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Impactos medioambientales de diferentes tipologías de forjados
Environmental impacts of different types of floor slabs

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Resumen-- **La implementación de un sector de la construcción más sostenible es una realidad hoy en día. Para ello conocer como impactan en el medioambiente las estructuras de hormigón y acero y de forma intrínseca sus respectivos elementos estructurales que la componen como son los forjados, pilares, vigas, muros etc., resulta una estrategia efectiva para generar sostenibilidad. Esta investigación trata de obtener los impactos medioambientales de seis tipologías de forjados más comunes en edificaciones. Estas son: losa maciza, forjado de viguetas in Situ, forjado de viguetas prefabricadas de hormigón, forjado de viguetas metálicas y finalmente forjados reticulares tanto de casetón perdido como de casetón recuperable. Para abordar esta investigación se ha modelizado en CYPECAD un edificio de oficinas, donde uno de los paños ha sido sometido a estudio. Para conocer los impactos medioambientales se ha utilizado la metodología por excelencia como es el Análisis de Ciclo de Vida (ACV). Los límites del sistema seleccionados para el ACV se corresponden con un alcance de la cuna a la puerta de la edificación y los resultados obtenidos han versado sobre ocho categorías de impacto. Entre los principales resultados por unidad de superficie (m2) de forjado y para la categoría de impacto Potencial de Calentamiento Global (kg CO2 eq), resulta que la tipología de forjado de losa maciza arroja un valor de 93,01 kg CO2 eq/m2, lo que supone un incremento de las emisiones de hasta un 51,68% con respecto a la tipología de forjado de viguetas de hormigón in Situ (44,94 kg CO2 eq/m2) e incluso un incremento del 53,27% con la tipología de forjado de viguetas metálicas (43,46 kg CO2 eq). Con esta investigación se ha podido obtener unos resultados que puedan extrapolarse de forma simple a otras edificaciones para determinar los impactos medioambientales.**

Palabras clave— Hormigón; Forjado; Estructura; Análisis de Ciclo de Vida; Sostenibilidad.

Abstract— **The implementation of a more sustainable construction sector is a reality today. To this end, understanding how concrete and steel structures and their respective structural elements, such as slabs, columns, beams, walls, etc., impact the environment is an effective strategy for generating sustainability. This research aims to determine the environmental impact of the six most common types of floor slabs in buildings. These types of floor slabs are: solid slabs, in-situ joist slabs, precast concrete joist slabs, metal joist slabs and, finally, both permanent and removable waffle slabs. To address this research, an office building has been modelled in CYPECAD, where one of the floors has been subjected to study. To determine the environmental impacts, the methodology par excellence, Life Cycle Assessment (LCA), was used. The system boundaries selected for the LCA correspond to a cradle-to-gate scope for the building, and the results obtained covered eight impact categories. Among the main results per unit area (m^2) of floor slab and for the Global Warming Potential impact category (kg CO_2 eq), it turns out that the concrete slab type yields a value of 93,01 kg CO_2 eq/m^2, which represents an increase in emissions of up to 51,68% compared to the in situ concrete joist slab type (44,94 kg CO_2 eq/m^2) and even an increase of 53,27% compared to the metal joist slab type (43,46 kg CO_2 eq). This research has yielded results that can be easily extrapolated to other buildings to determine their environmental impact.**

Index Terms— Concrete; Floor Slab; Structure; Life Cycle Assessment; Sustainability.

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I. INTRODUCTION

THE construction sector is currently undergoing development to become more sustainable in the near future and thus adapt to the Sustainable Development Goals (SDGs) proposed by the United Nations (Naciones Unidas, 2024). In particular, the construction sector would fit in with goals *Nº. 9 Industry, Innovation and Infrastructure, Nº. 11 Sustainable Cities and Communities, and Nº. 12 Responsible Production and Consumption.*

It is well known that concrete and steel buildings have a significant environmental impact, justified by the fact that producing and using these materials has a negative impact on the environment. For instance, the production of 1 tonne of cement, which is used for multiple applications in the construction sector, emits between 0.62 and 0.72 tonnes of CO_2 eq (Colangelo et al., 2018), which means that globally between 8% and 9% of global CO_2 eq emissions correspond to this sector (Feiz et al., 2015).

Consequently, the new structural regulations require certain sustainability criteria to be met in new building projects. An example of this is the new Spanish structural code (Ministerio de Transportes, 2023), which establishes the definition of a structure's contribution index to sustainability.

One of the most used methodologies for determining environmental impacts is *Life Cycle Assessment* (*LCA*). This methodology makes it possible to obtain the respective impacts on the environment and human beings of a product, service or organisation. The guidelines that define the application of LCA are UNE-EN ISO 14040 (UNE-EN ISO 14040, 2006) and UNE-EN ISO 14044 (UNE-EN ISO 14044, 2006). There are also other complementary standards for the specific application of LCA to buildings, such as UNE-EN ISO 15643 (UNE-EN ISO 15643, 2021).

Consequently, previous research such as that by Ferreiro et al., has been applied to the field of research, optimizing the CO_2 eq emissions associated with the configuration of concrete and steel reinforcement for a structural element such as the pillars of a residential building (Fraile-Garcia et al., 2019). Along the same lines, Los Santos-Ortega et al., applied the LCA methodology to determine the most sustainable solution for a hydroelectric power plant building using a reinforced concrete or steel structure configuration (J.Los-Santos-Ortega et al., 2022).

Therefore, given the current background and the significant benefits being generated, there is a clear need for this research. This research aims to generate knowledge about the environmental impacts associated with the most common types of floor slabs used in both residential and industrial buildings. The objective is to understand which of the various types evaluated is the most sustainable alternative and, based on this, to generate results per unit of surface area, such as square metres of floor slab. This will enable designers to extrapolate the results to any other project outside the scope of the research and to make a preliminary and simple assessment of the corresponding environmental impacts on this structural element.

II. METODHOLOGY

These consecutive sections describe and explain the methodology used to obtain environmental results based on the different types of floor slabs most used in buildings today. First, the case study of the building and its respective characteristics and design parameters are explained. Subsequently, the methodology for obtaining environmental impacts, such as *Life Cycle Assessment* (*LCA*), is defined.

III. CASE OF STUDY

The building on which the various types of floor slabs are to be studied is a reinforced concrete structure corresponding to a tertiary building type, i.e. a conventional office building. The layout of the building was kept as simple as possible, as the main objective of the research is not the design of an office building but rather an environmental comparison between different types of floor slabs. The building has a length of 20 m and a width of 9 m, giving a floor area of 180 m^2. The building has a total of two floors, a ground floor and a first floor, with a clear height between floors of 3 m. Access between floors has been modelled using a lift or a conventional reinforced concrete staircase (see Fig.1). The modelling and calculation of the structure was carried out using CYPECAD structural calculation software (CYPE Ingenieros, 2025).

A. *Structural Elements Common to Design*

This section describes the structural elements that will be common to all the alternatives designed, i.e. the pillars, beams, roof and foundations. Firstly, it is defined that all structural elements are composed of the same material, HA-25 reinforced concrete, i.e. it has a characteristic compressive strength (f_{ck}) at 28 days of 25 MPa. The reinforcing steel is of the B500S type (B: corrugated steel bar; 500: elastic limit of steel (MPa); S: weldability of steel).

The pillars have a rectangular section measuring 40 x 40 cm, spaced 3.8 m apart on the horizontal axis and 4.3 m apart on the vertical axis. The structure has a total of 18 pillars.

The foundation consists of a 50 cm thick foundation slab, which is surrounded by foundation beams with a rectangular cross-section of 40 x 50 cm that brace the pillars of the structure.

The beams are rectangular suspended beams. Two sizes are proposed: for the first-floor slab, these suspended beams have dimensions of 40 x 30 cm, and for the roof slab, they are 40 x 20 cm.

In the case of the roof corresponding to the second-floor slab, which is common to all alternatives, it is modelled using a solid floor slab with a thickness of 20 cm.

The lift wall surrounds an area of 2.25 m² (lift shaft) using a 30 cm thick reinforced concrete wall. This starts from the foundation level and protrudes 1.5 m above the roof slab level (a higher height is simulated where the lift's own hoist machinery is usually installed) (see Fig.1).

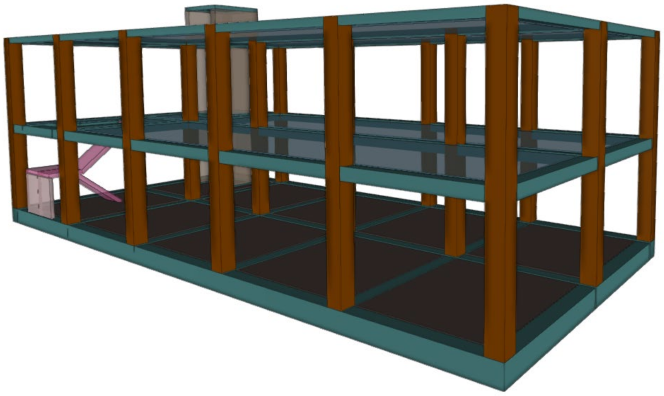

Fig. 1. 3D representation of the reinforced concrete structure under investigation.

Before explaining the various alternatives for the floor slab that will be studied, the loads acting on the building must be considered. To do this, the Structural Code for reinforced concrete buildings in Spain (Ministerio de Transportes, 2023) is used. The first of these loads is wind. For this purpose, the building is designed to be in an environment with a roughness rating of Type IV (urban, industrial or forest area), as well as a wind zone of Type B (basic wind speed: 27 m/s), corresponding to the town of Logroño (La Rioja). The following types of loads to be defined correspond to the categories of use of the building. Considering the objective of the research study and the fact that it is a tertiary office building. A Use Category B (Administrative Areas) is defined for both the ground floor and the first floor.

In the case of the roof slab, the defined use category is type G1 (Roofs accessible only for maintenance. Not concomitant with the rest of the variable actions). Finally, two types of surface loads are defined for the floor slabs: a load (Q) and a dead load (CM), both with the same value of 2.5 kN/m^2, representing the partition walls and office furniture present on the floor slabs. Finally, for the slabs to be analysed, an exposure class XC1 is defined, justified because the reinforced concrete of the slab is in enclosed spaces with low air humidity (RH<65%) as defined by the Structural Code (Ministerio de Transportes, 2023).

B. Floor slabs alternatives

After discussing the structural elements that are common to all study alternatives, this section describes which floor slab alternatives have been modelled. The first step is to identify which of the floor slabs available in the structure will be analysed, which turns out to be the first-floor slab. It is divided into two very different areas (see Fig. 2), the first corresponding to the section on the left where the staircase landing and the lift wall are located. This slab section remains constant in all alternatives with a 30 cm thick solid slab configuration. The rest of the slab will be where the various slab alternatives are modelled. This results in a net surface area of 120.12 m².

Although the different slab alternatives (see Table I) vary in terms of their intrinsic structural configuration, it has been decided to make them all uniform so that they adopt common design parameters. For example, the total thickness of the slab in all alternatives is set at 30 cm. In those alternatives that use hollow blocks, these will always have a height of 25 cm, and the distance between the centre lines of the slab ribs will always be 72 cm, with a joist rib width of 12 cm, always leaving a 5 cm compression layer.

TABLE I
FLOOR SLAB ALTERNATIVES EVALUATED IN THE RESEARCH

Nº	Denomination	Principal characteristics
1	Solid floor slab	30 cm thick
2	Prefabricated concrete joist floor slab	25 cm hollow brick + 5 cm compression layer
3	In-situ concrete joist floor slab	
4	Metal joist floor slab	The joist is an IPE 80 (S235) profile
5	Lost formwork reticular slab	25 cm formwork + 5 cm compression layer
6	Recoverable reticular formwork	

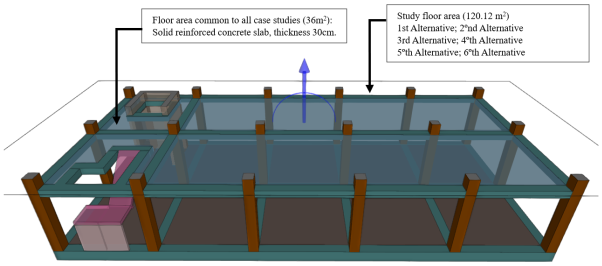

Fig. 1. 3D representation of the floor slab studied in the research.

IV. LIFE CYCLE ASSESSMENT

The UNE–EN ISO–14040 (UNE-EN ISO 14040, 2006) and UNE–EN ISO–14044 (UNE-EN ISO 14044, 2006) establish the methodology to be applied when performing a *Life Cycle Assessment* (*LCA*) of a product/service/organisation.

A. Objective, Scope and Functional Unit

The main objective of this LCA is to determine the environmental impacts resulting from the use of various types of slabs available for reinforced concrete buildings. Therefore, the scope of the system will be from cradle to gate. For this reason, the functional unit is defined as the execution of 120.12 m^2 of floor slab in a tertiary building, this being the area available for the study of the various types of floor slabs.

B. System Boundary of LCA

Sustainability in building and the application of the LCA methodology is carried out in accordance with UNE-EN 1564 – '*Sustainability in construction. Framework for the assessment of buildings and civil engineering works*' (UNE-EN 1564, 2021). According to this standard, the study of a building can be divided into a series of phases based on its life cycle. In the specific case of this research, and according to the scope and objective set out, only the production phases (A1-A3) and construction of the different floor slabs (A4-A5) are studied (see Table II). It is justified that the rest of the subsequent phases, such as use and maintenance, as well as the end of the building's life, do not present any differences in environmental terms.

TABLE II
STUDY PHASES AND PROCESSES APPLIED TO A BUILDING IN ACCORDANCE WITH UNE-EN-1564.

Phase	Process	Included in the LCA
Production	A1: Supply of raw materials	✓
	A2: Transport to the factory	✓
	A3: Manufacturing	✓
Construction	A4: Product transport	✓
	A5: Construction and Installation process	✓
Use Maintenance	B1: Use	✗
	B2: Maintenance	✗
	B3: Repair	✗
	B4: Replacement	✗
	B5: Refurbishment	✗
	B6: Energy use in service	✗
	B7: Water use in service	✗
End of Life	C1: Deconstruction and Demolition	✗
	C2: Transport	✗
	C3: Waste Treatment	✗
	C4: Landfill	✗

C. Life Cycle Inventory (LCI)

The LCI refers to the compilation of all the elementary flows that participate in the various unitary processes that give rise to the functional unit and which, as a result, are defined within the limits of the system under study.

The definition of this LCI is imposed by the CYPECAD design programme itself, which determines the respective quantities of materials such as concrete, reinforcing steel, etc., based on the structure's design, and to which a manufacturing process, transport, etc. are associated. In other words, the programme has its own unit processes that define each material used in the structure. However, Table III shows the main quantities of concrete (m^3) and steel reinforcement (kg) obtained for each floor slab alternative, which will determine the difference in environmental impact between floor slab alternatives.

D. Life Cycle Impact Assessment (LCIA)

Before explaining the results, the classification and characterisation phases of the various material, energy and resource flows identified in the LCI must be defined. This is to transform these quantities into environmental impact values in their corresponding impact categories. In its LCIA results, CYPE offers a total of eight impact indicators or impact categories, which are defined in Table IV, along with their respective acronyms.

TABLE III
MAIN QUANTITIES OF CONCRETE AND STEEL REINFORCEMENT BY FLOOR SLAB ALTERNATIVE

Nº	Concrete (m^3)	Reinforcement Steel (kg)	IPE 80 Rolled Steel (kg)	Abacus reinforcement (kg)
1	36,04	2.427	-	-
2	12,68	156	-	-
3	12,60	425	-	-
4	11,93	-	3.104	-
5	23,55	753	-	358
6	22,68	782	-	282

V. RESULTS AND DISCUSSION

Although all the results are presented in the impact categories assessed in TABLE 4, special attention is paid to certain specific impact categories, such as *Global Warming Potential (GWP)* and *Abiotic Depletion Potential for Fossil Resources (ADPE)*, because these impact indicators are the best known and most widely interpreted by society as a whole (Los Santos - Ortega et al., 2023). They are also very present in previous research related to the field of study (Fraile-García et al., 2015; Fraile-Garcia et al., 2019; J.Los-Santos-Ortega et al., 2022; Santos-Ortega et al., 2024). These results are plotted individually in Fig.3 and Fig.4. For the rest of the results based on the impact category, the results are combined in Fig.5.

As can be seen in Fig.3, the x-axis shows the various alternatives for floor types evaluated in the research, and the y-axis on the left shows their correspondence with the total kg of CO_2 eq for the surface area of the floor slab analysed (120.12 m^2). On the other hand, the right-hand y-axis shows a very interesting result because it expresses the kg CO_2 eq per unit of surface area, in this case the square metre of floor slab (m^2). This result can be directly extrapolated to other building projects, where CO_2 emissions can be estimated directly and quickly as a result of using one type of slab or another with similar characteristics.

The first observation in Fig.3, which can be extrapolated to the rest of the impact indicators and is independent of the type of floor slab, corresponds to the question of where the greatest environmental impacts occur and in which phases of a building's LCA. These turn out to be in phases A1-A3, which define the production of the materials and components that make up the floor slab. Broadly speaking, this includes emissions associated with the production of concrete and steel reinforcement, which, in percentage terms, accounts for more than 97% of the impact, with the remaining 3% of the impact value for phase A4 referring to the transport of materials from the place of manufacture to the construction site. The final phase, A5, covers emissions associated with the construction of

TABLE IV
CATEGORIES OF ENVIRONMENTAL IMPACT AND RESOURCE USE USED IN THE RESEARCH

Environmental Impact Category	Unit
Global Warming Potential (GWP)	kg CO_2 eq
Stratospheric Ozone Depletion Potential (ODP)	kg CFC-11 eq
Soil and Water Resource Acidification Potential (AP)	kg SO_2 eq
Eutrophication Potential (EP)	kg $(PO_4)^{3-}$
Tropospheric Ozone Formation Potential (POCP)	kg Ethylene
Abiotic Resource Depletion Potential for Non-Fossil Resources (ADPE)	kg Sb eq
Abiotic Resource Depletion Potential for Fossil Resources (ADFP)	MJ
Total Renewable Primary Energy Use (PERT)	MJ
Total Non-Renewable Primary Energy Use (PERNRT)	MJ
Net Freshwater Resource Use (FW)	MJ

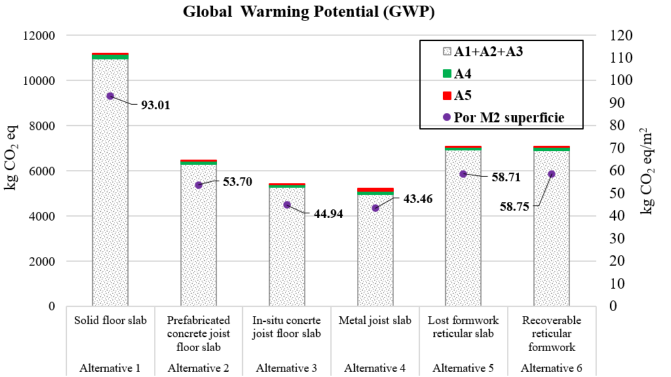

Fig. 2. Environmental results for the Global Warming Potential (GWP) impact category for the various floor slab alternatives.

this type of slab, such as concrete pouring activities on site (pumping, vibrating, lifting materials, placing, etc.).

Regarding this first interpretation, it should be noted that, if an attempt is made to improve the sustainability of these structural elements, these actions should focus on the early stages of manufacturing, as these have the greatest impact on the environment. Consequently, the effectiveness of implementing a sustainability improvement would be significantly reflected in these early stages (A1-A3).

Once an initial analysis has been carried out to determine the stages of construction in which the environmental impacts are most significant, the respective environmental impacts of the various types of floor slabs are then discussed, both for the *Global Warming Potential (GWP)* impact category (Fig.3) and the *Abiotic Depletion Potential of Fossil Resources (ADPE)* impact category (Fig.4).

As can be clearly seen, the highest CO_2 emissions occur in alternative Nº1 (solid floor slab) with a total emission value of 11.16 tCO_2 eq, which is equivalent to a surface emission factor of 93.01 kg CO_2 eq/m^2. The justification lies in the quantities associated with this slab alternative (see TABLE 3). As can be seen, the solid floor slab is a type of slab where lightening elements such as hollow blocks, coffers or joists are non-existent. The absence of these materials is compensated for by greater quantities of steel and concrete. The manufacture and preparation of 1m^3 concrete is associated with CO_2 eq emissions that usually range between 173-400 kg CO_2 eq, depending on the type of concrete used (properties of the cement used, its characteristic strength, etc.) (Kurda et al., 2018). These CO_2 eq emissions per m^3 of concrete are significantly higher than those that can be generated for a prefabricated element such as a prefabricated concrete block or joist (Madrid et al., 2022). Consequently, the greater the amount of fresh concrete and steel reinforcement used, the greater the environmental impact.

After alternative Nº1 (solid floor slab), the following types of flooring with the greatest environmental impact in terms of *Global Warming Potential* (*GWP*) are lost formwork grid flooring (58.75 kg CO_2 eq/m^2) and recoverable formwork grid flooring (58.71 kg CO_2 eq/m^2), which have practically the same CO_2 eq emissions values. The reason why these floor slab alternatives rank second is that, although the reduction in concrete use is noticeable (see TABLE 3) with a decrease in cubic metres of concrete of 37.07% (-13.36 m^3). The amount of steel reinforcement is quite high, justified because in reticular floor slabs it is necessary to create abacuses with the joints with the pillars to avoid punching failure. Therefore, as shown in TABLE 3, although the amount of steel reinforcement bars for the composite floor slab is 753 and 782 kg respectively, an extra amount must be added for the reinforcement of the abacuses, 358 and 282 kg respectively, resulting in an increase in environmental impact.

Finally, the alternatives corresponding to the types of prefabricated concrete joist slabs (53.70 kg CO_2 eq/m^2) and In Situ slabs (44.94 kg CO_2 eq/m^2) rank third and fourth respectively. Once again, there is a decrease in the amount of concrete to be used compared to the solid slab alternative (-23.36 m^3), and the same is true for the reinforcement of the floor slab. Logically, the amount of steel bars for the prefabricated joist slab is the lowest of all the alternatives studied (156 kg), while the in-situ joist slab requires 425 kg.

The difference lies in the fact that the reinforcement of prefabricated joists is not considered, whereas when done on site, this reinforcement must be in place to form the joist legs. Despite this increase in the amount of steel used, CO_2 eq emissions are slightly lower than for prefabricated joists. This difference can be justified mainly by the A4 transport process corresponding to prefabricated joists. Unlike in situ slabs, both the ready-mixed concrete and the steel reinforcement must travel the same distance, normally about 60 km (Mel Fraga et al., 2014). However, when adding the constraint of a prefabricated element such as a joist, its respective transport process must be taken into account and added to this type of slab, resulting in an increase in CO_2 eq emissions and continuously higher energy consumption in subsequent phases such as installation and commissioning (A5).

If we analyse this fact and the environmental impacts associated with the unitary process of constructing 1 m² of solid floor slab and 1 m² of metal joist floor slab with the characteristics set out in TABLE 3. And according to the unit processes and material flows used, as reflected by CYPE (CYPE Ingenieros, 2025), which are broken down in TABLE 5, the difference found can be determined. Firstly, it should be noted that there are materials whose contribution to the environmental impact is minimal (resin, solvent, paper, cardboard, plastic), and that if cut-off rules for contribution to the environmental indicator were applied, they could be eliminated. It is established that the differences recorded are based on the amount of steel and concrete. As for steel, its emission factor is 0.53 kg CO_2 eq per kg of steel, and in the case of the CYPE solid floor slab, it establishes a total requirement per square metre of 21.348 kg, whereas for the metal joist floor slab, the established amount is 13.317 kg. Here we see an initial difference, although not a very significant one, as it only amounts to an increase of 4.715 kg CO_2 eq/m^2. Where we really see notable differences and their respective transfer to environmental impacts is in the concrete material. According to TABLE 5, concrete accounts for 738.68 kg/m² in solid slabs and only 187.6 kg/m² in joist slabs, representing an increase of approximately 74.6%. Considering that the emission factor for

HA-25 concrete is 0.1 kg CO_2/kg concrete, the difference between the two types of floor slabs is determined to be 55.108 kg CO_2/m^2 associated solely with the concrete material. However, in metal joist slabs there are lightweight vaulting elements (referred to in TABLE 5 as *Precast Concrete*). The emission factor assessed by CYPE for hollow blocks is 0.08 kg CO_2 eq/kg precast concrete, i.e. 20% lower than that of in-situ concrete. Therefore, it can also be concluded that the use of precast elements, despite the added transport process, helps to improve the sustainability of floor slabs. In conclusion, it can be concluded that the environmental benefit of metal joist slabs lies largely in the fact that the quantities of in-situ concrete used are very small.

TABLE V
ENVIRONMENTAL IMPACTS FOR THE POTENTIAL GLOBAL WARMING CATEGORY (GWP) PER SQUARE METRE OF SOLID FLOOR SLAB AND METAL JOISTER FLOOR SLAB.

Material	**Quantity solid floor slab (kg)**	**Solid floor slab kg CO_2 eq**	**Quantity metal joist floor slab (kg)**	**Metal joist floor slab kg CO_2 eq**
Wood	0,702	-1,306	0,057	-0,106
Steel	21,348	11,328	13,317	6,613
Resin	0,024	0,079	-	-
Solvent	0,004	0,058	-	-
Plastic	0,033	0,158	0,030	0,144
Galvanised steel	0,252	0,645	0,018	0,046
Concrete	738,675	73,868	187,6	18,760
Precast concrete	-	-	120	9,60
Paper, cardboard	0,216	0,188	-	-
Total		**85,016**		**35,058**

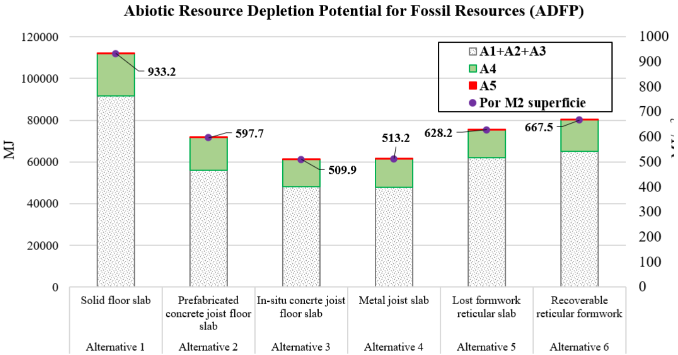

Fig. 3. Environmental results for the impact category Potential Depletion of Abiotic Resources for Fossil Fuels.

Firstly, it should be noted that the same trend recorded and explained in the results for the *Global Warming Potential* (*GWP*) category is applicable to the *Abiotic Depletion Potential for Fossil Resources* (*ADFP*) impact category, where, if the results are expressed by surface area factor, the decreasing order of impact is: Solid Slab (933.2 MJ/m²) > Recoverable Lattice Slab (667.5 MJ/m²) > Non-Recoverable Lattice Slab (628.2 MJ/m²) > Precast Concrete Joist Slab (597.7 MJ/m^2) > Metal Joist Slab (513.2 MJ/m^2) > In-situ Concrete Joist Slab (509.9 MJ/m^2).

However, unlike in the past, where the greatest environmental impacts came from the material manufacturing phase (A1-A3), with virtually no impact from subsequent phases (A4-A5), here they can be observed and contribute more significantly to the impact indicator. An example of this is the alternative of prefabricated concrete joist slabs, where 21.95% of the energy (MJ) is associated with the transport process, while for the rest of the alternatives this contributes around 18.24% on average.

The internal combustion process is carried out by combustion in an internal combustion engine that consumes traditional fuels such as diesel or petrol. This combustion process generates elements such as NO_X, CO_X, water vapour and suspended particles. All these chemical components affect impact categories directly related to the atmosphere, such as *Potential Tropospheric Ozone Formation, Potential Stratospheric Ozone Depletion, Potential Eutrophication, and Potential Acidification of Soil and Water Resources* (see Fig.5).

Finally, another highly valued resource whose efficient use and exploitation is booming in the construction sector is water. This resource has a direct impact on the impact category *Net Freshwater Use* (*FW*), as can be seen in Fig.5. Regarding this impact category, it is worth noting that in other impact categories previously explained, the impact of water use in phase A5 (construction) was not visible.

The justification lies in the fact that LCA modelling, and more specifically ICV modelling, takes into account the amount of water used in the curing and setting process of the concrete used to create the slab, which has an even greater impact than phase A4 (transport). Subsequently, the greatest impact occurs in the primary phases (A1-A3), where the creation of the concrete mix consumes around 150 litres of water per m^3. In addition, the production of aggregates (coarse and fine) in mining operations involves high water consumption in internal washing, sieving and screening operations, as well as the watering of tracks in gravel pits and quarries to prevent the emission of dust and particles into the atmosphere. Therefore, in those flooring alternatives where larger quantities of concrete are used, a higher impact indicator is obtained in the category of *Net Use of Freshwater Resources* (*FW*). Following this, it is important to highlight that water consumption is quite high in the construction sector.

VI. CONCLUSIONS

The main conclusions drawn from the research are discussed below. The first of these is that, regardless of the type of floor slab, those that use more concrete and steel reinforcement have a greater overall environmental impact. This is justified because the environmental impact associated with prefabricated elements such as hollow blocks or joists is lower in terms of their manufacture. However, there may be opposite cases, such as that of prefabricated concrete joist slabs and in situ joists.

It is also evident that the initial phases of executing the structure corresponding to the manufacturing processes of the materials (A1-A3) that make up the structure are critical areas, as these phases are identified as having the greatest impact on the indicators, with the subsequent phases of installation and placement (A4-A5) having a minimal impact.

Of the six types of floor slabs evaluated in the research and for almost all the impact categories taken into account, it can be

Fig. 4. Environmental results for the various slab alternatives in the rest of the impact categories.

observed that, from highest to lowest sustainability, the types would be solid slab, recoverable coffered grid slab, lost coffered grid slab, prefabricated joist slab, metal joist slab and in situ joist slab.

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