# Life cycle assessment of steel and reinforced concrete structures: A new analysis tool

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ABSTRACT: In this paper is discussed the life cycle of steel and reinforced concrete structures using a simplified life cycle analysis. The developed methodology consisted in quantification of a series of parameters both economic and environmental that characterize both reinforced concrete and metallic structures. Based in the life cycle analysis, five parameters were selected in order to make the assessment, in witch: energy consumption, water, $CO_2$, $SO_2$, $NO_x$. A database was developed into a software program that can perform life cycle analysis of these types of structures giving their physical properties. As a result the software outputs the total amount of emissions caused by the production of a given structural element as well as determines the structural costs giving in the end a global project analysis.

## 1 INTRODUCTION

The concept of sustained development, defined in the Brundtland report in 1987, is a very complex and dynamical challenge that demands contributions of the most diverse activity sectors.

In 1996 the document named "The Habitat Agenda" written in the II Habitat conference that occurred in Istanbul mentions problems related with human communities and specifically refers the participation of the construction industry in the sustained development:

"…encourage the development of methods that are economically and environmentally sane, as well as in the production and distribution of the materials used in construction, including the strengthening of the industries of traditional construction materials that use raw materials that are available as close as possible"

This declaration shows the significance of the construction industry in a sustained development, because this economical activity influences the environment and the well fare of the population as it contributes to the dissipation of the natural resources, energy consumption, air pollution and the creation of waste.

In civil engineering construction, we should have present the life cycle assessment while we select the materials in order to valuate the whole environmental impacts that are directly associated. In order to accomplish reliable results, we should not only define criterions or requests, but also establish a methodology of valuation and environmental characterization of materials in analysis.

In the international scenario, the responsible entities have been present. Between them we have the International Organization of Standardization, in which the ISO 14000 norm as become one of the most relevant tools in the environmental managing. The application models of Life Cycle Assessment (LCA) for selection of construction materials constitutes, at present, a more complete methodology, bounding the materials selection with a global environmental performance (e.g. environmental impacts). The Life Cycle Assessment follows four basic steps, in which step can consist in one or two phases as can be seen in fig.1.

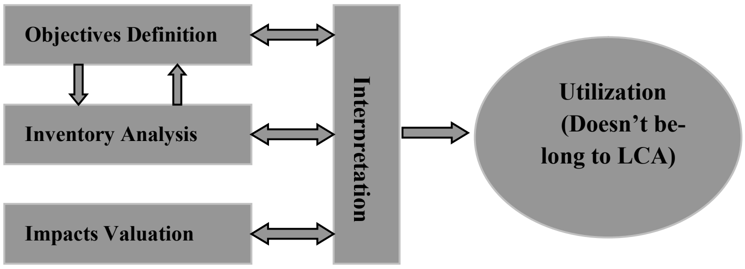


**Figure 1 – Scheme of the Life Cycle Assessment phases.**

Currently there are no software tools available to help decision makers assess in direct manner energy consumption, water, $CO_2$, $SO_2$ and $NO_x$ values regarding the construction of a building. The need for such tools has resulted in the environmental deterioration and the need of quantification of such parameters. The application of this tool will enable decision makers to better manage the LCA of a building by developing appropriate control measures to minimise these risks by, for example, prioritising their operational maintenance strategies.

In this study we've focused on the environmental impacts caused by the manufacturing and transport of necessary materials to build a reinforced concrete or a steel structure. The final results allowed us to decide which structure is more sustainable financially and environmentally. To do so, a software program was developed that allows a Life Cycle Assessment of the parameters earlier referred of any kind of structure. All collected data was inserted in the database program regarding Portuguese parameters in order to create a more accurate simulation.

## 2 EXPERIMENTAL WORK

The structure's LCA was based in the existing values of the most significant emissions produced in the extraction, production and transformation of the materials used in the conception of the structure. The water consumption and the energy consumption were also considered. The next step was to make a discrimination of the reinforced concrete into its constituents: cement, aggregates, steel bars and wood (formwork). In order the results to be representative of the building construction in Portugal, we've made a campaign in the Portuguese industry that operates in civil engineering construction and sells the raw materials used in the building construction. The data referring to the materials used in reinforced concrete was made available by Cimpor S.A (1) for the cement type used and Siderurgia Nacional (3) facilitated the values for the steel bars. In the aggregates case, the parameters were gathered from an aggregate manufacturing factory (2) and the data used for the formwork (wood) was obtained in the publication CIMAD (4). Regarding the structural steel and because there aren't any industry operating in Portugal, we had to use data from a Spanish company named Arcelor (5) and located in Madrid.

The selection of the several ambiental parameters to be compared was based on the significance of these in ambiental impact terms. The issue of the concordance between the parameters that were given by the companies above mentioned was also considered. It is strictly necessary that all of the several materials have the same parameters. Only so we can make a proper analysis. Once all the data were converted to the unitary value it was possible to estimate the value of the environmental impact caused by the materials in study. Each impact was represented graphically.

**Table 1**- **Environmental parameters relative to the production of reinforced concrete**

| | Cement | | Aggregate | | Water | | Steel | | Wood | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Energy Consumption** | 2,9 | GJ/ton | 0,01 | GJ/ton | 0 | | 1,872 | GJ/t | 0,306 | GJ/m$^3$ |
| **Water** | 0,18 | m$^3$/ton | 0 | m$^3$/ton | 0,5 | m$^3$/m$^3$ | 0,66 | m$^3$/t | 0 | m$^3$/m$^3$ |
| **$CO_2$** | 675 | Kg/ton | 0 | Kg/ton | 0 | | 0,036 | t/t | 0 | t/m$^3$ |
| **$SO_2$** | 0,15 | Kg/ton | 0 | Kg/ton | 0 | | 0,005 | t/t | 0 | t/m$^3$ |
| **NOx** | 2 | Kg/ton | 0 | Kg/ton | 0 | | 0,001 | t/t | 0 | t/m$^3$ |

We've considered in the energy consumption values, an average standard from Central Europe (6) because measurements are yet to be made for Portugal. Also taken in consideration in this work were the ambiental impacts caused by the transport of steel to Portugal (6). As such, we have estimated the distance between Guimarães (place were the building is found) and Madrid (location of the factory) resulting in an impact due to the transportation based on the weight of the transported steel and the distance between cities added the corresponding emission value per unit of distance due to the emissions produced by the engine of the truck (table 3). The total environmental impact is given by the sum of the production of the steel and its transportation.

**Table 2**– **Environmental parameters of structural steel production**

| | Value | |
|---|---|---|
| **Energy Consumption** | 10 | GJ/t |
| **Water** | 6,6 | m$^3$/t |
| **$CO_2$** | 1,51 | t/t |
| **$SO_2$** | 0,0011 | t/t |
| **NOx** | 0,001 | t/t |

**Table 3**– **Environmental parameters of structural steel transportation**

| | Value g/(ton.km) | Distance(km) |
|---|---|---|
| **$CO_2$** | 120 | 700 |
| **$SO_2$** | 0,1 | |
| **NOx** | 1,9 | |

After collecting all values regarding the parameters in issue, a software tool named EcoBuild was developed in Visual Basic. The first step when running EcoBuild was to load the database entries with those presented in tables 1-3, the built in database is very dynamic so it can be easily upgradeable for future works.

The valuation of the ambiental impact of the building materials was made by studying a usual building located in the city of Guimarães. A representative portico of the building (fig.2c) was used in order to assess construction materials of the reinforced concrete structure and then a comparison is made with an equivalent steel portico.

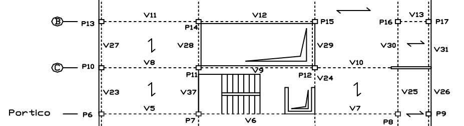

**Figure 2 - structural scheme and portico of the building**

The portico was constituted with tree beams of different dimensions and one type of pillar in a total of 4 pillars. The different dimensions are summarized in table 4.

**Table 4 – Dimensions of reinforced concrete structural elements**

| **Pillars** | **width (m)** | **height (m)** | **length (m)** |
|---|---|---|---|
| P1 | 0,3 | 0,3 | 3 |
| **Beams** | | | |
| V1 | 0,25 | 0,6 | 6 |
| V2 | 0,25 | 0,6 | 7 |
| V3 | 0,25 | 0,6 | 5 |

In the concrete composition per cubic meter was used 350kg of cement from the Cimpor 32.5 kind I. The aggregates used were sand rolled extracted from the river and granitic gravel with a total of 1900Kg/m$^3$. Was also accounted the total steel bars length used for the reinforced concrete. The pillars used $\phi$ 8 and $\phi$20 steel bars and the beans ranged from $\phi$ 6, $\phi$ 8, $\phi$ 16 and $\phi$ 25 steel bars. The associated cost per cubic meter of concrete was 324,22€ with a total amount of reinforced concrete 3,78m$^3$.

**Table 5 – Properties of the steel structural elements**

| **Pillars** | **Type** | **weight (Kg/m)** | **length (m)** |
|---|---|---|---|
| P1 | HEB240 | 83,2 | 3 |
| **Beams** | | | |
| V1 | INP400 | 92,6 | 6 |
| V2 | INP400 | 92,6 | 7 |
| V3 | INP400 | 92,6 | 5 |

Concerning the equivalent steel portico, it was selected a HEB240 for the pillars and INP400 for the beams. Was determined a cost of 2€/kg with a total of 2665,2Kg of steel. Table 5 summarizes the properties of the steel used for comparison.

## 3 RESULTS

Analysing the figure 3, we may notice that the steel structure as greater energy consumption than the reinforced concrete structure.

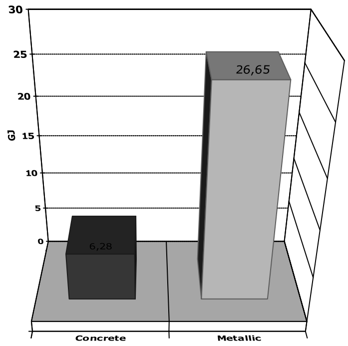


**Figure 3 – Energy Consumption**

The steel structure consumes about 27 GJ while the reinforced concrete structure consumes about 6 GJ, resulting in 4.5 times more energy consumption.

**Table 6 – Summarized results**

| | **Concrete** | **Steel** |
|---|---|---|
| **Water($m^3$)** | 2,82 | 17,59 |
| **$No_x$(kg)** | 3,69 | 6,21 |
| **$CO_2$(kg)** | 931 | 4248 |
| **$SO_2$(kg)** | 5,42 | 3,12 |

The data regarding the water consumption indicates that the steel structure consumes about 6.2 times more than the reinforced concrete structure.

In the analysis made to the $NO_x$ emissions, we can see that, once again the reinforced concrete structure does less harm to the environment; it releases approximately 2 Kg while the steel structure releases 68% more to the atmosphere.

As we examine the Carbon Dioxide emissions, the difference is quite significant. The steel structure releases 4248 Kg of $CO_2$ while the reinforced concrete structure releases only 931 Kg, i.e., 88% less.

Only in the $SO_2$ emissions reinforced concrete structure presents a larger amount, releasing 2.5 Kg, 47% more than the equivalent steel structure.

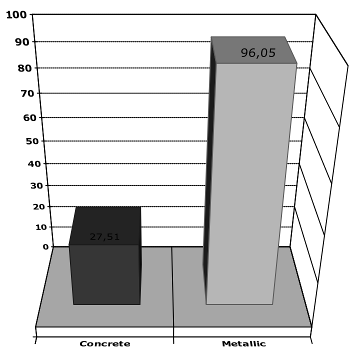


**Figure 4 – Global analysis**

As a result, when we carefully analyse in global terms (fig.4), it's clearly evident that the total environmental impact caused by the construction of the same portico in steel is much bigger than using reinforced concrete, causing about 3.5 more impact.

## 4 CONCLUSIONS

Making an analysis of the given structure that we can observe the environmental impacts caused by the steel structure are vastly greater than the ones caused by the reinforced concrete structure. Consequently, the kind of structure that is friendlier to the environment is the reinforced concrete. There is only one parameter that causes more damage to the environment in the reinforced concrete structure: the $SO_2$ emissions. Though it makes more damage to the environment, its difference is only of 0,8Kg. We therefore conclude that globally the steel structure is less sustainable.

We consider important to add that although the steel structure is less sustainable, the steel is a resource that may reach a recyclable rate of 100%. The item wasn't considered in our study.
The developed software program can be downloaded in the Civil Eng. Materials Research Group webpage: http://www.civil.uminho.pt/web/gmc/

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