INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

ACADEMIA MILITAR
DULCE ET DECORUM EST PRO PATRIA MORI

Environmental Impact of Building Structures –

CO_2 Production

Extended Abstract

Valter António Martins Henriques

Supervisor: Prof. Dr. Fernando António Baptista Branco (IST)

Lisbon, October 2011

1. Introduction

It is undeniable that in recent decades, the climate has changed rapidly. Nowadays there is considerable concern on this subject, so it is important to carefully study this issue using examples that can be applied in construction in order to obtain solutions involving minor impacts on the environment.

Before addressing the issue of environmental impact related to the production and application of concrete, it is necessary to be aware of the relationship between this and the technological choices that are made nowadays. Therefore, Mehta (2001) and Holdren / Erlich cited by Habert (2010) suggest that the following expression can be taken, to show the environmental damage (*D*) in terms of three other parameters:

$$D = f(P.I.W) \tag{1}$$

where *P* stands for population, *I* is the index of industrial and urban growth, and *W* is an indicator of the degree to which the culture promotes the waste of natural resources and may be associated with an increased standard of living.

In Figure 1 the exponential increase in CO_2 emissions may be seen during this century which is evaluated by estimating the population growth from 6 to 9 billion, industrial development and increasing urbanization recorded rates. This work may therefore contribute to a better understanding of the aspects that permit control of the parameter *W*, which has a multiplier effect on the calculation of environmental damage, making it possible to control the damage caused by this parameter. For this purpose it is necessary to raise awareness and inform both the average consumer, and the professionals in the construction sector, about the models and economic and technological choices that promote a careful consumption of energy and natural resources.

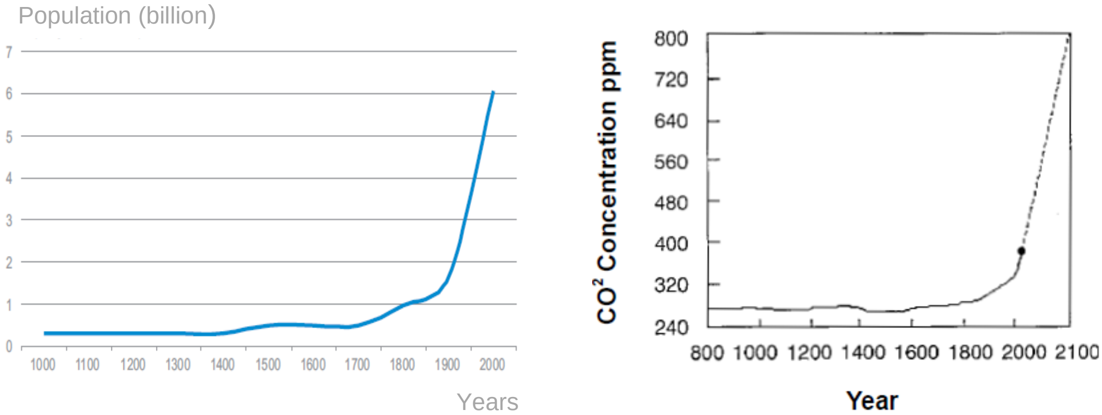

Figure 1 - Left: Evolution of population during the last millennium [4]; right: history and forecast of atmospheric concentration of CO_2 [3].

Carbon emissions are a major environmental challenge that society today has to face, and they clearly occupy a prominent place in the theme of climate change on our planet. Nowadays, this also occupies an important place in economic issues, due to the financial penalties set by the European Union (EU) for those who exceed the allowed emissions.

2. Global Climate Changes

The Intergovernmental Panel on Climate Change (IPCC) refers to climate change as a variation of the properties of the climate and its persistence over a period of time, typically decades or longer. This variation of the global atmospheric composition could be due to natural causes or human activity.

Issues like general warming of the climate, and more frequent occurrence of natural disasters which have a major impact both on social conditions through loss of life and at an economic level have been investigated by both the scientific community, and in books, web sites, movies, television and radio, and they all converge on a basic idea: our habits will have to be modified to reduce the impact to which we subject the environment, otherwise we can expect a future full of disasters resulting from the responses of nature. This paper makes an approach to the construction industry, in order to make comparisons of the emissions of CO_2 between different types of concrete until it is placed on site.

3. Concrete and the environment

From what has been discovered about climate changes, it is easy to understand that the current way of life led by human activities, is quickly becoming unsustainable at social, economic and environmental levels. The construction industry is one of the most active sectors in Europe and at the same time it is the activity where most non-renewable raw materials in the world are consumed. This topic should be taken seriously, and improvements in the construction industry should be discussed.

The most common concrete includes a binder, usually Portland cement (10-20%), thin and thick aggregates (70-80%) and water (7-9%). If necessary, to improve specific characteristics, chemical additives (less than 1%) may be added, this description is presented in Figure 2.

For the durability and quality of the concrete structure, appropriate constituent materials must be selected, effective supervision must be conducted at the work site, due to the fact that usually the concreting is done in situ, and it also depends on the labour responsible for the production, placing, and curing of the concrete.

Concrete can incorporate into its constitution a lot of waste from other industries. Currently there are studies on a number of kinds of waste that can be embedded in concrete. The incorporation of these wastes lead to superior environmental performance, and it can improve several properties in cement and concrete. These wastes can be such as:

-Wastes with pozzolanic characteristics;

-Fly ash;

-Blast furnace slag;

-Silica fume;

-Ash from urban solid waste;

-Glass waste;

-Waste aggregate fillers;

-Construction and demolition waste.

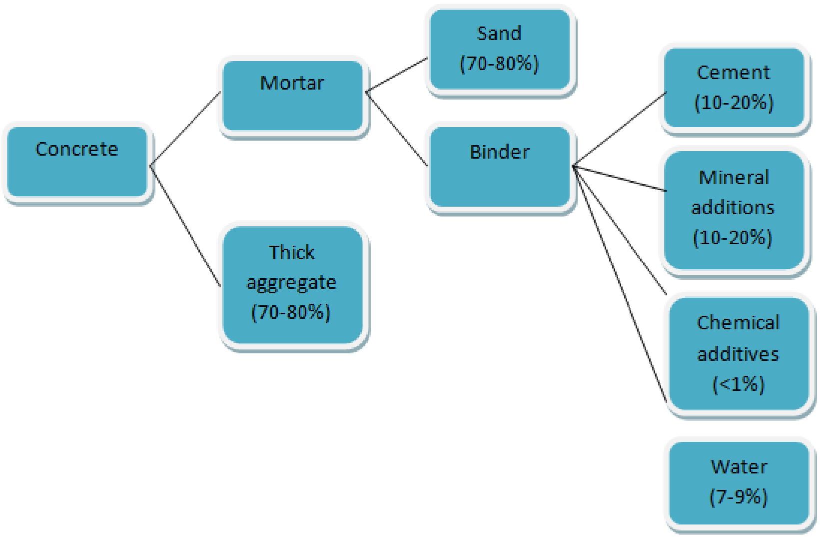

Figure 2 – Constitution of concrete.

4. Life Cycle Analysis

To cope with the growing awareness of the importance of environmental preservation and the impacts associated with various products, there have been a wide variety of methods, including the Life Cycle Analysis (LCA). This analysis is particularized in Figure 3 for the production of concrete, it allows the flow of the system to be evaluated, whether at the level of inputs (energy and raw materials), or at the level of outputs (product, emissions to air, to the water, and to the soil, etc.). The principles of the method of LCA will be used in this paper, due to the fact that it is a well suited method to the ultimate purpose of this study: the evaluation of the environmental impact of 1m^2 of a building construction, based on concrete as the building material.

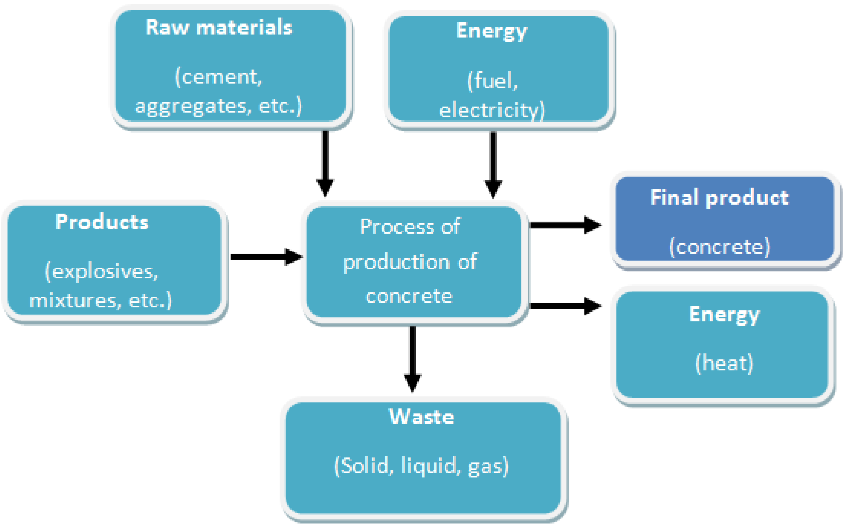

Figure 3 – Inputs and outputs of the life cycle in the production of concrete. Adapted from [1].

5. Adopted Impact Model for Case Study

For the case study a "cradle to gate" system analysis was performed, in other words, from the stage of obtaining the raw materials until the final placement of concrete on site. In this study, the following boundaries were established in the analysis of the life of the concrete:

- Cement:
    - Manufacturing process, which considers:
        - The use of explosives in the quarry;
        - The extraction machine;
        - Transport to crusher / mill;
        - Internal transportation in the plant;
        - Energy costs in the plant (crusher / conveyor / ventilation, etc.).

    - Transporting the loaded vehicle to the concrete manufacturing centre, and return without cargo.

- Aggregates:
    - In this work, have been considered represented by the crushing machine all the preparations for the gravel, such as:
        - The use of explosives in the quarry;
        - The extraction machine;
        - Transportation of blocks by a truck then loaded into the crushing machine;
    - Transport of aggregates by a loaded truck into the concrete manufacturing centre and return without cargo.

- Water:
    - Only the effects of the pumping stations were considered in the calculations, not the additional effects of:
        - Treatment;
        - Distance to point of consumption.

- Sand:
    - Extraction with machine;
    - Transport of the loaded vehicle to the concrete manufacturing centre and return without cargo.

- Concrete manufacturing centre:
    - Processes related to the concrete manufacturing centre, which include the operation of:
        - Mixer;
        - Supply system and weighing of aggregate and binder;
        - Additives and water tanks with pumping;
    - Transport with self-mixer vehicle of the concrete from the concrete manufacturing centre to the work site, and return without cargo;

- Placement of concrete on site:
    - Pumping equipment;
    - Vibrating equipment;
    - Use of crane on site.

- Formwork:
  - Cutting of trees, represents processes such as:
    - Positioning of the machine;
    - Timber cutting and tumble of the pieces of wood;
  - Transformation of shuttering boards, which represents the processes of:
    - Peeling, drawing and sawing wood;
  - Transport of formwork to site and return of the vehicle without cargo.

- Excavation:
  - Excavation;
  - Transportation to landfill with the vehicle loaded and return empty.

6. Application to a Case Study

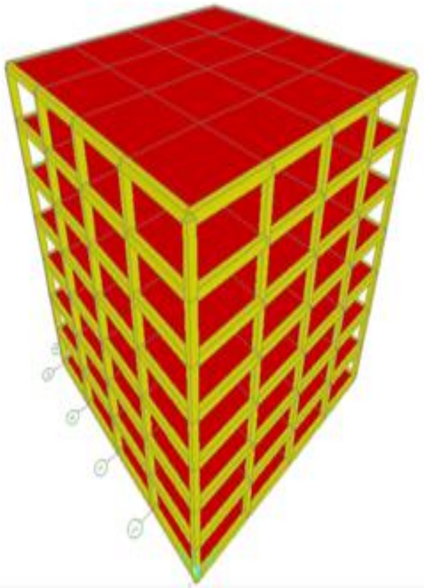

Figure 4 - Building type considered.

For a better understanding of the data above, we will consider a typical building 7 storeys high (Figure 4), with an area of 300 m^2 per floor, which is a total area of 2100 m^2, in a generic region in urban territory. The data presented in the next subchapters refer to the production of 1 m^3 of concrete- gCO_2/m^3 of concrete (functional unit used). For our example the floor will have a thickness of 0.20 m (taking, for example the value of 0.17 m thick slab, adding to this 20% of the thickness, corresponding to the total volume of concrete of beams, columns, etc.), so in the end we can assess the amount of CO_2 that is released to produce 1 m^2 of floor of the building type taken.

6.1. Obtained Values

All the final results, according to the boundaries adopted in the analysis of life of the concrete are presented below.

FINAL TABLES

Cement CO2 (g/m3 concrete)				
Type	I	II	III	IV
Production	222620,1	184606,7	67270,5	206415,0
Transport	485,1			
Σ	223105,2	185091,8	67755,6	206900,1

Aggregates	
Activity	CO2 (g/m3 concrete)
Crusher	202,5
Transport	1940,4
Σ	2142,9

Water	
Activity	CO2 (g/m3 concrete)
Pumping Stat.	18,0
Σ	18,0

Sand	
Activity	CO2 (g/m3 concrete)
Extraction	1868,3
Transport	970,2
Σ	2838,5

Formwork	
Activity	CO2 (g/m3 concrete)
Cutting	160,1
Transformation	4,0
Transport	462,0
Σ	626,2

Concrete plant	
Activity	CO2 (g/m3 concrete)
Production	372,9
Self-mixer vehicle	12685,0
Σ	13057,9

Excavation	
Activity	CO2 (g/m3 concrete)
Excavation	2780,2
Fuel	2887,5
Σ	5667,7

On site	
Activity	CO2 (g/m3 concrete)
Pump	3481,3
Vibrator	12,1
Crane	1911,0
Σ	5404,4

Emission of CO2 per m3 of concrete [CO2 (g/m3 concrete)]				
	I	II	III	IV
Cement	223105,2	185091,8	67755,6	206900,1
Aggregates	2142,9			
Water	18,0			
Sand	2838,5			
Formwork	626,2			
Concrete plant	13057,9			
Excavation	5667,7			
On site	5404,4			
Σ	252860,7	214847,4	97511,2	236655,7

Emission of CO2 per m2 of floor [CO2 (g/m2 floor)]				
	I	II	III	IV
Cement	44621,0	37018,4	13551,1	41380,0
Aggregates	428,6			
Water	3,6			
Sand	567,7			
Formwork	125,2			
Concrete plant	2611,6			
Excavation	1133,5			
On site	1080,9			
Σ	50572,1	42969,5	19502,2	47331,1

After obtaining the data for 1 m^3 of concrete, it is possible to work it in order to get the value of CO_2 emissions per m^2 of floor.

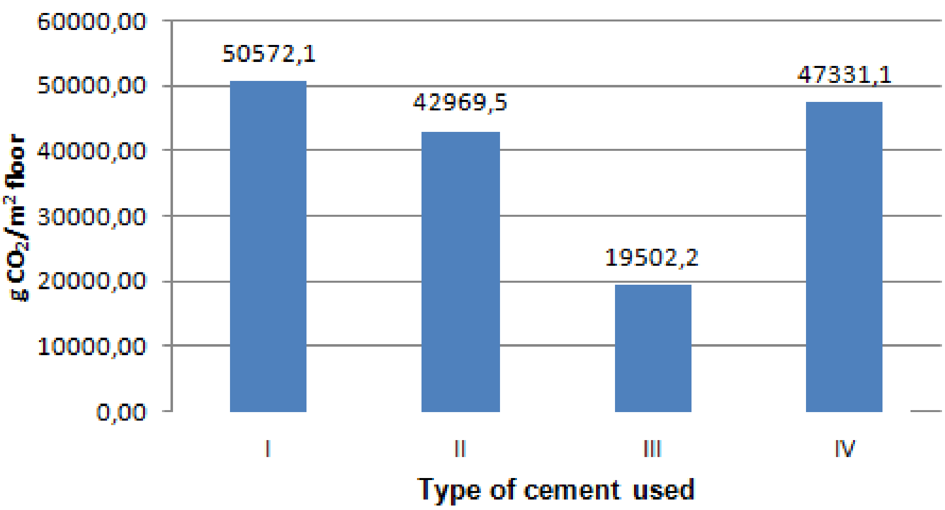

Figure 5 - Evolution of CO_2 emissions per m^2 of floor (floor gCO_2/m^2).

7. Spreadsheet

The use of LCA software is somewhat complex, which may require specific long time training to use. In this work a spreadsheet is provided that presents the above values in the "Final Table" sheet. This Worksheet is a user-friendly interactive interface. This interface can show the emissions of CO_2 per m^3 of concrete and per m^2 of floor of a building. Parameter values can be easily changed and adapted to another situation, even if they deviate from the case study devised for this work.

There may be some limitations on the program presented, since there is no other available option to increase the number and type of machines and processes considered. However, because Excel is an easy tool to use, this can be solved by someone with some experience in this field.

8. Conclusions

This paper has shown that cement production is the main source of environmental impact generated by the use of concrete, followed by the influence of transport distances and the use of equipment with fuel consumption.

This study has shown values of emissions in the order of 50 $kgCO_2/m^2$ of floor, for the concrete that uses the type of cement most damaging to the environment (CEM I), and a value of 19,5 $kgCO_2/m^2$, for the concrete that uses cements with the lowest level of clinker (CEM III). The values obtained are not absolute, in other words, they only refer to this particular case study, and have involved numerous approximations and simplifications to obtain the final data.

References

[1]. *CEMBUREAU Environmental Product Declaration for Cement - User's Guide.* 2008.

[2]. IPCC. *Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva : Intergovernmental Panel on Climate Change, 2007.

[3]. Mehta, P. Kumar. Reducing the Environmental Impact of Concret. *Concrete International.* Outubro 2001, pp. pp. 61-66.

[4]. Pinheiro, Manuel Duarte. *Ambiente e Construção Sustentável.* Amadora : Instituto do Ambiente, 2006.