). In this assessment, a GWP indicator has been used according to 2007 IPPC factors of classification with a time scope of 100 years.
The results from this assessment may be used to compare the carbon impact of different types of materials that can be used in the construction process for similar structural purposes. The results of the data collected will be useful in providing multiple criteria for the action in regard to embodied carbon reduction. The stages of the construction process that have been considered in this assessment are manufacturing, transport, building demolition and finally the disposal of the building material (Rashid and Yusoff, 2015). The functional unit used is 1 kg of material. Although useful in the evaluation of a building’s life cycle, it cannot be used to compare two materials that have varied physical properties. The inventories used for assessed stages are selected from European aggregates in the Ecoinvent v2.0 database. The applicability of this data to any country is determined by the level to which the data's features are adapted to the aggregates. Because the assessment was carried out with a stationary focus, values for various processes that are contained in the life cycle inventories are intermediate and thus do not analyse their variation in time. The SimaPro v7.1.8 software is used in this LCA to measure the sensitivity of the input data in order to improve its performance (Ciroth, Franze and Berlin, 2009).

SimaPro is the most widely used software for life cycle assessment. It provides a framework for data input and output and the efficient analysis of this data in using efficient conventional and modern life cycle assessment modes (Herrmann and Moltesen, 2015). The use of SimaPro in running a life cycle assessment improves the efficiency of the evaluation and simplifies the process. SimaPro is also useful in testing the sensitivity of the life cycle assessment due to difference in parameters and scenarios. The software does this by creating assumptions with varying parameters. SimaPro databases contain relatively transparent data as compared to other life cycle assessment software (Herrmann and Moltesen, 2015). This increases the credibility of the data analysed in the life cycle assessment. Besides its high efficiency, SimaPro is robust in its features and easy to use (Ciroth, Franze and Berlin, 2009).

In the final stage of the life cycle, which is disposal, common disposal methods have been considered including incineration and landfilling. The impact reduction arising from the recycling of recyclable building materials has been fully allocated to a new secondary material that a product of the recycling of the primary material (Rashid and Yusoff, 2015). The building materials being analysed are classified into several categories namely: bricks and tiles, insulation material, concrete and wood materials.

The above life cycle assessment above gives a good estimation of the global warming potential for building materials. The results obtained should be considered approximations of real environmental footprints for real building materials. The impacts observed in this assessment are slightly higher than the impacts recoded in other studies due to the use of the broad limit systems that have been mentioned above. Other factors that can justify this
difference are the hypotheses associated with the life cycle assessment method for instance end of life scenarios, life of material and data quality demands (Rashid and Yusoff, 2015). For example, as result of the above stated factors, the global warming potential for a normal brick is higher than in other studies that neglect certain steps especially in the final stages which are infrastructure and disposal.

Differences in results that might be caused by scenario uncertainties can be quantified by use of a sensitivity analysis which may be conducted by the use of life cycle assessment software like SimaPro. Model uncertainty is associated with the inadequate knowledge of the framework in use during the life cycle assessment. In a standard LCA, most uncertainties in are caused by assumptions made and estimates in the quantities of data used (Huijbregts, 1998).

By determining the carbon impact of different building materials through the life cycle assessment we can compare the global warming potential of the individual materials and thus decide on the type of materials to use for minimal carbon emission (Huberman and Pearlmutter, 2008).

3.2 Sourcing Recyclable and Reusable Building Materials

Besides choosing low carbon products, the reduction of the carbon footprint from the material components of a building can also be done by use of different designs and structural methods. Using recyclable building materials contributes to the reduction of energy needed in the production of these products (Thormark, 2002). Additionally, the reuse of building materials sourced from other buildings reduces the amount of newly manufactured materials.

The reuse of building products requires keen direction and focus in the designing process due several hurdles arising from the relative novelty of the processes. Reusing in construction can take place in four different forms depending on the source of the products. The four types of reused products are:

a. On-site reused products: These are reusable building materials such as bricks or sometimes full structures that are sourced from older buildings into new ones on the same construction site.

b. Salvaged products from other sites: These are building materials that are taken from demolition sites; usually in the area around the construction site. These usually require no or minimal reprocessing.

c. Reconditioned materials: These are materials salvaged from demolition of older buildings and required some modifications or reprocessing.
d. Recycled content building products (RCBP’s) – RCBPs are readily available recycled materials such as steel and gypsum boards acquired from demolition sites (Thormark, 2002).

In the use of these products, it is key to note that the design process at certain stages has to change in order to accommodate the new strategies and actions needed in the solidification of the building design (Falk, 2012). Additionally, market conditions for reused and recycled products are different from directly manufactured products. Recycled components have the least impact on the design because they are readily available on an off-the-shelf basis (Addis, 2012). Materials salvaged from other sites, however, are often difficult to integrate into the building design. This is because these components often need to be determined and obtained at the suitable time in the process of design which may prove difficult (Guy and McLendon, 2000). On-site reuse of building materials allows the architectural or design team to evaluate materials that are already on-site and to determine their usefulness in the construction of the new building. The evaluation of the potential for the use of recyclable and reusable materials should therefore be carried out during the design process.

From previous projects, it has been observed that a key condition for the usage of recyclable and reusable products is the developer or client is fully aware of the process and the implications that it brings. Due to the relative novelty of this type of practice, developers have often differed with the design team on decisions concerning the usage of recyclable and reusable products in construction in the place of standard materials (Addis, 2012). This may be attributed to the differences in the process in regard to issues like funding which in this case often occurs earlier in the construction process: the design stage. The use of a contractor in this case is therefore highly advised (Thormark, 2002). The use of salvaged products should have implications on the type of contract used. Additionally, alternative agreements need to be developed in the case where the client strongly differs with the type of products stated in the design (Guy and McLendon, 2000). When setting goals for the construction of a building using salvaged material, decisions on the level of salvaged materials to be used should be made on several facts. These include:

a. Due to their methods of obtainment, salvaged products are available readily and cost effectively in small volumes. Consequently, effective use of these products can be better achieved in smaller buildings.

b. The knowledge of sites where these materials can be salvaged by the team itself can be effective in reducing the costs of obtaining the products as well as increasing the efficiency of the process.

c. A 25% use of recycled products in a building can be easily achieved when these products are readily demountable; which is the case with most salvaged products.
for instance steel and heavy timber components. For small building designs, 75% usage of these materials is possible (Guy and McLendon, 2000).

Recycled steel can be used in place of newly acquired steel to decrease the carbon impact of a building. This is because the energy for manufacture or processing is eliminated. The uses of steel in the construction of a building range from the reinforcing of concrete to the making of steel doors (Tam and Tam, 2006). The structural functions of recycled steel are similar to those of standard steel. The high levels of energy consumption associated with the manufacture of standard steel are therefore reduced thus reducing the carbon emissions caused by steel materials.

Recycled timber from demolition sites is also good example of the re-use of construction material for more sustainable construction (Addis 2012). Despite timber having the lowest carbon impact among most materials on the construction process, the re-use of timber is an important action in the reduction of the carbon discharge of a building. Energy used in obtaining timber and its transportation (assuming the materials are collected on-site) can be saved thus reducing the carbon emissions however minimal.

To ensure maximum reduction in the amount of embodied carbon, knowing the exact implications of the use of reused and recycled products on the carbon footprint of the building is therefore paramount.

### 3.3 Carbon Sink Building Materials

The use of materials that capture CO₂ gases can help reduce a building eventual carbon impact. Carbon sink building materials are mainly made from wood which is harvested from trees (Buchanan and Levine, 1999). Resulting from the process of photosynthesis, wood materials act as natural reservoirs for carbon. They accumulate large amounts of carbon dioxide from the atmosphere over indefinite periods of time. This process is known as carbon sequestration. In the use of wood materials, it is paramount to ensure that the wood is harvested from sustainably managed plantations. The environmental harm caused by use of non-sustainable wood offsets the benefits of using low carbon materials in construction. This is because the carbon sinks in the wood is destroyed during illegal logging (Frühwald, 2007).

There exist several types of wood materials that may be used in the construction of a building. Timber and lumber can be used in the construction of frames during construction. Another type of wood that can be used in construction in efforts to reduce carbon impact is engineered wood which is a product of the intricate ‘gluing’ of different wood fragments. Common examples include plywood, fibreboard and the oriented strand board. In the case of
partitioning of buildings’ rooms, plywood can be used in place of bricks to make temporary walls. Hardwood materials can also be used in flooring instead of conventional flooring materials (Buchanan and Levine, 1999).

In some cases, soil which is also a carbon sink substance is mixed with other elements to produce bricks for buildings. When done efficiently, the soil used can be useful in the sequestering of carbon emissions emanating from different human activities (Constantz and Youngs, 2010).

### 3.4 Natural Light Design

Throughout the full life sequence of a building, the energy generated for lighting needs contributes to the discharge of CO₂ and other greenhouse gases into the environment. Increasing the possibility for natural light during the day is therefore an important consideration during the designing of a building (Jenkins and Newborough, 2007). Bigger window designs would increase the amount of natural light entering the building thus reducing the need for usage of electric energy in the lighting of the building. The reduction in the unnecessary use of lighting energy would cause a subsequent decrease in the carbon emissions. An estimated 30% of energy usage can be saved from the usage of day lighting designs. Solar control window films, high performance curtain wall systems and light shelves are some of the day lighting equipment useful to the cause (Jenkins and Newborough, 2007). Light colour interior wall finishes can also aid in the efficient redistribution of light in the building during the day.

The use of roof lights, which are windows that are built onto the roof area of a building, can be efficient in ensuring efficient lighting in a building throughout the day (Sansom and Pope, 2012). In an efficient design, light that penetrates through a building’s roof light goes deep into the centre of the structure. This consequently causes the decrease in use of artificial lighting and thus reduces the amount of carbon emissions from the energy used. Hinged or sliding roof lights also aid in the natural ventilation of a building therefore saving energy that could have otherwise been used up in the running of air-conditioning systems. Limitations to the usage of roof lights can be attributed to dirt accumulation and staining that occurs on the surface over time (Sansom and Pope, 2012).
4 Results

The results from the life cycle evaluation of various building materials are represented in the tables 4.1 to 4.4. The outcome impacts represented refer to 1 kg of material. Differences in impact can be determined by the different densities of the materials.

4.1 Bricks and Tiles

Due to the high energy spending in their production, ceramic floor tiles reflect the highest primary energy demand. In situations where these materials are transported through long distances, the primary energy and global warming potentials increase. For exterior paving material, using quarry tiles would cause a 13.45MJ\text{eq/kg} reduction in primary energy demand and a drop in GWP by 0.57 kg CO_2\text{eq/kg} compared to the use of ceramic tiles (Kellenberger et al, 2007). For roofing materials, the results show that concrete leads to an energy saving of up to 42% as compared to roof tiles made of ceramic material. In the case of building bricks, using light clay bricks which are made up of straw and normal clay reduce the impact thus preventing the emission of CO_2 by 0.27 kg in comparison with normal bricks. In certain cases, technological advances in the manufacture of building materials cause a difference in the carbon impact. For instance, the use of tunnel kilns in place of older types, such as the intermittent kilns, causes an increased efficiency of 20% in energy conservation (Kellenberger et al, 2007).

Table 2: LCA results for brick and tile building materials

<table>
<thead>
<tr>
<th>Building Material</th>
<th>Density of material (kg/m\text{\textsuperscript{3}})</th>
<th>Thermal conductivity (W/mK)</th>
<th>Primary energy Demand (MJ\text{eq/kg})</th>
<th>Global warming Potential (kg CO_2\text{eq/kg})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal brick</td>
<td>1799</td>
<td>0.96</td>
<td>3.57</td>
<td>0.27</td>
</tr>
<tr>
<td>Light clay brick</td>
<td>1020</td>
<td>0.39</td>
<td>6.27</td>
<td>-0.01</td>
</tr>
<tr>
<td>Sand-lime brick</td>
<td>1480</td>
<td>0.70</td>
<td>2.18</td>
<td>0.12</td>
</tr>
<tr>
<td>Ceramic tile</td>
<td>2050</td>
<td>1.00</td>
<td>15.69</td>
<td>0.86</td>
</tr>
<tr>
<td>Quarry tile</td>
<td>2100</td>
<td>1.50</td>
<td>2.20</td>
<td>0.29</td>
</tr>
<tr>
<td>Ceramic roof tile</td>
<td>2050</td>
<td>1.65</td>
<td>4.59</td>
<td>0.43</td>
</tr>
<tr>
<td>Concrete roof tile</td>
<td>2370</td>
<td>1.8</td>
<td>2.75</td>
<td>0.26</td>
</tr>
</tbody>
</table>


4.2 **Insulation materials**

The choice of insulation materials determines a building carbon impact. Conventional insulation materials such as expanded polystyrene (EPS) have high levels of processing making their carbon emissions detrimental. The table below shows the global warming potentials of different insulation materials from the above life cycle assessment.

*Table 3: LCA results for insulation materials*

<table>
<thead>
<tr>
<th>Building material</th>
<th>Density of material (kg/m³)</th>
<th>Thermal conductivity (W/mK)</th>
<th>Primary energy Demand (MJeq/kg)</th>
<th>Global warming Potential (kg CO₂eq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane slab</td>
<td>30</td>
<td>0.03</td>
<td>105.54</td>
<td>7.36</td>
</tr>
<tr>
<td>Cork slab</td>
<td>150</td>
<td>0.05</td>
<td>51.50</td>
<td>0.81</td>
</tr>
<tr>
<td>Polyurethane rigid foam</td>
<td>30</td>
<td>0.03</td>
<td>103.78</td>
<td>6.78</td>
</tr>
<tr>
<td>Rock wool</td>
<td>50</td>
<td>0.04</td>
<td>26.29</td>
<td>1.51</td>
</tr>
<tr>
<td>Cellulose insulator</td>
<td>50</td>
<td>0.04</td>
<td>10.48</td>
<td>1.83</td>
</tr>
<tr>
<td>Sheep wool</td>
<td>180</td>
<td>0.07</td>
<td>20.67</td>
<td>0.14</td>
</tr>
</tbody>
</table>

While emissions from EPS materials average at 7%, natural insulation materials such as sheep wool produce 98% less. The greatest carbon impact recorded above is that of expanded EPS tiles and rigid polyurethane foam whose carbon emission stands at 105.5 and 103.4 (MJeq/kg) respectively (Kellenberger et al, 2007). These results can be attributed to the high-processing energy used and the methods of disposal.

4.3 **Wood Products**

Wood products register the lowest carbon footprint among all the building materials analysed. The primary energy consumption of these products is minimal. This is because the energy requirement in timber products is often due to the material’s biomass. The results of the LCA in regard to wood products are represented in the table below.
Table 4: LCA results for wood building materials

<table>
<thead>
<tr>
<th>Building material</th>
<th>Density of material (kg/m³)</th>
<th>Thermal conductivity (W/mK)</th>
<th>Primary energy Demand (MJeq/kg)</th>
<th>Global warming Potential (kg CO₂eq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glued timber</td>
<td>600</td>
<td>0.13</td>
<td>27.39</td>
<td>0.54</td>
</tr>
<tr>
<td>Air-dried timber</td>
<td>600</td>
<td>0.13</td>
<td>18.40</td>
<td>0.27</td>
</tr>
<tr>
<td>Kiln dried timber</td>
<td>600</td>
<td>0.13</td>
<td>20.99</td>
<td>0.30</td>
</tr>
<tr>
<td>Particle board</td>
<td>600</td>
<td>0.13</td>
<td>34.66</td>
<td>0.04</td>
</tr>
</tbody>
</table>

The total emissions from the use of wood materials in construction are also determined by the method of wood drying used. As shown in the table above, the total carbon emission and power demand for air-dried wood is lower than that of kiln-dried wood which records 20.99 MJ-Eq/kg and 0.30 kg CO₂eq/kg respectively (Kellenberger et al, 2007).

4.4 Cement

Cement is the element of concrete which has the biggest carbon footprint. Different types of cement are available in the market and with the raising demand of sustainable materials, low-carbon cements have been made. The table 4 below presented the GWP of a tone of different type of cement. Research and engineering process have allowed to reduce 5.6 times the carbon footprint of traditional cement compared to clinker-free cement. The use of clinker in the manufacture of traditional cement makes it the least environmentally sustainable material in this category.

Table 5: LCA results for a tone of cement

<table>
<thead>
<tr>
<th>Building material</th>
<th>Global warming Potential (kg CO₂eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I Portland cement</td>
<td>850</td>
</tr>
<tr>
<td>CEM II/A One of France most used cement</td>
<td>750</td>
</tr>
<tr>
<td>CEM II/B One of France most used cement</td>
<td>620</td>
</tr>
<tr>
<td>CEM III/A Low-carbon cement</td>
<td>460</td>
</tr>
<tr>
<td>CEM III/B Low-carbon cement</td>
<td>260</td>
</tr>
<tr>
<td>Clinker-free cement HUKR</td>
<td>150</td>
</tr>
</tbody>
</table>
4.5 **Re-Use and Recycling**

The use of recycled products is a vital practice in the reduction of a building’s carbon impact. Reusable materials obtained from demolition sites include timber materials such as roofing frames and hardwood flooring units. The use of recycled timber eliminates the cost of processing as well as the energy used in their manufacture. In the case of roofing frames, the use of recycled timber would amount to the total saving of about 18 MJ per kg of timber in energy demand (assuming the reusable timber is obtained on-site) (Addis 2012). The energy and consequent emissions saved takes place because the materials require little or zero processing unlike the case of newly acquired materials.

The recycling of steel also aids in the reduction of carbon impact. On a general perspective, the reuse steel in the building of metal doors in a building would save a total amount of $11 \times 10^9$ joules per ton of steel where the processing takes place in a basic oxygen furnace (Tam and Tam, 2006). Recycled steel could also be used in the reinforcement of concrete, therefore, reducing the carbon impact in the case where reinforced concrete is preferred over other types.

4.6 **Using Carbon Sink Materials**

The use of carbon sink materials, mostly harvested from wood can contribute highly to the reduction of carbon emissions by a building. The amounts of CO2 sequestered by the use of sustainably acquired wood are estimated at 1 ton per m$^3$ of wood (Salazar and Meil, 2009). Using timber roofing frames in the place of steel or aluminium would imply that most of the CO2 emitted by the building would be absorbed throughout the building’s life sequence. The use of timber in the making of intermediate walls and floors for its carbon sinking properties is also an environmentally sustainable action.

4.7 **Day lighting**

The total energy that is used up in the lighting of a building amounts to 40% of a building’s total energy consumption (Jenkins and Newborough, 2007). Reducing the necessity for non-natural lighting during the day is, therefore, a feasible action in reducing the energy consumption for the building and the subsequent carbon discharge. The use of roof lights is an efficient way of ensuring efficient and sustainable lighting in a building of any size. Opening roof lights can also be used in assisting natural ventilation.
4.8 Case Study: Quai d’Issy Competition

In order to design a building with a carbon footprint of less than 980kgC0$_2$eq/m$^2$ of floor area, several choices had to be taken to respect this objective. The results given above have shown some ideas of what can be done to reduce the carbon footprint when designing it but, in some cases, it is impossible to use a certain method due to the surroundings, the demands of the client or the building materials suppliers. Knowing the methods and the results that they can give is a real strength when working on a project with such a difficult objective. The architectural design team must have a great knowledge in engineering to anticipate problems and therefore, be able to create a building as wanted and not just a result of technical solutions.

4.8.1 Design method

In this section, the process that has been followed to design a low-carbon building is presented and will put the light on the reasons that some methods with really interesting results could not be put in place.

i. Sourcing building material

The building materials represent one of the major contributions to the carbon footprint of an architectural project, contractors, structural engineers and even clients can have an insufficient knowledge on alternatives to traditional concrete in matter of structure, for example. Sourcing low-carbon materials and collecting samples to look at and present is an efficient way to have a better understanding of how to use them and getting a clearer idea of what the building will look like. The photo below illustrates some materials that had a low-carbon impact but would still bring a qualitative design.
ii. Understanding the surroundings

Low-carbon methods can be applied only if they can be relevant for the project and be applied with a good knowledge of the surroundings and the nuisances that are coming from it. The plot discussed in this paper is surrounded by high traffic car lanes which are noisy and contribute to polluting the air. The figure below illustrates the perturbances around the plot, the data have been collected on open data base of the city of Paris.
Therefore, reducing the carbon impact of the ventilation by using natural ventilation could not fit this project. The air outside is too polluted to be able to guarantee a good air quality for the occupants with natural ventilation.

The high traffic car lanes and the railroad around the plot produce a lot of noise which has to be cancelled by the building to provide a decent work environment to the users of the building. To block such high noise levels, there are two classic options: facade with a low percentage of glazing or with triple or double-skinned glazed facade. Production of glazing has a high global warming potential thus having double-skinned glazed facade would be a tremendous loss in the global carbon footprint of the building. It has therefore been decided to have two different facades, a fully glazed one on the river side, to provide high natural lighting and a half-glazed facade on the railroad side to reduce the noise level produced by the trains and the Boulevard périphérique, as illustrated in the figure below.

![Facades choice of the quai d'Issy project](image)

**Figure 9: Facades choice of the quai d'Issy project**

### 4.8.2 Carbon footprint results

The following figures show the different choices in terms of structure, facade, finishing stage materials and heating and cooling systems and their influences on the carbon footprint of the building designed. These results have been calculated with data collected in the INIES data base which is the only inventory of LCA which is accepted in the carbon footprint measurement in France.
iii. Carbon footprint of the structure

![Figure 10: Carbon footprint of the structure](image1)

iv. Carbon footprint of the facade

![Figure 11: Carbon footprint of the facade](image2)

v. Carbon footprint of the finishing stages
vi. **Carbon footprint of the heating and cooling system**

By choosing the option that had the lowest carbon footprint for the structure, facade, finishing stages and heating and cooling system, it has been calculated that all its life the building would have a carbon footprint of 930 kg CO₂eq/m² of floor area which is less than the objective of 980 kg CO₂eq/m² of floor area.

vii. **Carbon footprint of the entire building**

By choosing the option that had the lowest carbon footprint for the structure, facade, finishing stages and heating and cooling system, it has been calculated that all its life the building would have a carbon footprint of 930 kg CO₂eq/m² of floor area which is less than the objective of 980 kg CO₂eq/m² of floor area.
5 Discussion

In recent years, rising concerns on the effects of construction on the global warming phenomenon have pushed research on the construction of low-carbon buildings (Wen, Siong, and Noor, 2015). Carbon discharge by buildings can be measured by the use of a life cycle assessment which is a useful tool in the cradle to gate approach in the evaluation of carbon footprint. Alternatively, a simple building’s carbon impact can be calculated by the use of a basic ratio calculation in the case where the carbon impact of the individual materials can be obtained (Krygiel and Nies, 2008). As seen in this paper, many actions have been developed and effected with the aim of reducing the amount of carbon emitted by buildings from cradle-to-gate. These actions include the use of low-carbon concrete, geothermal heat pump, reused and biobased materials and having every designing choices made in regard to their carbon footprint.

Several methods have been considered above for the construction of a low-carbon building in regard to the building materials used and design decisions concerning the same. Early assessment of the carbon impact of the potential building products is an integral step in ensuring the least amount of carbon content in the building design (Chou and Yeh, 2015). An LCA detailing the individual carbon impacts of building materials is conducted and the results given in different categories namely bricks and tiles, insulation materials, wood materials and finally cement and concrete. From the life cycle analysis of different types of bricks and tiles, it is concluded that in comparison, the usage of quarry tiles over ceramic tiles would save energy demand and the amount of carbon emissions. This may be attributed to the high level of energy consumption associated with the manufacture of ceramic (Bribiàn, Capilla and Usón, 2011). The use of quarry tiles is therefore more environmentally sustainable than ceramic tiles. It can also be concluded that the use of light clay bricks in the place of primary clay bricks offers better sustainability potential for a building. Similar brick materials may differ in global warming potentials due to the various technological advances, or the absence of the same, in the manufacture of the products. For the case of insulation materials, it can be concluded that the use of conventional materials such as EPS causes the highest amount of carbon emissions due to the high-processing levels in the manufacture (Bribiàn, Capilla and Usón, 2011). The use of natural insulating materials such as wood wool or cork provides the best option for the reduction on the carbon impact. The modes of extraction for natural insulation materials require minimal energy as opposed to conventional products which involve high amounts of energy consumption. From the LCA results regarding the comparison of global warming potentials for wood products, it can be concluded that despite the low carbon impact caused by wood materials, the carbon footprint can further be reduced by use of air dried rather than kiln-dried wood products. The use of clinker in the manufacture of traditional cement increases the
carbon impact of a building. However, the use of lime mortars over cement and concrete mortars is the most sustainable solution due the carbon dioxide absorption qualities that lime products possess. By conducting a life cycle assessment for building materials, decisions on the type of material to use for the least carbon impact can be made (Wang et al, 2010). Good knowledge of the implications of the new practices in the reduction of carbon emissions is, however, paramount in choosing materials for construction. It is therefore advisable to have the relevant personnel in the design team to avoid missteps in carrying out tasks of new nature.

The use of salvaged building products from demolition sites is one way of ensuring minimal carbon impact levels. The energy for production of the building products is eliminated and the subsequent carbon emissions controlled (Thormark, 2002). In cases where reusable products need reprocessing, the energy needs remain below those of standard produced materials. Many environmental and economical benefits arise from the re-use and recycling of building products. It is, however, important to take into account the various implications that are brought about by the use of salvaged building materials. Varying constitutions in mass and other specifications in recycled and reused products create the need for specialized planning during design (Falk, 2012). Involving experts on these materials in the design process is an advisable action. It is also important to note that due to the often scarce availability of these materials, salvaged building products can only amount to a small portion of the total material constitution of the building. For smaller structures, however, the average usage of salvaged materials can amount to up to 75% of the total building material (Thormark, 2002). For continued progress with the design of low carbon buildings in the future, the building’s structural design should favour the disassembling of the various building components (Falk, 2012). This will serve to facilitate in the re-use and recycling of the material to be used in the construction of the building.

If done efficiently, the substitution of certain building materials with carbon sink products results in the reduction of carbon emission in building (Buchanan and Levine, 1999). Most carbon sink materials used in construction are harvested from wood. As seen above, by use of timber for frames, hardwood floors and other building units, large amounts of CO₂ can be absorbed into the wood by the process of sequestering. However, for the process to occur, the wood in question must have been obtained sustainably. Wood acquired through illegal logging produces opposite results (Frühwald, 2007). Total absorption of all carbon emitted by a building is possible when these materials are used appropriately.

Another method discussed above to increase a building’s environmental sustainability is by implementing the use of day lighting. Energy consumed by the building for lighting can be saved by the use of natural light in the place of artificial lighting during the day (Jenkins and Newborough, 2007). Roof lights are an efficient tool in ensuring effective penetration of light into the building. In certain cases, roof lights are built with hinges or sliding door mechanisms
in order to assist in the natural ventilation needs of a building. It is therefore a highly useful method for the conservation of energy in both capacities of day lighting and natural ventilation (Sansom and Pope, 2012).

The case study presented has also highlighted the importance of choosing with care the building materials that will be used in a project. Timber structures have shown to reduce by almost 30% the carbon footprint of a structure if they replace at least 80% of the concrete elements. This result can be only true if the trees used to manufacture the timber elements are coming from the closest forest possible and if the trees are harvested in a sustainable way. The same result can be observed when the choice of window frame is taken, aluminium and timber frame helps to diminish up to 18% the carbon footprint of a glazed curtain wall compared to just aluminium frame. Using reused materials reduce of 12% the carbon footprint of the finishing stages but depending on the quantity needed, the contractors may be limited in materials if the sourcing has been done at an early stage of the construction. This can, however, change in the coming years by the development of the network like CycleUp who specialize in making accessible used materials to contractors.

In order to stop the production of environmentally degrading building material, it is necessary for the use of low-carbon materials to be promoted. Continuous use of sustainable building materials will lead to faster replacement of less sustainable products. Government policies on low carbon construction should constantly be revised and implemented in order to encourage better and environmentally friendly architectural developments. There is also a significant need for the update of existing inventories for building materials' databases. Standard measuring units for the carbon impact of construction materials should be dictated for easier analysis of the carbon emission potential of a building and the individual components involved.
Bibliography


