02-006 – Simplified comparative analysis of structural sustainability: equivalent CO_2 emissions and investment costs in industrial buildings with different materials – Análisis comparativo simplificado de sostenibilidad estructural: emisiones equivalentes de CO_2 y costes de inversión en naves industriales con distintos materiales

Romero Mera, Francisco[1]; *De La Cruz López, M. Pilar*[2]; *Cartelle Barros, Juan José*[3]; *Del Caño Gochi, Alfredo*[4]

(1) Universidade da Coruña, Escuela Politécnica de Ingeniería de Ferrol, (2) Universidade da Coruña, Escuela Politécnica de Ingeniería de Ferrol, Departamento de Ingeniería Civil, Campus Industrial de Ferrol, (3) Universidade da Coruña, Escuela Politécnica de Ingeniería de Ferrol, Departamento de Ciencias de la Navegación e Ingeniería Marina, CITENI - Campus Industrial de Ferrol, (4) Universidade da Coruña, Escuela Politécnica de Ingeniería de Ferrol, Departamento de Ingeniería Civil, Centro de Innovación Tecnológica en Edificación e Ing. Civil – CITEEC

English Spanish

Nowadays, sustainability is a fundamental topic in structural engineering. This paper presents a comparative study of five open-plan industrial buildings, designed according to Spanish standards, located in Ferrol (Spain), with common dimensions: 20 m of structural span, 7 m of column height, 6 m of separation between frames and 42 m length. The buildings analyzed are designed with different types and structural materials: steel rigid portal frames with hot-rolled profiles, and with welded sections of variable height; steel rigid portal frames with trussed girders; precast concrete frames with prestressed delta beams; and triple-hinged glulam portal frames. The study also includes the auxiliary structure (purlins and side rails), bracing and foundations. Estimates of equivalent CO_2 emissions and investment costs for each solution are compared, providing an analysis that allows identifying the most sustainable options from a simplified environmental and economic perspective, taking into account the two indicators referred to. This work offers practical tools, very simple to use, as an aid in decision making in the design of industrial building structures, contributing to the debate on the optimization of resources in structural engineering.

Keywords: *Structural engineering; Sustainability; Industrial buildings; Steel; Concrete; Glulam*

Actualmente la sostenibilidad es un eje fundamental en la ingeniería estructural. Esta ponencia presenta un estudio comparativo de cinco naves industriales diáfanas, diseñadas y calculadas según normativa española, ubicadas en Ferrol, con dimensiones comunes: 20 m de luz estructural, 7 m de altura en pilares, 6 m de separación entre pórticos y 42 m de longitud. Las naves analizadas se construyen con diferentes tipos y materiales estructurales: pórticos biempotrados de acero con perfiles normalizados laminados en caliente y con perfiles armados de canto variable; pórticos de acero con jácena de cubierta en celosía; entramados de hormigón prefabricado con vigas delta pretensadas; y pórticos triarticulados de madera laminada encolada. El estudio incluye también la estructura auxiliar (correas), los arriostramientos y las cimentaciones. Se comparan las estimaciones de emisiones de CO_2 equivalente y de costes de inversión de cada solución, proporcionando un análisis detallado que permite identificar las opciones más sostenibles desde una perspectiva ambiental y económica simplificada, teniendo en cuenta solamente los dos indicadores referidos. Este trabajo ofrece herramientas prácticas, muy sencillas de usar, como ayuda en la toma de decisiones en el diseño de estructuras de naves industriales, contribuyendo al debate sobre la optimización de recursos en la ingeniería estructural.

Palabras claves: *Ingeniería estructural; Sostenibilidad; Naves industriales; Acero; Hormigón; Madera laminada encolada*

1. Introduction and objectives

Human activity has transformed the planet throughout history, resulting in considerable loss of biodiversity and altering the natural functioning of ecosystems, sometimes irreversibly (Von Wehrden, 2016). This is primarily due to unsustainable growth patterns over time. The planet, its ecosystems and all living things are under threat.

Sustainable development and sustainability are concepts that have gained considerable notoriety in different industrial sectors, including construction. Currently, there is a growing awareness of the use and reuse of natural resources with a view to sustainable development in the environmental, social and economic spheres.

There are models for assessing sustainability of construction systems. Some were part of Spanish regulations that have now been repealed. This is the case of the Spanish instructions for concrete and structural steel EHE-08 and EAE (Ministerio de la Presidencia, 2008 and 2011). Others are in force, such as the sustainability annex of the current Spanish Structural Code (Ministerio de la Presidencia, 2021). Outside the regulatory environment, with a similar approach but greater academic rigour, Mel Fraga (2017) has proposed a model for sustainability assessment of concrete structures that includes durability aspects. All these models have the same problem: they do not allow for comparative analysis with structures made of other materials, such as glue-laminated timber (glulam).

To the best of our knowledge, only Hegeir et al. (2022) have attempted to address this problem by carrying out a comparative assessment of equivalent CO_2 (CO_{2-eq}) for three types of pitched roof portal frame, respectively made of steel, reinforced concrete and glulam. However:

- The steel and concrete structural types analysed by these authors are, respectively, steel portal frames with constant section bars, and cast-in-place reinforced concrete portal frames with rectangular constant section bars, in both cases with nonmoment connections to the foundations. These types are not usually employed in reality and, in any case, are rare in industrial construction.
- The structural materials used in that publication are not the usual ones (S460 steel instead of S275, and GL30c glulam instead of GL24h).
- The study does not include the auxiliary structure (purlins and side rails), nor the intermediate columns of the end portal frames. It also apparently does not include bracings and footings tie beams.

The aim of this article is to solve these problems. A case study of investment cost and global warming potential (CO_{2-eq}) benchmarking for commonly used industrial building structures is presented. Different structural types and materials are used, including main and secondary structures (purlins and side rails), bracings and foundations. A cradle-to-gate assessment is carried out with the following life cycle phases: extraction and processing of raw materials (A1), transportation of raw materials to the factory (A2), and manufacturing processes (A3).

2. Materials and methods

2.1 Case study

The case study includes five open-plan industrial buildings, located in Ferrol (La Coruña, Spain), with the following dimensions: 42 m length, 20 m frame span, 7 m of column height, pitched roof with 10% slope, and 6 m separation between portal frames. The buildings are designed with the following structural types and materials:

1. S275 steel rigid portal frames with hot-rolled sections and eaves haunch. Cold-rolled ZF (Z overlap) type purlins and side rails made of S235 steel. S275 steel bracing. As with the other options, the structural steel can come from recycling or reuse, with the exception of the purlins and side rails, which are always recycled. Foundation by means of perimeter-tied individual footings, with C30/37 concrete and B500B steel; this type of foundation is used in the rest of the alternatives. An admissible ground pressure of 2 kp/m^2 has been used in all cases. Besides that, for all the options, and for any concrete element, conventional and low-emission concrete can be used.
2. Steel tapered rigid frame portals made of double T welded section profiles with variable section height. Same type of purlins, side rails and bracing as in alternatives 1.
3. Steel rigid portal frames with Warren truss roof girder made of S275 and S355 steels, and hot-rolled columns made of S275 steel. Same type of purlins, side rails and bracing as in alternatives 1 and 2.
4. Prefabricated portal frames with pre-stressed delta beams of C50/60 concrete with Y1860 and B500B steel, supported by neoprene pads on C30/37 reinforced concrete columns with B500B steel. C45/55 concrete purlins with Y1860 steel.
5. Triple-hinged portal frames made of GL24h glulam certified by prestigious organisations such as the Forest Stewardship Council (FSC). Purlins and side rails of the same glulam material. Bracings of GL24h glulam and S275 steel.

No account is taken of the building's envelope, floor slab or building services but their loads are taken into account, being the same for al alternatives.

2.2 Structural design

The structural design has been carried out according to the relevant Spanish codes (Código Técnico de la Edificación and Código Estructural, practically the same as the Eurocodes). Several commercial design programs have been used (Cype 3D, Dlubal RFem and Civil Studio) and Excel spreadsheets of our own elaboration.

2.3 Investment costs

The information needed to estimate the direct investment costs for normal materials has been obtained from the database of CYPE Ingenieros (2025). The cost overrun for low-emission concrete structures has been estimated at 5%, according to Bostanci et al. (2018) and CYPE Ingenieros (2025). For reused steel structures, a cost overrun of 7% has been used, in agreement with Dunant et al. (2018) and Sirje-Vares et al. (2019). The percentages considered for indirect costs and profit margin are 13% and 10%, respectively, for all the structures analysed. Value added tax (VAT) is not taken into account. The economic values used here are reference estimates to date for Spain, and may vary depending on the region, the manufacturer and the fluctuations in the cost of materials.

Table 1 shows the unit prices for the foundation elements. Table 2 do the same for steel elements. Table 3 include this type of information for precast concrete elements. Finally, Table 4 shows the unit prices for glulam elements. All these data are updated as of April 2025.

Table 1: Unit prices for foundation elements.

Item	Unit price
Reinforced concrete foundation footings (C30/37; B500B)	212 €/m^3
Footings tie beam (C30/37; B500B)	220 €/m^3
Blinding concrete (HL-150)	88 €/m^3

Table 2: Unit prices for recycled and reused steel elements.

Item (all of them include painting)	Price - recycled	Price - reused
S275JR hot-rolled beams	2.27 €/kg	2.43 €/kg
S275JR beams with welded sections	2.40 €/kg	2.57 €/kg
S275JR hot-rolled columns	2.35 €/kg	2.51 €/kg
S275JR columns with welded sections	2.47 €/kg	2.64 €/kg
S275JR bracing	2.47 €/kg	2.64 €/kg
S275J0 tubular bars	2.61 €/kg	2.79 €/kg
S355J2 tubular bars	2.79 €/kg	2.99 €/kg
Average S275JR hot-rolled beams, columns & bracing	2.37 €/kg	2.53 €/kg
Average S275JR welded-section beams, columns & bracing	2.45 €/kg	2.62 €/kg
Average S275 columns and bracing for steel truss	2.48 €/kg	2.65 €/kg
ZF type S235JRC cold-rolled galvanised purlins & side rails	3.96 €/kg (only recycled)	
Column base plates	220 €/Unit	235.4 €/Unit

Table 3: Unit prices for precast conventional and low-emission concrete elements.

Item	Price - conventional	Price - low-e
60x40 cm reinforced concrete pillars	1,618 €/Unit	1,699 €/Ud
40x40 cm reinforced concrete pillars	670 €/unit	704 €/Unit
Concrete beams in end wall lintels	117 €/m	123 €/m
Pre-stressed concrete delta beams	650 €/m^3	683 €/m^3
Pre-stressed concrete tubular purlins	50 €/m	53 €/m

Table 4: Unit prices for GL24h glulam elements.

Item	Unit price
Variable-height columns with double section 140x(520-1200)	1,645.00 €/m^3
Columns with constant section 140x360	920.47 €/m^3
Columns with constant double section 140x280	1,171.43 €/m^3
140x280 section purlins	1,144.90 €/m^3
100x240 section side façade rails	1,240.42 €/m^3
100x200 section end façade rails	1,268.00 €/m^3
Variable-height beams with section 160x(520-1200)	1,760.00 €/m^3
80x80 section flange brace	1,878.13 €/m^3
140x140 section bracing elements	1,288.78 €/m^3
Beams with constant section 140x280	1,098.73 €/m^3
140 diameter spacers	1,288.78 €/m^3

2.4 CO_2 equivalent emissions

The information needed to estimate $CO_{2\text{-eq}}$ emissions covers the already alluded life cycle phases (A1 to A3), and is based on verified Environmental Product Declarations (EPDs), all based on the EN 15804:2012+A2:2020 standard.

EPDs have been obtained from different European countries. There is variability with respect to the energy mix in different nations. On the other hand, there are differences between the industrial processes of the manufacturers of a same product. For example, energy efficiency is not always the same, and sometimes there can be significant differences between companies with old and modern factories. Therefore, average data of those included in the different EPDs for the same product have been used.

As anticipated, the use of conventional and low-emission concrete has been contemplated. The latter is designed to reduce the carbon footprint associated with its production and use. This is possible, for example, by reducing the clinker content, replacing it with supplementary materials such as blast furnace slag, fly ash or pozzolans. Low-emission cements such as calcium sulphoaluminate or geopolymers ones can also be used. Finally, recycled aggregate can be employed.

For the foundations, the materials have been studied separately. For the rest of the concrete structures, specific EPDs of beams, columns and secondary elements (purlins) have been used that present a similar amount of steel as the elements of this study, as well as the same or similar types of concrete and steel.

For the steel elements, conventional steel EPDs from recycling and reused steel from the dismantling of buildings have been used. In both cases, the surface treatments of shot blasting and painting or, where appropriate, galvanising are included.

The data for beams, columns and other glulam elements include the surface treatments applied, both varnishes and pesticides.

A summary of the $CO_{2\text{-eq}}$ emission data for all materials and structural elements in this study is shown in Table 5. The corresponding EPDs have been obtained from various sources of information, mainly from the databases of EPD Norge (2024), and the Institut Bauen und Umwelt (2024).

3. Results

3.1 Design results

The design results obtained for each type of structure are shown below.

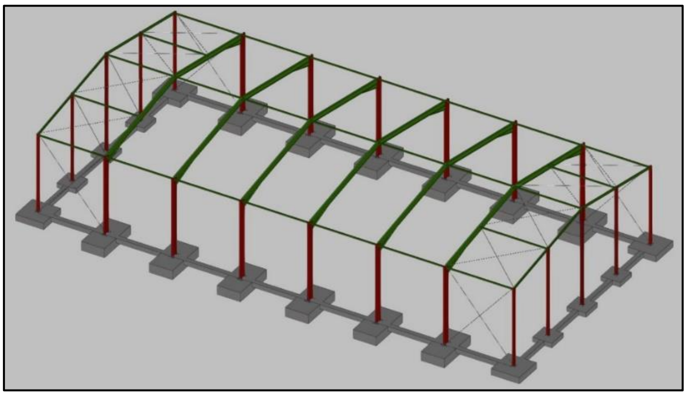
3.1.1 Steel rigid portal frames with hot-rolled sections

The steel of the main structure is S275JR. For the main rigid portal frames (Fig. 1), the calculation leads to IPE 400 rafters and IPE 450 columns. The rafters and columns of these frames have L 40x4 section flange braces to reduce the lateral buckling length. The end portal frames have HEA 180 sections for the corner columns, IPE 180 rafters, and HEA 180 and HEA 200 intermediate columns. At the ends of the roof and side facades, the building is braced with roof and wall X-bracing with S275 steel rods of circular section with diameters between 16 and 20 mm. Purlins and side rails are made of cold-rolled galvanised S235 steel, with section ZF 200x2.5 and ZF 225x2.5, respectively. The corner footings measure 250x250x55, the intermediate ones at the ends 170x170x40, and the remaining ones 205x385x80 cm. In this and the other alternatives, the foundation tie beams have a section of 40x40 cm.

Table 5: Global warming emissions in phase A1-A3 for all materials and elements employed

Material / Element	GWP-total	Unit
HL-150 blinding concrete	134.5258	kg $CO_{2\text{-eq}}/m^3$
C30/37 foundations concrete	168.2180	kg $CO_{2\text{-eq}}/m^3$
B500B foundations steel	0.5028	kg $CO_{2\text{-eq}}$/kg
S235 galvanised steel cold rolled profiles	2.2129	kg $CO_{2\text{-eq}}$/kg
GL24h and GL32h glulam beams and columns	-639.7459	kg $CO_{2\text{-eq}}/m^3$
C50/60 low-emission precast concrete delta beams (incl. steel)	154.3195	kg $CO_{2\text{-eq}}$/t
C50/60 conventional precast concrete delta beams (incl. steel)	215.9500	kg $CO_{2\text{-eq}}$/t
Conventional precast reinforced concrete column	185.4455	kg $CO_{2\text{-eq}}$/t
S275 and S355 recycled steel beams	0.9917	kg $CO_{2\text{-eq}}$/kg
S275 and S355 reused steel beams	0.0467	kg $CO_{2\text{-eq}}$/kg
Low-emission precast reinforced concrete purlins	109.0000	kg $CO_{2\text{-eq}}$/t
Conventional precast reinforced concrete purlins	208.0000	kg $CO_{2\text{-eq}}$/t
Low-emission precast reinforced concrete beams	85.5667	kg $CO_{2\text{-eq}}$/t
Conventional precast reinforced concrete beams	137.0000	Kg $CO_{2\text{-eq}}$/t

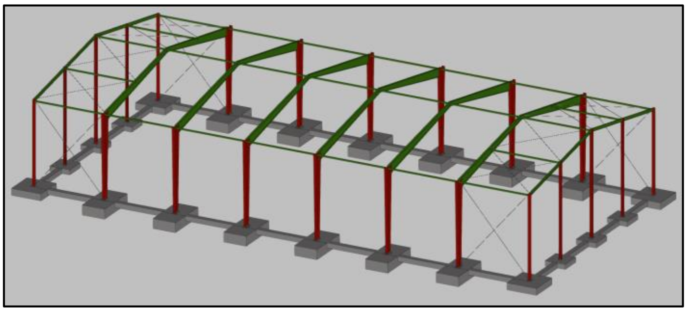
Figure 1: 3D model of the steel rigid portal frames with hot-rolled sections alternative.



3.1.2 Steel rigid tapered portal frames with welded section profiles

The steel of the main structure is again S275JR. For the main rigid portal frames (Fig. 2), the calculation leads to rafters and columns of variable height, with sections 200x10x8(H:690/300)x8x200x10 and 250x10x8(H:300/690)x8x250x10, respectively. The rafters and columns of these frames have L 40x4 flange braces to reduce the lateral buckling length. The end portal frames have HEA 180 sections for the corner columns, IPE 220 rafters, and HEA 180 and HEA 200 intermediate columns. The bracing, purlins and side rails are as in the previous option. The corner footings measure 250x250x55, the intermediate ones at the ends 170x170x40, and the remaining footings 190x365x80 cm.

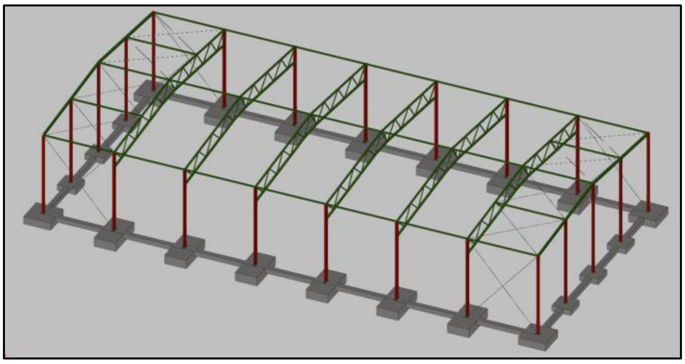
Figure 2: 3D model of the steel rigid tapered portal frames alternative.



3.1.3 Steel rigid portal frames with trussed roof girders

Now the choice is for main steel rigid portal frames, with Warren truss roof girders (Fig. 3). For these beams, the calculation leads to SHS 60x6 and SHS 70x6 tubular section profiles in S275J2 steel for the web elements; SHS 120x8 in S355J2 steel for the top chord; and RHS 150x130x8 in S355J2 steel for the bottom chord. The columns are IPE 300 in S275JR steel. The end frames, made of S275JR steel, have HEA 180 sections for all columns, with IPE 220 lintels. The bracing is similar to the one in the previous options, with 16 mm diameter steel rods. The purlins and side rails are as in the preceding alternatives. The corner footings measure 230x230x65, the intermediate ones at the end frames 160x160x50, and the remaining footings 185x340x75 cm.

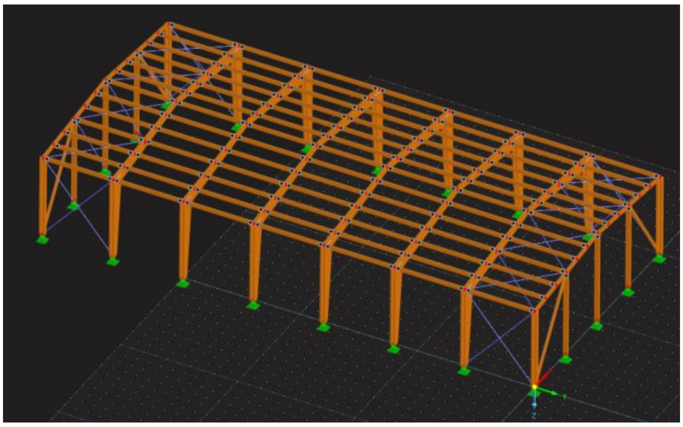
Figure 3: 3D model of the steel rigid portal frames with trussed roof girders option.



3.1.4 Triple-hinged glulam portal frames

GL24h glulam is used. For the main frames, triple-hinged portals are employed (Fig. 4), resulting in columns of variable height and double section 2xR140(520-1200), with spacers every 420 mm; the lintels are also of variable height, in this case of single section R140x(520-1200). Both the lintels and the columns of these frames have R80x80 section braces to reduce the lateral buckling length. The end portal frames have R140x360 sections for the intermediate columns and R140x280 lintels; the corner columns are of double section and constant height 2xR140x280 with spacers every 420 mm. There are R140x140 square section diagonal bracing bars, located at the final spans of the end portal frame, in its own plane. In addition, at the ends of the roof and side facades, the building is braced with roof and wall X-bracing with S275JR steel rods of circular section with 16 mm diameter. The purlins, the side façade rails and the end façade rails are R140x280, R100x240 and R100x200, respectively. The corner footings measure 200x200x85, the intermediate ones of the end frames 200x150x70, and the remaining footings 350x200x75 cm.

Figure 4: 3D model of the triple-hinged glulam portal frames alternative.

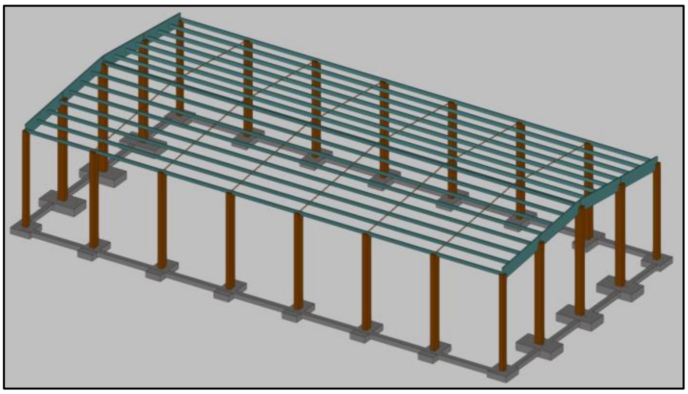


3.1.5 Precast concrete structure

The most common structural type is chosen, which results (Fig. 5; the roof delta beams are represented by wired model) in precast reinforced C30/37 concrete columns with B500B steel, with a section of 40x60 in intermediate frames, and 40x40 cm in end frames. C50/60 concrete delta beams with Y1860 and B500B steels, with a double T section and a variable height between 60 and 175 cm. C40/50 prestressed concrete end girders with Y1860 steel, and a section of 40x40 cm. And C45/55 prestressed concrete tubular purlins with Y1860 steel.

There are no side rails, because most often prefabrication companies offer a complete package, including precast concrete façades made of solid or sandwich slabs, usually laid horizontally, supported directly on the columns. The corner footings measure 170x170x50, the intermediate ones at the end walls 310x170x65, and the remaining footings 130x250x50 cm.

Figure 5: 3D model of the precast concrete structure option



3.2 Economic and environmental results: classification

The quantities of materials used in the different structural options are given in tables 6 to 10, respectively, for the steel rigid portal frame with hot-rolled profiles; the steel tapered rigid portal frames one; the one using steel rigid portal frames with trussed roof girders; the precast concrete one; and the one using glulam.

From the quantities included in these tables, using the data available in tables 1 to 5, which include prices of materials and $CO_{2\text{-eq}}$ emissions, rankings are obtained. Table 11 shows the classification according to the total investment cost, and Table 12 displays the ranking according to $CO_{2\text{-eq}}$ emissions.

Table 6: Materials used in the steel rigid portal frames with hot-rolled sections option.

Material / Element	Amount	Units
S275 steel	21,684.75	kg
S235 steel	10,771.92	kg
B500B steel	5,620.76	kg
C30/37 concrete	109.27	m^3
HL-150 blinding concrete	16.91	m^3

Table 7: Materials used in the steel rigid tapered portal frames alternative.

Material / Element	Amount	Units
S275 steel	19,665.95	kg
S235 steel	10,771.92	kg
B500B steel	5,010.32	kg
C30/37 concrete	100.41	m^3
HL-150 blinding concrete	15.85	m^3

Table 8: Materials used in the steel rigid portal frames with trussed roof girders option.

Material / Element	Amount	Units
S355 steel	6,963.88	kg
S275 steel	11,249.27	kg
S235 steel	10,089.24	kg
B500B steel	4,795.66	kg
C30/37 concrete	91.24	m^3
HL-150 blinding concrete	14.50	m^3

Table 9: Materials used in the precast concrete option.

Material / Element	Amount	Units
C30/37 concrete	96.74	m^3
C40/50 concrete	4.69	m^3
C45/55 concrete	19.62	m^3
C50/60 concrete	29.93	m^3
HL-150 blinding concrete	11.96	m^3
B500B steel	10,148.69	kg
Y1860 steel	1,797.84	kg

Table 10: Materials used in the glulam alternative.

Material / Element	Amount	Units
GL24h glulam	82.45	m^3
S275 steel	314.05	kg
B500B steel	4,980.50	kg
C30/37 concrete	102.64	m^3
HL-150 blinding concrete	15.16	m^3

Table 11: Ranking according to investment cost (excluding VAT).

Rank	Alternative	Contract execution cost
1	Conventional concrete – precast frames	137,053 €
2	Recycled steel – frames with trussed roof girders	140,267 €
3	Low-emission concrete – precast frames	143,066 €
4	Reused steel – frames with trussed roof girders	144,797 €
5	Recycled steel – tapered portal frames	147,253 €
6	Reused steel – tapered portal frames	151,830 €
7	Recycled steel – hot-rolled frames	153,692 €
8	Reused steel – hot-rolled frames	158,426 €
9	Glulam frames	174,985 €

Table 12: Classification according to global warming potential (A1-A3 kg of $CO_{2\text{-eq}}$ emissions).

Rank	Alternative	Emissions (kg $CO_{2\text{-eq}}$)
1	Glulam frames	-30.623,58
2	Reused steel – frames with trussed roof girders	42.887,22
3	Reused steel – tapered portal frames	46.297,87
4	Low-emission concrete – precast frames	48.130,41
5	Reused steel – hot-rolled frames	48.332,63
6	Conventional concrete – precast frames	59.055,92
7	Recycled steel – frames with trussed roof girders	60.098,63
8	Recycled steel – tapered portal frames	64.882,16
9	Recycled steel – hot-rolled frames	68.824,13

4. Conclusions

4.1 Global warming potential

For the study carried out, in terms of $CO_{2\text{-eq}}$ emissions, taking into account phases A1 to A3 of the life cycle, the certified glulam structure presents the best environmental result, with negative $CO_{2\text{-eq}}$ emissions. This is because sustainably managed forests, during their life cycle, capture CO_2 from the atmosphere and store it as carbon in their biomass; in this case, the trees from which the glulam is made absorb the CO_2. It should be noted that wood not coming from responsibly managed forests is not sustainable, because it contributes to the disappearance of the planet's forest mass. Only reputable certifications ensure that the forest mass is increasing or remaining constant.

In second place, steel structures from re-use perform better than precast concrete structures, except for the case of steel portal frames with hot-rolled profiles, which performs slightly lower than the low-emission concrete precast structure.

On the other hand, when comparing the low-emission concrete option with the recycled steel ones, the first has a better environmental performance, with 25% to 43% lower emissions.

Making the same comparison between recycled steel structures and the conventional concrete one, the environmental results are still better for concrete, with emissions being between 2% and 16% lower.

Focusing on concrete structures alone, a reduction in emissions of around 23% can be observed if a low-emission structure is used.

In the case of steel structures, a reduction in emissions of around 40% can be achieved with reused steel. However, Kanyilmaz et al. (2023) draw attention to the fact that the problems of traceability, quality certification, availability and lack of know-how need to be solved for the reuse of steel structures. It will also be necessary to update the relevant regulations. The designer will therefore see its legal liability adequately covered by them when designing this type of structure. However, those authors believe that the future of this reuse is promising, given the current level of technology.

4.2 Investment costs

In terms of the investment cost, the conventional precast concrete structure shows the best result, followed by the steel structure with a trussed roof girder, with a very small economic difference of around 2%.

The third place is occupied by precast low-emission concrete structures, with a difference of about 6,000 €. That variation is so small that low-emission concrete are almost quite competitive in price compared to conventional ones.

The rest of the steel structures present an economic difference of between 5% and 15% with respect to the conventional reinforced concrete prefabricated one. On the other hand, if we make a comparison between steel structures, we can see that the economic difference between recycled and reused steel, for the same structural type, is around 4,500 € . Again, the difference is small, and reused steel are quite competitive in price with respect to recycled one.

Finally, the glulam structure has the highest investment cost, with a difference of 27% compared to the prefabricated concrete one.

5. Limitations and future developments

The limitations of this work and possibilities for future developments are outlined below.

- The dimensions of the buildings studied are limited to a 20 m structural span. A study covering different structural spans should be considered.
- The life-cycle study phases are limited to A1 to A3 but, taking into account the rest of the life cycle, the results could change. It is advisable to move along this path, addressing at least typical cases including transport to site, on site works, and maintenance.
- A single impact category indicator is used: global warming potential (GWP). Future work can include at least the remaining mandatory indicators of the EN 15804:2012+A2:2020 standard.
- Social aspects have not been included due to the difficulty of finding information on key indicators such as employment generation. These are considered to be very important and an attempt should be made to include job creation and accident rate indicators, as a minimum.
- This is a deterministic study, and it would be advisable to carry out a future one with probabilistic indicators. Thus, for example, environmental indicators that take into account the variability recorded when consulting the EPDs.

With all of the above, it would be appropriate to build a multi-criteria model that includes all environmental, social and economic aspects, and allows for an overall sustainability ranking, and partial environmental, social and economic classifications. On the other hand, it would be interesting to carry out the same type of study for conventional building structures for offices, dwellings, and other conventional buildings.

6. References

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Use of generative artificial intelligence

Generative artificial intelligence has not been used in this work.

Communication aligned with the Sustainable Development Goals