PAPER #3.10

STEEL STRUCTURES SUSTAINABILITY: REUSE OF AN EARLY 20TH CENTURY STEEL STRUCTURE

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ABSTRACT

According to the EU's climate service, for the first time, global warming has exceeded 1.5ºC above pre-industrial levels, across an entire year. In the era in which climate change is a reality, the 3 R's (Reduce, Recycle and Reuse) are more needed than ever. Steel, as a structural material has many advantages. Its strength, ductility and isotropy are well known, and the fact that can be continuously recycled without degradation or change its properties is really important, but above all, the possibility to be reused makes it more advantageous than other structural materials.

In this paper, a steel structure built at the beginning of the 20th century is presented. The structure was dismantled around the 1970s and instead of being sold as steel scrap to be melted down again, it was reassembled in a new site for a new use. More than 120 years after it was first erected, the structure is still standing and in good use.

Nowadays, thanks to the effort made towards the efficient use of energy in buildings during the use stage, the operational energy of buildings has been significantly reduced, however, it is still needed a huge effort to reduce the embodied energy or embodied carbon emissions for a resource-efficient construction. In this last point, reuse is of paramount importance as shown in this case of study, where the carbon footprint is obtained considering that the lifetime of the building has more than doubled the expected working life period.

KEYWORDS
Reuse; steel structures; embodied carbon; Estación de Aragón; sustainability.

1. INTRODUCTION

In the European Union, the building and construction sector accounted for about 37% of global emissions in 2021 (UN Environment Programme 2022). The quantification of greenhouse gases emitted in the construction of a building (production phase), measured in mass of CO_2 equivalent, constitutes the embedded carbon. For its analysis, depending on the available data, and the objective of the assessment, one of the following stages of the building life cycle is considered: cradle to gate, gate to gate and cradle to grave. In each of these scenarios, the emissions of CO2 generated in some or all of the following processes is considered: extraction of raw materials, processing, assembly into usable products, transport and on-site assembly (from cradle to gate). Only on-site assembly (from gate to gate), or It can also include emissions generated to renovate and maintain the building throughout its lifetime and those resulting from the demolition of the building and waste management at the end of its lifetime (from cradle to grave).

Nowadays, thanks to the effort made towards the efficient use of energy in buildings during the use stage, the operational energy of buildings has been significantly reduced, however, it is still needed a huge effort to reduce the embodied energy or embodied carbon emissions for a resource-efficient construction. It is estimated that between 2020 and 2050, more than half of the total carbon emissions from all new global construction will be due to embedded carbon (GBCE 2021). Therefore, the transition to a circular economy, directly linked to Sustainable Development Goal 12 'Ensure sustainable consumption and production patterns' and Goal 13 'Climate action' plays a crucial role in reducing these emissions. This work is focused on the analysis of the embedded carbon footprint of a more than a century old steel structure still in use, fifty years after its reconstruction in a new location.

This study is the first phase of a larger research project that involves structural optimisation. For this paper, the study begins with an extensive documentary research to locate all accessible information on the original building, followed by fieldwork in the new location of the building to identify the conditions of the current structure, its changes and modifications with respect to the original, and finalises with the design of the structural model of the existing structure, in order to evaluate the embedded carbon. The obtained results will constitute a positive carbon footprint, given that in this case we started from a deconstructed building at the end of its useful life.

2. THE BUILDING

The steel structure under study is the hall of the Valencia station of the train line from Calatayud (Zaragoza, Spain) to Valencia (Spain) of the Central Railway Company of Aragón founded in 1894 by a group of Belgian businessmen (see the route in figure 1).

The train line departing from Calatayud and calling to Teruel and Sagunto arrived to Valencia to the Alameda station, first opened in 1902. The Alameda station (also known as Aragon's station) was the Valencia terminus of services provided by the Central Company of Aragón until 1968. The masonry building with the services for travellers and offices was designed, in a neoclassical style, by the architect José María Belda, and the steel structure of the hall that covered the station platforms was designed by the engineer Francisco Domenchina, as stated in the original documents of the project. The new railway station was built on the site where the old Convent San Juan de Ribera, demolished in 1898 for the construction of the new terminal, was located.

Figure 1. a) Location map b), c) Route from Calatayud to el Grao de Valencia. Source: a). IGN map. b) Hernández Villaplana 2007; c) Via Estrecha cifccc 2023;)

The line suffered severe damages during the Spanish War (1936-1939). In 1941 all the Spanish the train lines were nationalised, and the building and the rail-line formed part of the newly created Spanish National Railway Network RENFE (*Red Nacional de los Ferrocarriles Españoles*, in Spanish). The station closed for travelers on the 25th March 1968 (Hernández Villaplana 2007).

The Aragón Central station ceased its travel activity in 1968, being still in used for materials deposit until its demolition. In 1973, RENFE, decided to sell everything of value before it was demolished in 1974 to clear the way for the new urban development on *Avenida de Aragón*. (Hernández Villaplana 2007). However, what could have been the end of the steel structure, doomed to be sell to be melted and used as scrap for the fabrication of new steel, changed radically its destiny thanks to Mr. Faubel.

Álvaro Faubel, a partner in European company leader in cocoa derivatives named Natra, acquired the steel structure and ordered its dismantling, transport and reassembly in a new industrial site located about 20 km from the original location (see the Google maps route in figure 2). According to Joan Lluís Llop y Bayo in the article published in the local press on 30 April 2000 (Llop 2022)

> The presumably low cost of acquisition and the speed of assembly were decisive in the decision to opt for a prefabricated building like this one (...) However, the complexity of transporting the large pieces, with a total weight of around 700 tons, and the appropriate photographic preparation to be able to assemble the whole thing later, were very laborious.

2.1. The former structure

In order to understand the design of the former structure, the original report and plans, kept in the Historical Archive of the Madrid Railway Museum (Archivo Histórico Ferroviario del Museo del Ferrocarril de Madrid, AHF-MFM) have been consulted. The report consists in twenty-two handwritten pages describing the structure, dimensions and considered loads in the design process, while the plans include the view of the north façade, the main frame view, a lateral view of the whole hall and the top view (see figure 3).

The main difficulties, regarding the analysis of the former structure has been to identify the elements described in the report and locate them in the drawings. This is due to the use of old-fashioned vocabulary and the fact that the dimensions and geometry included in the memory do not match those in the plans. Additionally, some issues, regarding the sizing of the bars, have been found in this first analysis.

The original structure of the open hall consisted of fourteen main 31 metres wide pitched frames with trusses separated 9.36 metres from each other. In between these porticoes, a couple of full web I-beams, supported by a set of orthogonal trusses connecting all the frames, were installed to share the weight and load of the orthogonal joists, on which the sheeting of the roof lied.

The main frames were completed with a pair of cantilever trusses 4.2 metres long built at 4.7 metres above ground level and connected to the columns at each edge. Therefore, the steel hall was a 39.4 metres wide and 140.64 metres long covered, but laterally open, rectangular space (see figure 4c).

Figure 2. Route from the old site to the new location. Source: (OpenStreetMap 2024)

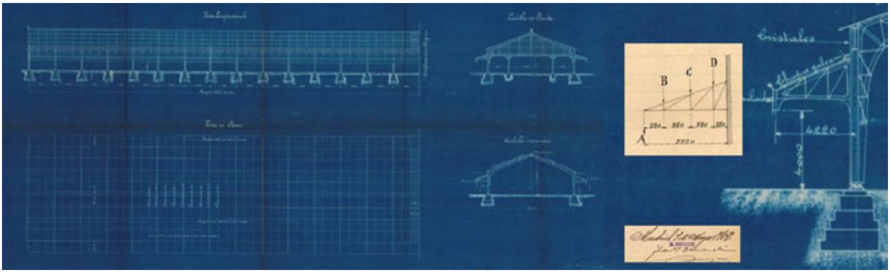


Figure 3. Original drawings. Source: (AHF-MFM, I 115/8-1 and I 115/8-2. Francisco Domenchina 1902)

Figure 4. Aragón's train station building in Valencia. Source: (a. BIVALDI 1907; b. and c. AVAF)

The façades that closed this structure were, on the north, a four columns pitched frame shown in figure 3 and on the south, the rear façade of the masonry building that housed the services for the travellers (figure 4a and figure 4b).

2.2. New life for the station's hall structure

A comprehensive study was carried on to trace the history of Natra, the company that bought the steel structure to give it a new use as an industrial building (Llop 2022).

Natra, focused on the extraction of theobromine from cocoa beans, was founded in 1943 (Natra n.d.). Along the 20th century, the company expanded by diversifying its production, being floated on the stock exchange in 1999. In 2002 Natra's activities related to theobromine extraction were transferred to the newly created Natraceutical company, selling the building and Natraceutical shares to Naturex Iberian in 2014 (Natra n.d.). In Septembre 2018 Naturex was acquired by Givaudan, (Givaudan n.d.) who sell it again in May 2024 to the Groupe Berkem, a leading player in bio-based chemistry (Groupe Berkem 2024)

As a result of the study of the history of the company, the new owners of the former station hall were tracked, and a visit to the premises, to observe in situ the present configuration and the conservation state of the steel structure, was requested. Some of the pictures taken in this visit are shared in figure 5. Figure 5a was taken from an older picture pinned up on the wall of the office. Figure 5b, was taken in May 2024 and it can be observed that the columns and the chords of the trussed beams are a bit rusty.

As can be seen in the outdoors picture in figure 5a, the position of the lateral cantilevers has been changed to align the surfaces of the main roof and the canopy roof. Additionally, new slender columns have been added at what was the tip of these trussed cantilevers.

Regarding the indoors pictures, figure 5c shows that an intermediate story has been included. In these images, the secondary beams and the joists cannot be seen. However, the image in figure 5d, shows the secondary beams, parallel to the main frames, the orthogonal trusses where these full web I-beams rest, and the joists, orthogonal to the frames and parallel to the orthogonal trusses.

Following the report and drawings of the original project and considering the geometry and layout observed on site, a model of the original structure has been built. figure 6 shows a portion of the model formed by three frames, the inner full web beams built between each two frames, the orthogonal trusses that connect all the frames in the out of plane direction, and the joists.

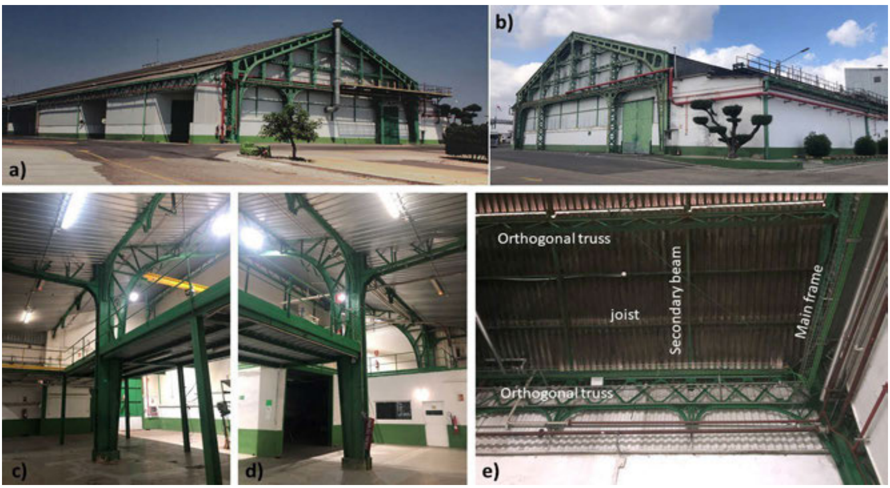


Figure 5. Images taken on site. Source: (The authors 2024)

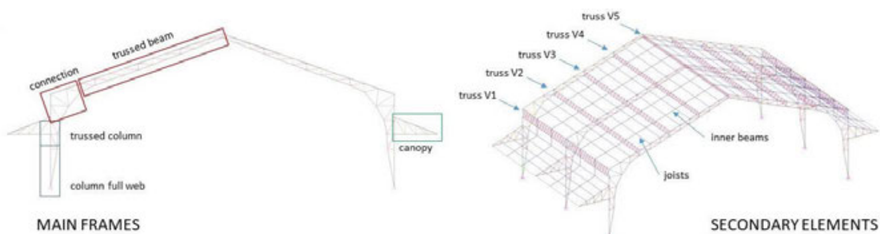


Figure 6. Model of the structure. Source: (The authors 2024)

3. THE EMBODIED CARBON OF THE ASSESSED STEEL STRUCTURE

The embodied carbon calculation process is usually based on the multiplication of the quantity of each involved material by the carbon factor's material. The carbon factor is normally measured, for each lifecycle module considered, in kilograms of equivalent CO_2 per kg of material (kgCO2e/kg).

The lifecycle modules are summarised in the graph in figure 7 , including the approximate distribution of A1 to C4 emissions proposed by the IStrucE brief guide to calculate embodied carbon (IStrucE, 2022)

As can be seen in the graph, the embodied carbon associated with A1 to A3 modules is the largest contributor to the embodied carbon of a building.

3.1. Geometry, layout and weight of the steel structure

In order to assess the embedded carbon of the reused structure, the cross sections described in the original report and plans of the project have been considered for all the elements but the main frame.

In the case of the main frames, the upper and bottom chord of the horizontal and vertical trusses was built including several plates to design flanges of variable thickness. In this study, for the sake of simplicity, an average cross-section has been considered along all the length of the upper and bottom chord.

Additionally, the design of the façade's frame involved a large number of elements, and taking into account the limited length of this paper, authors have decided not to include this frame in the calculations. Therefore, for the purpose of this paper, all the frames have been considered equal to the main frame.

With the aim of obtain the final weight of the structure, the considered cross sections of all the elements of the structure have been drawn, and their area, volume and weight have been calculated.

The shape of the cross sections, the designation, length and weight of the members of the main frame are shown in table 1, while the trusses that connect the main frames in the out of frame direction (V1 to V5 in figure 6) are described in table 2. Table 3 presents the secondary elements: inner beams and joists, both designed with IPN cross-sections. Finally, table 4 lists the elements of the canopy.

The summation of the partial weights is outlined in table 5, where, in order to calculate the whole weight of the steel structure, the total number of each type of element that formed the structure is included.

3.2. Carbon factor values

The embodied carbon associated with the production stage depends on the material specifications. It includes the mining of raw materials, the transport and the manufacturing process. Considering that the steel members of the structure in this studio case were

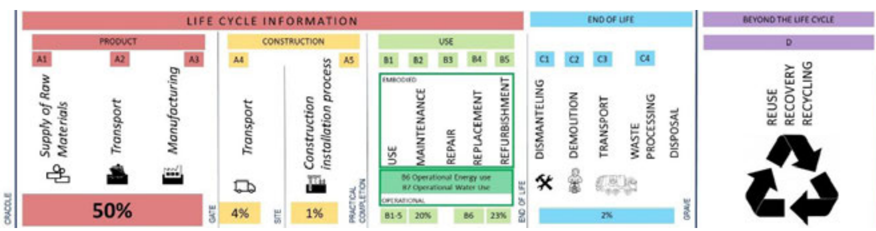


Figure 7. Life cycle stages and modules. Source: (The authors 2024, based on IStrucE, 2022)

manufactured more than 120 years ago, the following estimations cannot be very accurate. Nevertheless, the rough values can give an idea about the most pessimistic scenario (minimum kg of CO_2e saved), as the obtained values will be the smallest value in the possible range of values.

The IStructE brief guide (IStrucE, 2022) suggests, for structural steel, a carbon factor ranging from 2.45 to 1.55 kgCO2e/kg being the data sources the British Steel Environmental Product Declaration (Tata Steel UK 2020) and the Inventory of Carbon & Energy database, respectively (Jones and Hammond, 2019)

NAME	Cross section	designation	length (m)	weight (T)	NAME	Cross section	designation	length (m)	weight (T)
TRUSSED BEAM									
upper chord		2L70.70.8 + flange + web	27.12	1.35	diagonal bars		2L50.50.6	25.68	0.24
bottom chord		2L70.70.8 + flange + web	27.42	1.42	vertical bars		2L60.60.6	10.02	0.10
CONNECTION									
upper chord		2L70.70.8 + flange + web	10.04	0.51	diagonal bars T1		4L60.60.6	5.92	0.12
bottom chord		2L70.70.8 + flange + web	6.24	0.32	diagonal bars T2		4L50.50.6	6.44	0.12
					diagonal bars T3		4L70.70.7	3.9	0.11
FULL WEB COLUMN									
external		6L60.60.6 2 webs Int. plate flange	5.2	0.53	variable section		4L70.70.8 web plate flange	6.76	0.364
TRUSSED COLUMN									
outer chord		2L70.70.8 + flange + web	5.2	0.26	diagonal 1		2L50.50.5	3.16	0.02
inner chord		2L70.70.8 + flange + web	5.22	0.27	diagonal 2		2L50.50.6	2.88	0.02
					diagonal 3		2L60.60.6	2.9	0.03

Table 1. Main frame structural members. Source: (The authors 2024)

On the other hand, the 2024 report of the Worldsteel association (Worldsteel association 2024) estimates that in 2022, 1.9 tonnes of CO_2 were emitted per tonne of crude steel cast. However, according to the report, CO_2 emissions intensity represents production weighted averages between blast furnace-basic oxygen furnace (BF-BOF) scrap based electric arc furnace (EAF) and direct reduce iron (DRI)-based EAF steel production. On a more detailed analysis of these figures, it can be found that 71.1% of the steel global production was BF-BOF steel, being the corresponding average CO_2 intensity 2.33 tonnes of CO2 per tonnes of crude steel cast, based on 2022 calculation.

Taking into account that assessed structure was dismantled and relocated in 1974, the needed values should already correspond to that time. Unfortunately, the Paris Agreement was adopted in 2015, more than forty years later, and there are not available data. Going back in time, despite the fact that the world steel association publishes their figures since 2002 (Worldsteel association n.d.) the 2024 report is the first publication that includes the assessment of emission values.

For the calculation of the embedded carbon of this structure, corresponding to the production stage, the carbon coefficient considered is the proposed by the IStructE brief guide, based on the British Steel EPD 2020. Considering that the calculated weight of the simplified structure is 222.63 T, the embedded carbon corresponding to modules A1 to A3 will be 545.44 T of equivalent CO_2.

NAME	Cross section	designation	length (m)	weight (T)	NAME	Cross section	designation	length (m)	weight (T)
TRUSS V1 between two frames (height 1 m)									
upper & bottom chords		2L 110.65.9 2L 110.65.9	9.36x2	1.76	diagonal bars		1 L50.50.5	81.15	0.30
TRUSS V2 and V3 between two frames (height 0.6 m)									
upper & bottom chords		2L 60.60.6 2L 60.60.6	9.36x4	0.81	diagonal bars		1 L50.50.5	40.57	0.15
TRUSS V4 between two frames (height 0.5 m)									
upper & bottom chords		2L 60.60.6 2L 60.60.6	9.36x2	0.81	diagonal bars		1 L50.50.5	40.57	0.15
TRUSS V5 between two frames (height 0.34 m)									
upper & bottom chords		2L 60.60.6 2L 60.60.6	9.36x2	0.81	diagonal bars		1 L50.50.5	40.57	0.15

Table 2. Orthogonal trussed beams structural members. Source: (The authors)

NAME	Cross section	designation	length (m)	weight (T)	NAME	Cross section	designation	length (m)	weight (T)
SECONDARY ELEMENTS									
Inner beams		IPN 120	44.9	0.49	Joists		IPN 80	9.39	0.055

Table 3. Secondary structural members: Inner beams and joints. Source: (The authors 2024)

NAME	Cross section	designation	length (m)	weight (T)	NAME	Cross section	designation	length (m)	weight (T)
TRUSS OF THE CANOPY									
upper chord		2L50.50.5 + web	4.22	0.05	diagonal bars		2L50.50.5	7	0.05
bottom chord		2L50.50.5 + 2 webs + flange	3.92	0.14					

Table 4. Canopy structural members. Source: (The authors 2024)

Top view	Element	Weight (T)	elements	Total weight
	Main frame	5.83	15	87.55
	Orth. trusses	5.92	14	82.98
	Inner beams	0.99	2*14	27.72
	Joists	0.055	22*14	16.94
	Canopy	0.248	30	7.44
			TOTAL	222.63 T

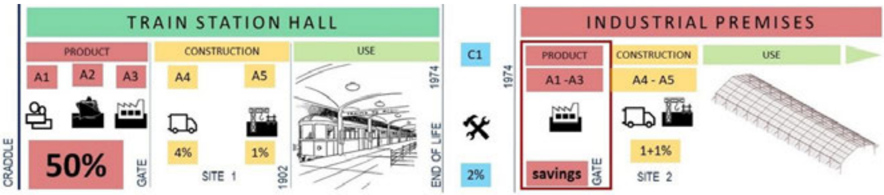
Table 5. Total weight of the structure. Source: (The authors 2024)

4. DISCUSSION

In this paper, an initial approach to the assessing of the carbon footprint savings of a steel structure manufactured at the beginning of the 20th century and still in use after more than 120 years is presented.

For two reasons, only the production phase has been considered: 1. there is no data available about where it was manufactured, so that the values for on-site transportation and assembly cannot be included, and 2. The structure was dismantled, transported and re-built in the new site.

To take into account this specific situation, the calculation should include the modules A4, and A5 for the first time that the structure was built, and modules C1, A4 and A5 for the de-construction process and rebuilding.



A1-A3 (T)	A4 (T)	A5 (T)	Lifespan: 72 years	C1 (T)	A1-A3 (T)	A4-A5 (T)	Lifespan: > 50 years
+545.44	+43.6	+10.9		+21.81	-545.44	+21.81	
			TOTAL 599.94 T				TOTAL - 501.82 T

Figure 8. Embedded carbon corresponding to A1 to A5 + C1 modules. Source: (The authors 2024)

Regarding this last point, and considering the percentages of figure 7, it could be concluded that, if the production stage (A1-A3) accounts for the 50% of the total emissions, the transport to the site (A4) around 4%, the construction module (A5) 1% and the deconstruction for 2%. For the reused structure, a 1% percentage has been proposed for modules A4 and A5. Total emissions corresponding to the product and construction stages for both structures can be summarised in the graph in figure 8.

5. CONCLUSION

The Basic Document, SE Structural Safety, of the Technical Building Code (Ministerio de Fomento 2019) establishes in Article 1, section 1.1 that, in the absence of specific indications, 50 years shall be adopted as the service period.

Considering that the original structure was in service for 72 years, and the current structure has been in use for almost 50 years, it is evident that the structure of the hall of the Aragón station has far exceeded this period.

In addition, with proper maintenance to solve the corrosion problems detected on the exterior elements of the building, it is expected that it will remain in use for a few more years.

In conclusion, Mr. Fauvel's decision to save the structure from being melted down and reused has meant, to date, a positive carbon footprint of at least 500 tonnes.

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