COMPARATIVE LCA OF TRADITIONAL STRUCTURES AND STRUCTURES MADE WITH THE NPS® SYSTEM

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ABSTRACT

In Europe, the construction sector has a significant impact on the environment. This is due not only to the operation of the buildings, but also to the production of construction materials and the disposal of construction and demolition waste. For this reason, it is important to carry out an environmental assessment of the buildings by considering their entire life cycle. Among the various building components, the structures are responsible for greater energy consumption and polluting emissions, especially during production. Therefore, a closer investigation of the relationship between structural and environmental performance can suggest new design strategies and a more efficient use of materials. To this end, the LCA analysis is a useful evaluation and comparison tool. This contribution illustrates the application of the LCA methodology for the comparative analysis of two buildings made with traditional technologies (steel and reinforced concrete) with the Tecnostrutture's NPS system.

1. Introduction

The building sector is one of the economic activities with the greatest environmental impact in Europe. It is estimated that the phase of building operation contributes alone to around 40% of total energy consumption and about 36% of CO2 emissions (European Parliament and Council of the European Union, 2010). In addition, further impacts derive from the production, installation and disposal of building materials. "Buildings and the built environment use half of the materials extracted from the earth's crust and produce 450 million tons of construction and demolition waste each year, i.e. more than a quarter of all produced waste" (COM/2004/0060 final).

The structures represent one of the most important subsystems of buildings, being responsible for major environmental impacts, especially during production (Takano et al., 2015).

The environmental performance of the structures may depend on several factors, which affect energy consumption and overall polluting emissions. For example:

The production of structural materials, where the optimization of processes (reduction of energy costs of steel and concrete production, recycling of raw materials, reduction of scrap and processing waste, etc.) can increase the sustainability of the structure.

The availability of structural materials, depending on the economic-productive and territorial context that characterizes the construction of a building, which can influence the impacts deriving from transport.

The efficiency of the structures, expressed in terms of specific weight/performance ratio, which reduces the quantity and weight of the materials used and therefore reduces the impacts deriving from production processes and from the use of yard equipment in the construction phase.

The durability of the structures, strictly dependent on the design, which consists of the selection of durable materials and treatments, the prevention of performance defects and malfunctions (including structural collapse), which can lead to substantial damages, and finally the effectiveness of the planned maintenance solutions.

The disassembly capability of the structures, which can make it possible to manage demolition operations better and can guarantee greater percentages of waste recovery through the recycling of raw materials or through the re-use of the structural elements for the construction of new buildings, thus reducing or avoiding new environmental costs.

In general, before the construction phase, design can play an important role in the efficient use of structural and non-structural materials, in the reduction of unforeseen factors in the construction phase and in the maintenance over time of the technical performances required.

The Life Cycle Assessment (LCA) makes it possible to assess, on a quantitative basis, the environmental impacts of the buildings in the production, construction, maintenance and end-of-life phases. Therefore, it can help designers and companies to effectively direct their efforts towards the implementation of the most “sustainable” products and processes. The general objective is a reduction in energy consumption and polluting emissions from structures and other building components to the same extent as that pursued in the operation of the buildings.

The study conducted in collaboration between the research unit of the University of Genoa and the company Tecnostrutture aims at comparing three alternative structural solutions, in steel, reinforced concrete and NPS® system, in terms of primary energy and equivalent CO emissions2.

2. Case studies: Description and evaluation methods

The LCA analysis was conducted on a single-storey building and on a multi-storey building, both built with the NPS system. In both cases, in order to develop the comparative LCA analysis, two more versions of the building were designed, one in steel and one in traditional concrete, which had to meet the following requirements:

- Geometries of the structures identical to those of the real structure.
- Static schemes similar to those of the real structure, except for particular needs linked to the constructive nature of the steel or reinforced concrete solution (e.g. introduction of bracing in the steel solution) and in compliance with the architectural project (functionality of the interior spaces).
- Comparable structural performances, in terms of the work rate of the elements and their deformability.
- Comparable fire resistance.
- Nominal life of the building of 50 years.

The functional unit of the LCA analysis was, in both cases, the structure of the building. Therefore, any non-structural component was excluded, when not strictly functional to the fulfilment of the performance objectives listed above. For example, the building infill elements were excluded but the fire protection elements of the structures were included where necessary. Furthermore, all the auxiliary materials used during the installation of the structures were included (for example, formworks and props).

In both cases, the aim of the LCA analysis was to evaluate the environmental performances of the three solutions over their entire life cycle (from cradle to grave). In particular, the analysis took into consideration two impact categories that are among those most investigated today: the primary energy consumption and the equivalent CO2 emissions. The first category expresses the total amount of energy consumed during the life cycle, including the entire energy chain, starting from the source extraction phase. The second category expresses the impact of gaseous emissions into the atmosphere by taking the equivalent amount of carbon dioxide emissions as a reference, which is one of the main causes of the greenhouse effect and therefore of climate change.

The useful life of the analysed structures has been set at 50 years. This was done for two reasons: the useful life value is consistent with the nominal life assumed for the structural calculation; the value of 50 years is consistent with many existing LCA studies conducted on structures. All stages of the life cycle were considered, with the sole exception of the usage phase, as it was not relevant for the purposes of the study.

The present analysis follows a bottom-up approach based on the definition of inputs (energy and materials) and outputs (emissions and waste) for each process within the different phases of the life cycle. This study was based on the technical standards EN ISO 14040:2006 and 14044:2006, which contain shared principles and general instructions for the LCA analysis.

As regards the production phase, the analysis used the Ecoinvent database, widely used in LCA analyses, which provides environmental data cradle-to-gate of construction materials, based on the European production context. With regard to the construction and transport of the finished products, it used the primary data provided by Tecnostrutture for the NPS® system, subsequently compared with secondary and literature data for the two conventional systems in reinforced concrete and steel. Similarly, for the maintenance phase, it adopted literature data on the durability and the average maintenance cycles required by the various building materials (in particular, by the finishes). Finally, for the end-of-life phase, it considered on-site demolition activities, transport of waste to disposal or recycling centres and the operations necessary to dispose of or recover waste. The evaluation of the impacts at the end of life has required the development of some hypotheses regarding the efficiency of waste recovery and the material recycling percentage. In this case, a recycling scenario was assumed with a strong recycling percentage of demolition and construction waste, in order to better understand the possible environmental benefits. The re-use of the structural members was excluded, due to the difficulty of predicting the conditions of integrity and re-use at the end of the cycle.

The first case study concerned an existing building: the single-storey building that houses the Municipality of San Felice sul Panaro (Figure 1). The second case study took into consideration a multi-storey building with a service purpose located in the Municipality of Aigle (Switzerland) (Figure 2).

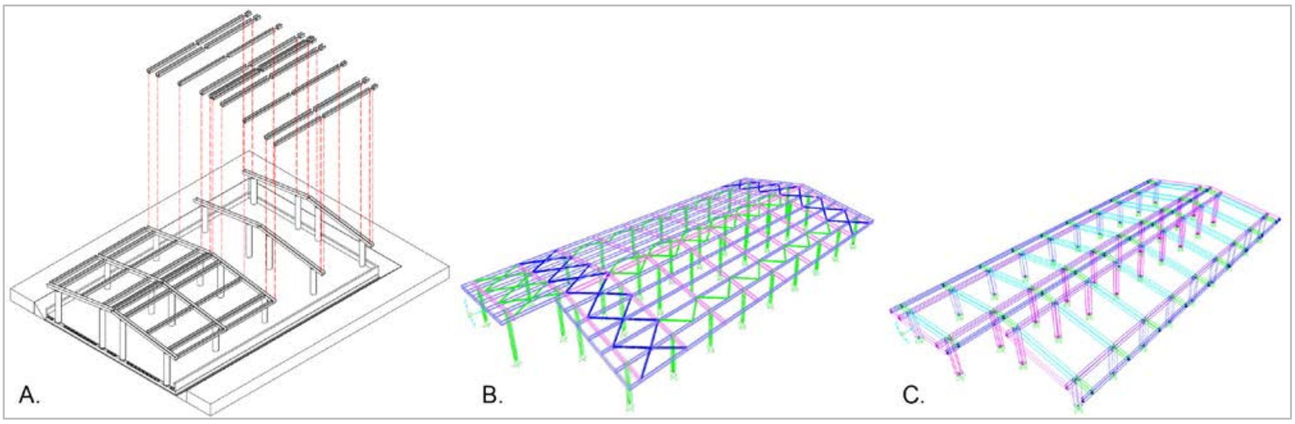

Figure 1. Single-storey building: A. NPS® system; B. conventional steel structure; C. conventional reinforced concrete structure.

Figure 2. Rendering of the multi-storey building considered in the analysis.

3. Conclusions

The analysis of the results obtained (Figures 3 and 4) shows how in both cases (single-storey and multi-storey buildings) the structure built with the NPS® system is the one with the lowest overall environmental impact, both in terms of primary energy consumption and of CO2 emissions. This result can be attributed to several aspects.

In general, it can be observed that the most significant phases of life for the environmental impacts of the three structures are the materials production and the end-of-life.

As far as the production phase is concerned, it is observed that it is strictly connected to the quantity by mass of the materials used and to the unit values of primary energy and CO2 emissions associated with them. Considering that these unit values of steel are much higher than those of concrete, with a ratio of about 37:1 for primary energy and of 18:1 for CO2 emissions, the mass quantity of this material is by far the most important aspect. For this reason, the steel structure, although using a much smaller mass of materials, has the most significant impacts.

The traditional concrete structure and the structure made with the NPS® system have very similar impacts in relation to the production phase. The NPS® system uses a greater quantity of steel but a smaller quantity of concrete than the traditional one. It is also noted that the reduced use of concrete in the NPS® system is essentially linked to two factors: the rigid-node frame system, which, although involving greater use of steel and concrete for the beams and columns, makes it possible to have no stiffening walls, and the optimization of the slabs.

The possibility offered by the NPS® system to achieve, with equal environmental impacts, a rigid node structure without stiffening walls (as in the traditional concrete structure) or bracing elements (as in the traditional steel structure) even in the presence of significant seismic loads, has a significant impact. In addition to the obvious architectural advantages, further structural advantages are implicitly associated with this structural solution, which, although not considered in this analysis, can be decisive in the future.

Indeed, it is now recognized that the design of architectural spaces that are more freely usable and modifiable decreases renovation interventions and increases their life span, thus reducing the impacts of the building over time.

As far as the end-of-life phase is concerned, it is observed that also in this phase the impacts of the structure built with the NPS® system are comparable, even if slightly lower, to those of the traditional concrete structure. This result derives again from the smaller quantities of concrete and the greater quantities of steel used in the NPS® structure. Indeed, based on currently developed technologies, steel has a higher recovery rate during demolition and greater efficiency in recycling processes. In this case, the steel structure is the winner (even if the impacts of the production phase are still prevalent).

One aspect of the construction phase not directly taken into consideration in the analysis but very relevant in terms of overall performance, is that linked to the time taken to complete the work. The NPS® structure, thanks to its construction system and the wide use of industrialized elements, guarantees very competitive construction times (Figure 6.19), even more competitive than the traditional steel system. This aspect, in addition to obvious economic advantages, offers further social and environmental advantages linked to the reduction of construction time in the specific area.

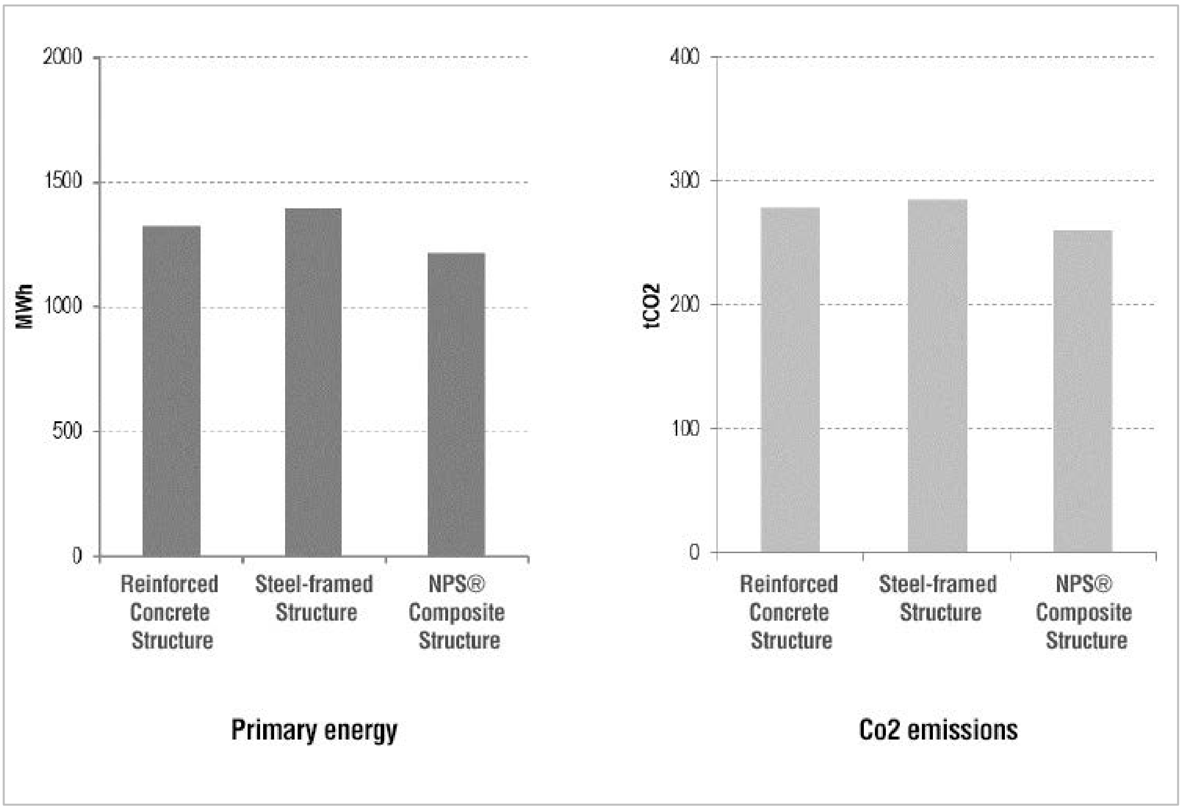

Figure 3. Results of the LCA for the single-storey building.

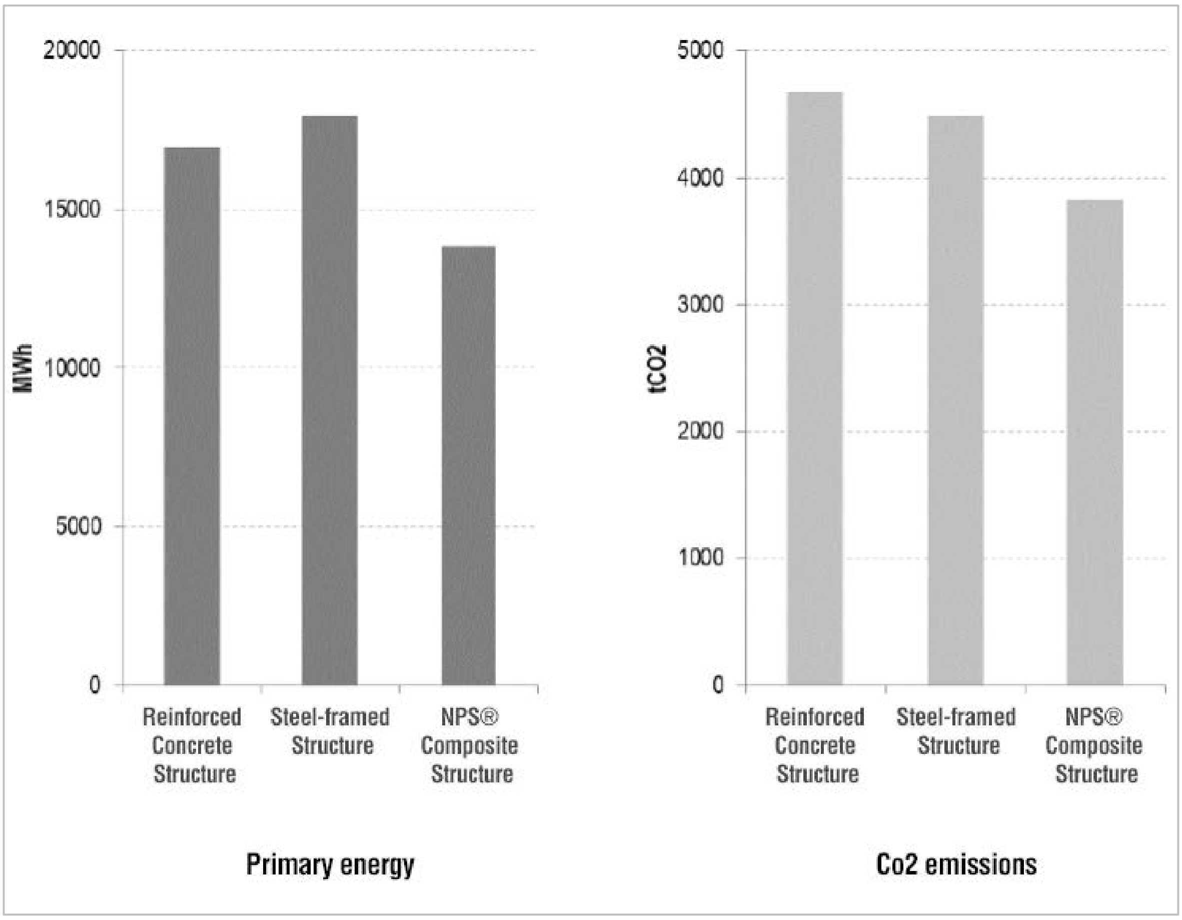

Figure 4. Results of the LCA for the multi-storey building.

4. Bibliography

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