STRUCTURAL AND ENVIRONMENTAL ANALYSIS OF REINFORCED CONCRETE STRUCTURE

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Abstract. Large amounts of energy and resources are consumed in construction industry and have great impact on environment. Current studies suggest that total CO_2 emissions due to the construction sector account for 8% of the global total emissions. Several studies have therefore investigated the environmental comparability of structures according to the material used. For instance, in some cases there is evidence of a 17.47% increase in CO_2 emissions between alternatives for the same structure. Due to generation of this data, more sustainable structures can be designed. For this purpose, several alternatives were generated by modifying structural parameters such as floor slab typology, distance between pillars, material of the vaults in a specific case of study. The methodology used was through the specific structural calculation program such as CYPE, in which reinforced concrete and metallic structures can be modelled. Subsequently, environmental studies were obtained from the various alternatives generated through the life cycle analysis (LCA) of each alternative. The field of study of LCA was from the production of the necessary elements to their implementation in the structure. In this way, it is possible to give the project a more global image of the impacts it generates, not only in economic but also in environmental terms. Some of the results obtained show that the use of a type of floor slab with certain characteristics compared to another type of floor slab represents an increase of approximately 17% in the kg of CO_2 equivalent emitted. Emissions are also influenced by the use of the vault material. On average, the expanded polystyrene vaults reduce CO_2 emissions by 5.31%, as the loads to be transmitted are reduced because the use of lightweight vaults means less load on other structural elements and therefore less use of concrete. As a result, alternatives with more environmentally friendly characteristics are obtained and more sustainable buildings are designed.

Keywords: reinforced concrete, one-way slab, lattice joists, in-situ joists, structural alternatives.

Introduction

As it is well known, the construction industry is an activity in which large amounts of energy and resources are consumed. Linked to this is to say that it is an activity that generates huge impacts on the environment, such as the consumption of raw materials, waste generation, drinking water consumption or greenhouse gases [1-3]. Therefore, there are already existing regulations which require or reflect the existence of a sustainability appendix in the project [4]. As a result, the need arises to apply an environmental analysis methodology such as the life cycle analysis (LCA) [5; 6], used in civil engineering projects as structures for hydroelectric power plants [7], railway installations [8], waste water treatment plants [9; 10] etc.

For all these reasons, this research aims to provide an environmental comparison of developed structural alternatives through LCA of these alternatives.

Materials and methods

Location and general description of the building

The location of the building is in the municipality of Logroño, in the north of Spain. Therefore, the definition of the design loads as well as the restrictions that can be applied to the structure must comply with Spanish regulations. The building is an office block with a width of 11 m and a length of 24 m, giving a floor area of 264 m^2. The building is configured on four floors where the offices, bathrooms, lift, stairs etc. are located. In addition, there is an underground garage at a level of -3 m, which requires the creation of underground walls. The height of each floor is 3.5 m, so the total height of the building is 10.5 m from the ground level.

Structural elements

The following is a brief description of the configuration of the various structural elements that make up the building. Steel bars type B500S and reinforced concrete type HA-25/B/20IIa have been used.

Walls

Two types of walls can be distinguished in the modelled building. The first is the underground wall that forms the garage. This wall is made of 30cm thick reinforced concrete. Its foundations are of the

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strip footing type. It has a flight and edge of 50 cm. The interior wall of the building corresponds to the lift shaft. This wall has been designed for the width of 20 cm thick, and its foundation is a strip footing with a width of 20cm and a depth of 50 cm.

Foundation

The configuration of the foundation used is by means of isolated footings joined by square section (40x50cm) centring beams, this is configured for the internal pillars of the building. The dimensions of the footings as shown in Table 1 vary according to their location.

Table 1

Dimensions of the footings

Type	Length, m	Width, m	Edge, m
1	2.50	2.50	0.55
2	1.90	1.90	0.50
3	2.30	2.30	0.50
4	2.70	2.70	0.60

Floor slab

For this structural element, three types of floor slab typologies have been chosen in order to carry out an analysis of various alternatives (Table 2). In addition, for each type of floor slab, the material of the vault varies. In some cases, it is concrete vault and in others expanded polystyrene. Some data are fixed, such as the floor slab edge of 30 cm, made up of 25 cm of vault edge and 5cm of the compression layer.

Table 2

Characteristics of floor slab alternatives

Type of floor slab	Type of concrete	Strength, MPa
Lattice joists	HA-25	25
Pretensioned joists	HA-35	35
In situ joists	HA-25	25

Beams

As for the beams that join the pillars, two types of typologies have been established, the first using flat beams of different dimensions (from 20x30 cm to 70x30 cm), and in some specific cases, we have opted for beams that hang down (greater moments of inertia) and, as before, they range from various dimensions (from 20x50 cm to 70x40 cm).

Pillars

The total number of pillars of the building is a function of the various proposed distance (Table 3) between them. They all start at the foundation and reach the roof height (10.5 m). The configuration of the columns is rectangular, 30x30 cm.

Table 3

Number of pillars of the structure as a function of distance

Distance between pillars, m	No of pillars	Strength of concrete pillars, MPa
4	21	25
6	15	25
8	12	25

Once the configuration of the structural elements has been explained, a series of alternatives are studied, in which each alternative will depend on the distance between the pillars, the type of floor slab and the type of vault used. A total of 18 alternatives were generated.

Of all the existing impacts, only the so-called Global Warming Potential (GWP) impact will be analysed, as it is the most representative for the construction industry. Its unit is kg of CO_2 equivalent. Fig.1 shows a 3D representation of the building modelled in the CYPE structural calculation program.

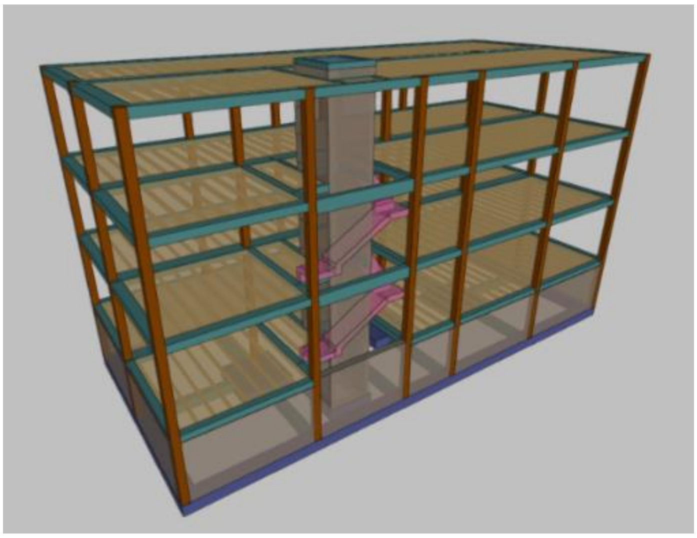

Fig. 1. **3D representation of the structure**

Results and discussion

It should be noted that all the generated alternatives meet the level of resilience, so all of them could be feasible. Fig. 2. Fig. 3. show the kg of CO_2 equivalents for the alternatives generated.

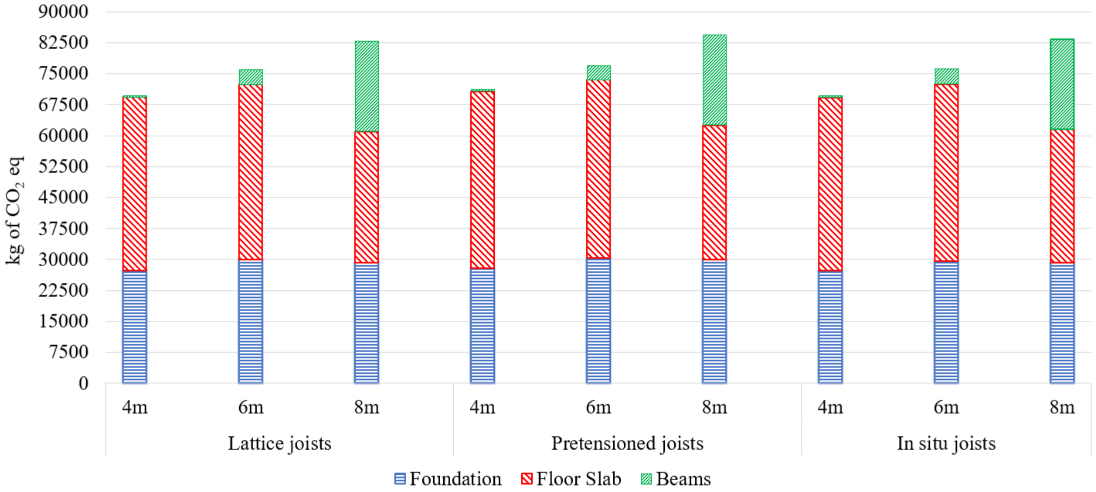

Fig. 2. **Graph of the kg CO_2-equivalents – concrete vaults**

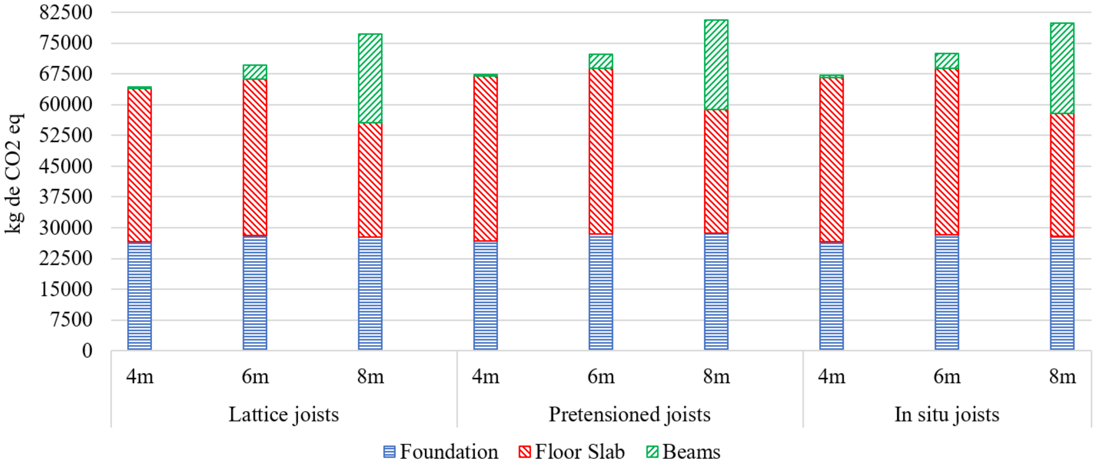

Fig. 3. **Graph of the kg CO_2-equivalents – expanded polystyrene vaults**

As it can be seen, the kg of CO_2 equivalents increase as the distance between pillars increases, this is due to the fact that larger distances between pillars mean larger dimensions of the structural elements (beams, foundations and floor slabs), and therefore a higher cost of the materials used (concrete and steel), which leads to increase in GWP derived from the manufacturing process and the transport of these materials.

This can be seen, for example, in the case of the reinforced concrete joist slab alternative with expanded polystyrene vault, where for a pillar distance of 8m with respect to a distance of 4 m the CO_2 equivalent emissions are increased by 16.71%, which translates into approximately 12,911.16 kg of CO_2.

Table 4 shows the values of increase of kg of CO_2 when using the concrete vault with respect to the expanded polystyrene vault.

Table 4

Number of pillars of the structure as a function of distance

Type of floor slab	Distance pillars, m	Increased kg of CO_2, %
Lattice joists	4	7.57
	6	8.31
	8	6.65
Pretensioned joists	4	5.47
	6	6.00
	8	4.46
In situ joists	4	3.80
	6	4.72
	8	4.32

As it can be seen, the alternatives that use expanded polystyrene vaults on average reduce their CO_2 emissions by a total of 5.31%. The justification for this reduction is due to the fact that being a lighter element than a concrete vault means that the loads to be transmitted to the foundations and pillars are lower, which consequently means a reduction in the dimensions of the same and therefore of the material associated with each structural element.

Conclusions

The results show that the choice of one alternative or another depends on many factors, such as geometry, type of technology used and materials. However, despite the fact that all the alternatives studied are viable in their execution, some produce greater environmental impacts than others. For instance:

1. As the distance between columns increases, the total CO_2 emissions increase. The pretensioned joists slab has the highest environmental impact. For both concrete and polystyrene vault alternatives.
2. For instance, for a lattice joists slab using expanded polystyrene vaults. There is an increase in CO_2 emissions of 16.71%, which means that 12,911.16 kg of CO_2 are emitted more. Due to the increase in the distance from 4 m to 8 m.
3. It is shown that the use of polystyrene vaults results in a slight increase in impacts compared to concrete vaults of 0.543%. An almost negligible value.

With all this, LCA can give a more global picture of the impact of the structure and create a new decisive item such as environmental impact when choosing an alternative for the project.

Author contributions

Conceptualization, J.L.S.; methodology, J.L.S and E.F.; software, J.L.S; validation, E.F. and J.F; formal analysis, E.F and J.F..; investigation, J.L.S., E.F., J.F.; data curation, J.L.S, E.F. and J.F.; writing – original draft preparation, J.L.S.; writing – review and editing, J.L.S.; E.F and J.F.; visualization, E.F., J.F.; All authors have read and agreed to the published version of the manuscript.

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