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French metallic train sheds of 1850 to 1930: structural specificities and the evolution of the restoration practices

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Surviving historic train sheds constitute a broad and representative sample of metal construction of the period 1850 to 1930 in France. This article gives a historical overview of the life of iron or steel train shed structures and questions what makes them authentic, discussing the validity of some of the restoration choices made since the 20th century regarding heritage preservation. First, the specificities of this architectural heritage are highlighted and compared with other countries and other types of construction. Then, based on extensive archive material held by the French national railway company SNCF, the modifications the metallic structures underwent as restoration projects were carried out are analysed. It appears that the restoration practices significantly evolved between the 1970s-1980s and the beginning of the 21st century, becoming more sensitive to heritage preservation. However, choices regarding roofing materials have an impact on the loading of the structure, while structural interventions change the appearance and the load distribution. This enhances the need to include considerations regarding the preservation of the structure in the early stages of restoration projects.

Keywords: France, train shed, 19th century, wrought iron, mild steel, restoration, roofing materials, roof loads, strengthening measures

1. Introduction

In France as in other pioneering countries of metal construction, train sheds built in the 19th and early 20th century were used by railway companies as showcases of their prestige and prosperity (Lemoine 2022). As a component part of station buildings, train sheds primarily had the function of covering railway tracks and platforms, but they were also designed to impress travellers. Through their metallic roof structures, they had to be “striking examples of refined technology” (Meeks 1956), and give a taste of the new industrial aesthetics. Over time, train shed structures witnessed a range of modifications while keeping a constant and strong architectural identity. The impact of a train shed restoration on its metallic structure was often almost imperceptible. Roof changes modified the loads in an invisible way and structural interventions blended in on account of uniform paint. A paradox emerges: even though the heritage value of train sheds relies strongly on their engineering qualities, restoration projects focused on preserving mainly their functionality, and more recently, on restoring the architecture. It seems like considerations about how to best preserve the structure itself were left out. While already mentioned in the preamble of the Venice Charter (ICOMOS 1964), “authenticity” has now become the “guiding star of heritage preservation” (Mager 2016). A train shed restored in an authentic manner should truthfully convey its “cultural significance” through its “material attributes” (ICOMOS 2011). However, using Mager’s words, authenticity remains a “blurry” concept and “must be found and defined anew in each case”[1]. It is therefore of interest to discuss what makes up the structural authenticity of train sheds, to integrate it as a criterion for heritage-friendly restorations. The first aim of the article is to underline the structural identity of French train sheds, by proposing an overview of the specificities of their metallic roof structure, compared with other countries and other types of construction. . The main structural principles are introduced

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[1] “Authenticity” was the annual theme 2022 of the German research program SPP 2255 “Cultural Heritage Construction” funded by the German Research Foundation DFG. https://kulturerbe-konstruktion.de/jahresthema/jahresthema-2022-tbd/?lang=en

and several structural components are analysed in detail: roof trusses, purlins and rafters, and skylight and gable structures.

The second aim is to raise awareness of the impact of restoration projects on the metallic structures, by tracinga history of the restoration practices and shedding light on structural aspects. The evolution of roofing materials in the course of restorations is detailed, stressing the consequences in terms of loading. Structural interventions are then analysed: removal and restoration of skylights and glazed gables, addition of maintenance equipment, and repair and strengthening measures on structural elements. .

Before those two aims are adressed, some insight is provided on the background of the study, regarding the evolution of restoration philosophies applying to train sheds from the 20th to the 21st century, and on the sources and features of the used dataset for the analyses, relating mostly to surviving train sheds.

2. Study background

Rail passenger transport developed in France from the end of the 1830s. For the structure of the first train sheds built in the 1840s and 1850s, iron was in competition with timber. Metallic structures were then prevalent until the end of the 1920s, when reinforced concrete became representative of a new modern age. With very few exceptions, French metallic train sheds were built between 1850 and 1930. Many were destroyed by fire or by war but about 40% have been preserved and are still in service.

Since their construction, those preserved train sheds have been regularly restored, every 37 years on average (Emile and Veston 2020). Standard restoration projects involved repairing or replacing the roofing, to keep the roof watertight, and repainting the metallic structure, to avoid corrosion. Train sheds were also subjected to various structural interventions: adding or removing, repairing or strengthening metallic elements. Until the 1980s, restoration projects focused mainly on maintaining the functional role of the train sheds. From the 21st century, train sheds were also acknowledged as a heritage to be preserved.

The first measures of statutory protection for railway stations were granted in the 1970s, but only for a handful of prestigious mainline stations, mostly in Paris, and for architectural elements related to the station buildings (Smith 1999; Striffling-Marcu and Veston 2022). Today, 72% of French train sheds enjoy some form of heritage protection (Emile and Veston 2020). It was primarily thanks to the development of the notion of industrial heritage in France in the 1980s (Gasnier 2011) that train sheds were considered with new interest and became associated with heritage values. Heritage values formalised by Aloïs Riegl in 1903 (Riegl 1903) are particularly relevant to assess load-bearing structures (Eberhardt and Pospisil 2022) and industrial heritage (Gasnier 2019). Train sheds have a strong use value, that was continuously present throughout their existence, and from the 1980s they regained their original symbolical value and acquired historical and creative values, from technical and artistic points of view.

Since 2005, the French national railway company SNCF (Société Nationale des Chemins de fer Français) has carried out an ambitious programme of train shed restorations, from which about 20 railway stations have already benefited, such as the station of Perpignan (Figure 1) or the prestigious Gare d'Austerlitz in Paris (Figure 2). Those recent restoration projects clearly sought to preserve or restore the original appearance, while addressing sanitary issues (removing asbestos and lead-based paint). A range of structural interventions was necessary. In 2019, because SNCF had identified the need to pool knowledge from past restorations, an extensive survey of surviving train sheds was conducted by the heritage department of AREP. AREP is a subsidiary of SNCF and a multidisciplinary architecture practice, with a strong expertise in designing and renovating railway stations. The study from AREP's heritage department gave a strong insight into the key architectural features of train sheds and recent restorations. It provided recommendations on how to assess the heritage value of individual train sheds, in order to prioritise upcoming restoration projects and improve future specifications.

Figure 1: Gare de Perpignan, built in 1896, Perpignan, France (Pictures from SNCF-AREP by D. Boy de la Tour and A. Striffling). (a) Before and (b) after restoration of 2013.

Figure 2: Gare de Paris-Austerlitz, built in 1869, under restoration in 2016, Paris, France (Picture from SNCF-AREP by M. Lee-Vigneau).

From the time of their construction, train sheds were acknowledged as engineering feats but were mostly studied for their architecture (Kanai 2005; Meeks 1956). Similarly, restoration projects were based on architectural choices.The potential impact of train shed restorations on their metallic structure was rarely taken into account. This is also reflected in accounts made in the literature about restorations of historic metallic structures, whether for train sheds or other types of construction. Only some isolated case studies focused on structural interventions and their consequences in terms of structural behaviour(Vitzthum, Voland, and Foster & Partners 2006; Springer, Merwar, and Bosse 2012).

3. Sources and features of the dataset

This study is based primarily on surviving French historic metallic train sheds. It builds upon and extends the internal study conducted by the heritage department of AREP. Defining train sheds as structureswith a single span, railway stations feature either single sheds or several adjacent sheds. Applying this definition, preserved French metallic train sheds built between 1850 and 1930 constitute a broad dataset of 90 sheds[2], distributed across the French mainland as shown on the map in Figure 3.

For each surviving train shed, the authors attempted to gather information tracing its life, from its construction to the present day, including intermediary states related to various restorations. The first and main source of information has been AREP. AREP contributed to the restoration of many historic train sheds and made related data available to the authors. Historical studies, that had been compiled by AREP’s heritage department since its creation in 1997, were particularly helpful. Data included also archive documents, photographs, before, during, and after restoration work, plans and calculation

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[2] This number differs from the 75 surviving train sheds mentioned by (Emile and Veston 2020). This is due to the fact that Emile and Veston count a train shed with multiple spans as just one shed, while the present article counts the spans individually. Furthermore, Emile and Veston include train sheds of all materials, while the present article considers only metallic train sheds.

notes, produced by AREP or their project partners, especially building contractors. However, a lot of interesting archive documents are detained by other entities within SNCF, for example regional engineering offices, which made the gathering of data more difficult. The authors succeeded in obtaining relevant historical and more recent archive material from local subsidiaries for eight railway stations. Additionally, historical archive documents were consulted at the national SNCF archive centre in Le Mans. This centre was created in 1995, with the purpose of bringing together all the historical archives of SNCF. Before 1995, the historical archives were kept, at best, in regional archive centres. In the historical studies provided by AREP or other SNCF entities, many of the scanned historical plans were indeed coming from regional SNCF archive centres. However, according to (Bowie 2009), ancient building plans of railway stations used to be kept on site at the various stations, because of continuing operational use, which delayed or prevented their transfer to an archive centre. Given the vast amount of data to be collected, the centralisation process in Le Mans is still ongoing and most of the archives are only summarily inventoried (Zuber 2009). After two days of consultation of documents related to ten pre-selected railway stations, relevant plans or notes were found only for two of them. More technical information was found in the literature, especially civil engineering periodicals from the time of construction of train sheds, such as *Nouvelles Annales de la Construction, Annales des Ponts et Chaussées* and *Le Génie civil*. These periodicals were readily available from the website Gallica powered by the Bibliothèque nationale de France[3].

When complete, the information gathered for each surviving train shed included: a historical study, summarising the life of the corresponding station, a photographical

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[3] https://gallica.bnf.fr/

survey, plans and calculation notes for the construction, intermediary restoration projects, and the most recent restoration since 2005, when relevant. There was no train shed for which all this information could be gathered. Consequently, pooling data was extremely valuable, if not necessary, to provide meaningful insights into the history of train sheds.. Overall, the study presented in this article relies on data gathered for the 90 surviving train sheds. However, the importance of the dataset varies depending on each study item, because of the fluctuating richness of available documentation.

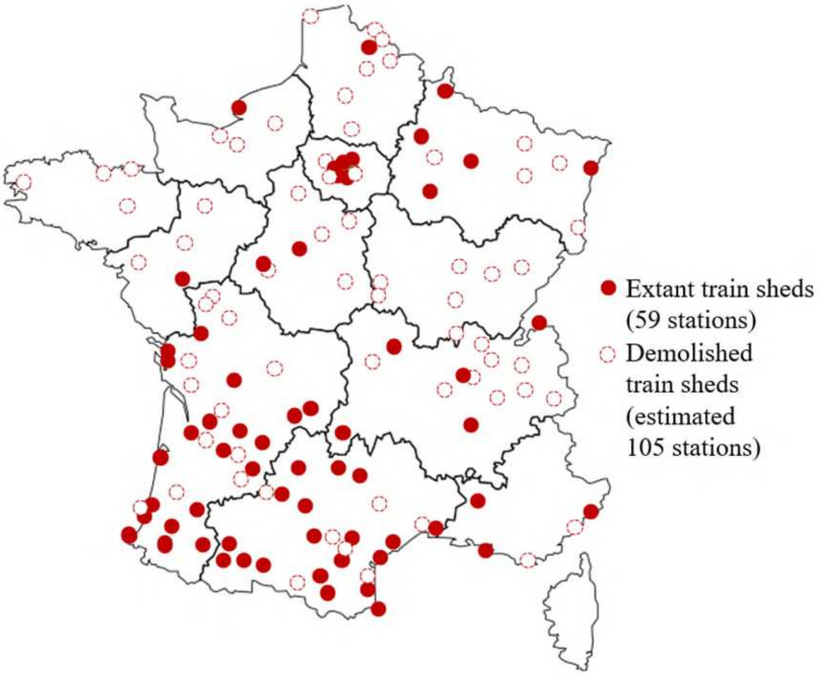


Figure 3: Map of France showing extant and demolished metallic train sheds (Map from SNCF-AREP, heritage department).

4. Structural specificities

4.1. Structural principles

The basic structure of historic metallic train sheds was very similar to traditional timber roofs (Figure 4). In plan, the layout of the structure was usually in the form of a rectangle, sometimes slightly distorted, if the station lied in a curve. The primary structural elements were the main roof trusses. They usually rested on columns or on the wall of the station building, except for some roof truss typologies starting from the ground. Within the roof trusses, the rafters were the elements following the straight or curved shape of the roof. Purlins were the girders spanning between the roof trusses, in the longitudinal direction of the train shed. Roof loads, including the weight of the roofing, snow and wind, were either directly transmitted to the purlins or to intermediate elements spanning between the purlins. Additionally, a skylight could be built along the ridge of the roof, with a structure supported by the roof trusses.

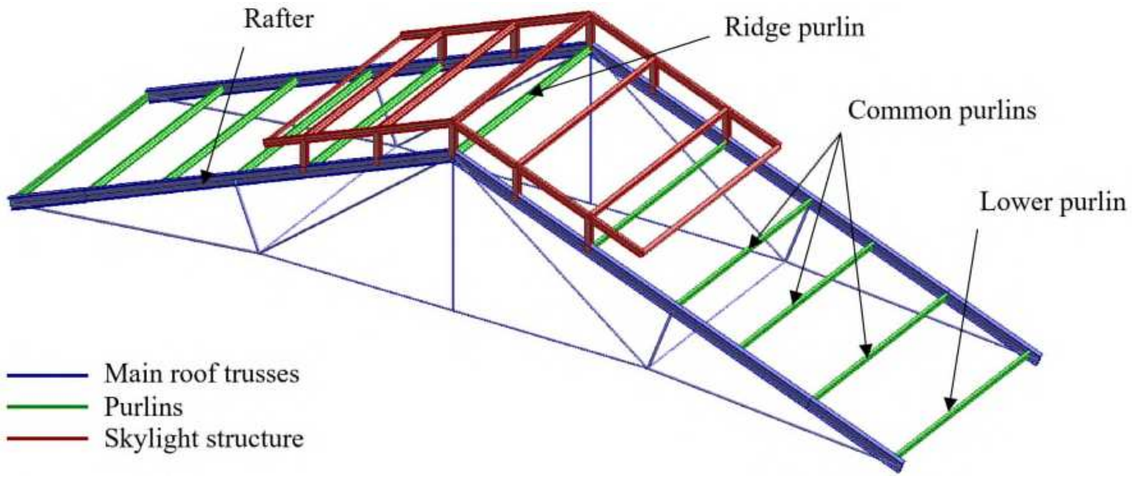


Figure 4: Schematic view of a metallic roof structure with designation of relevant structural elements.

4.2. Roof trusses

The main challenge in the structural design of a train shed in the 19th century concerned the roof trusses. Their typologies have been extensively described in historical and more recent literature and classified according to different criteria. Distinction could be made between trusses with or without tension ties (Cordeau 1901), trusses with straight or bent components (de Bouw 2010) or trusses inspired by the principles of traditional timber trusses or of stone arches (Schädlich 2015). Many types of roof trusses were developed, and despite mutual influences of European countries, different types were favoured in

France, the United Kingdom or Germany (see Figure 5). This was partly due to the nationality of the inventors: the two Frenchmen Polonceau and de Dion for the eponym trusses, the English Turner for the sickle girder, and the German Schwedler for the 3-hinged arch (Kanai 2005).Regarding surviving French train sheds, the heritage department of AREP identified that four main types of roof trusses prevailed: Polonceau trusses, de Dion trusses, triangulated trusses and arches (Figure 6(a)). Arched roofs are a minority in France, double-pitched roofs are the rule. Polonceau trusses, the stages of development of which can be witnessed through the various sheds at the Gare Saint-Lazare in Paris (Belhoste 1999), were by far the most popular, because they were rational and economic (Holzer 2010). They were easy to calculate and necessitated less material. However, the prevalence of Polonceau trusses decreased with time. Thanks to the widespread distribution of basic laminated profiles from the 1870s, riveted triangulated trusses became more economic than Polonceau trusses that required the manufacturing of special components for their radial struts and for the connections of struts and ties. Also, the tension ties of Polonceau trusses were deemed unaesthetic, cluttering up the interior space, so that other alternatives such as triangulated trusses or de Dion trusses were favoured (Lemoine 1986). Polonceau trusses are still represented in about half the extant sheds (Figure 6(b)). As opposed to France, many German train sheds were built with arches starting from the ground, featuring 2 or 3 hinges, and no tension chord (Weller and Tasche 2006). The 3-hinged arch was the dominant system in German train sheds until World War I, because it was statically determinate, thus easy to calculate, and could cover very large spans.

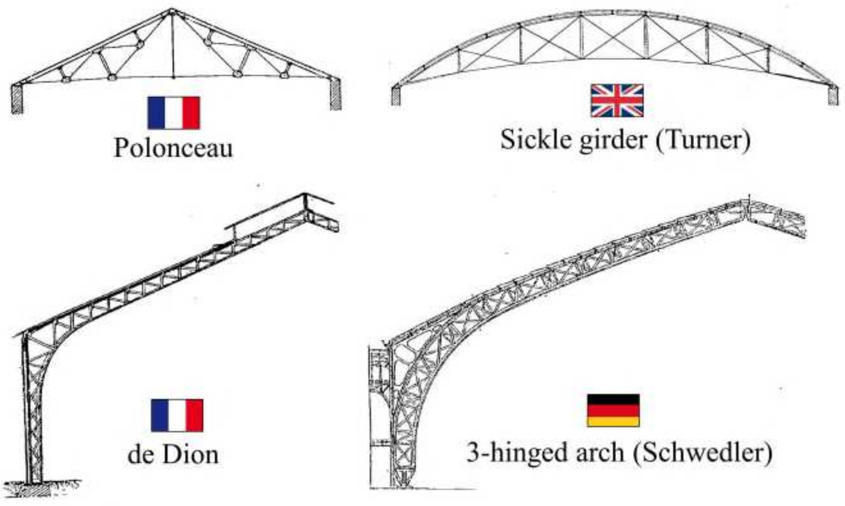
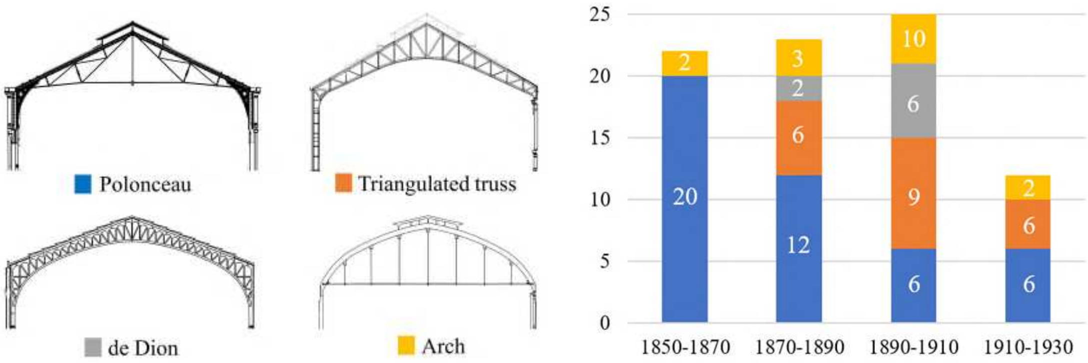


Figure 5: Examples of roof truss typologies favoured in different countries, with the name of their inventor (Pictures from (Cordeau 1901, 222-233)).



(a) (b)

Figure 6: (a) Typologies of roof trusses used for French train sheds (Drawings from SNCF-AREP, heritage department); (b) Number of sheds of each type built in 20-year periods ranging from 1850 to 1930.

Within France, some regional preferences existed regarding roof truss typologies, due to the system of private railway companies. Railway stations were distributed throughout the country according to the star-shaped network centred on Paris, defined in 1842. From the beginning of passenger transport, the lines of national interest were conceded to private companies. At the end of the 1850s, six major companies emerged[4], which did not merge until the creation of SNCF in 1937 (Lemoine 2022). The map on Figure 7 shows surviving railway stations with metallic sheds, according to the company they were built by[5].

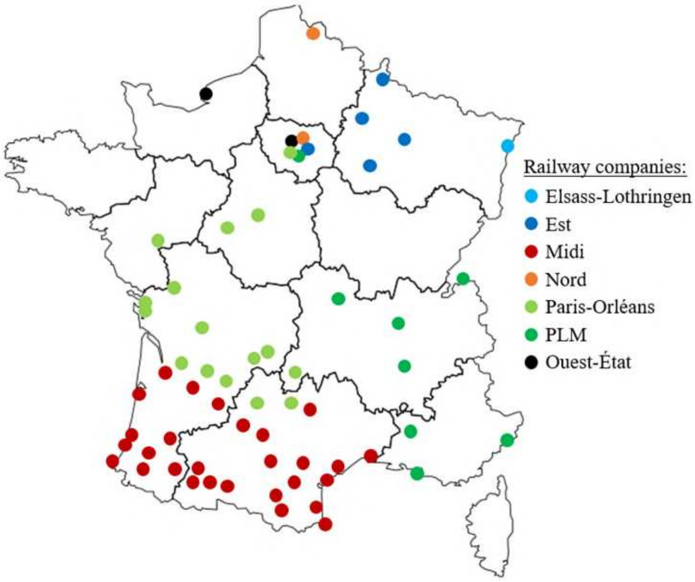


Figure 7: Map of surviving railway stations with a metallic shed, according to their original railway company (Map from SNCF-AREP, heritage department).

For each company, the architecture of their railway stations contributed to create a territorial identity (Lemoine 2022), so that several series of similar station buildings were built, as well as series of train sheds. Roof trusses constituted a major architectural

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[4] By order of creation: Compagnie du Paris-Orléans, Compagnie des Chemins de fer du Nord, Compagnie du Midi, Compagnie des chemins de fer de l'Est, Compagnie des chemins de fer de l'Ouest, Compagnie du PLM (Paris-Lyon-Méditerranée). The railway companies were commonly referred to with their short name, as "le Paris-Orléans", "le Nord", etc.

[5] The station of Strasbourg is the only exception, as it was built in 1883 when the Alsace-Lorraine region belonged to the German Empire.

feature and were therefore key to this territorial identity. As an example, in the South-West of France, the Compagnie du Midi commisionned a series of train sheds with pointed truss arches, with or without tension chord, that is still well-preserved.

(a) (b)

Figure 8: Series of similar train sheds (Pictures from SNCF-AREP). (a) Gare de Montauban, full view, Montauban, France; (b) Gare de Bédarieux, full view, Bédarieux, France.

Beyond the type of roof truss, differences between France and other countries are also revealed by the spans. Figure 9(a) shows the largest spans of roof trusses for train sheds built between 1840 and 1940 in France, Germany, the United Kingdom and the United States, according to their date of construction[6]. With a box and whisker chart, Figure 9(b) underlines the fact that the spans in France were significantly smaller, while the longest spans were built in the United States. This could be interpreted as French designs being more inclined towards delicacy than monumentalism. However, the ratio of height compared to width was higher for French train sheds than English ones (Kanai

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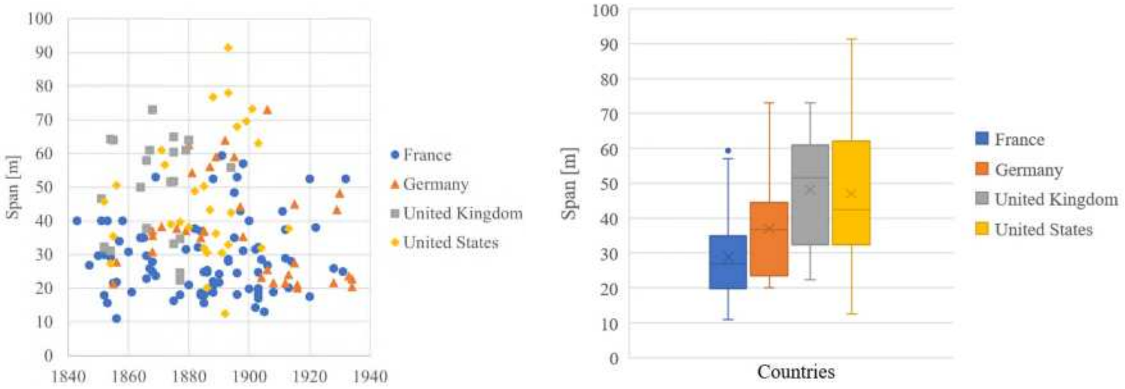
[6] This dataset was gathered from different sources and comprises railway stations both surviving and demolished: 83 French stations (SNCF data and (Kanai 2005)), 37 German stations (Krings 1985; Werner and Seidel 1992; Weller and Tasche 2006), 23 English stations and 29 American stations (Meeks 1956).

2005): the French had a taste for height as a factor of grandiosity, supposedly originating in the French gothic cathedrals.

Regarding heritage assessment, roof truss typologies are useful because their characteristics are easy to gather from photographs or plans and the extensive literature which is available. They are a good indicator of heritage value, based on criteria such as their span, their degree of ornamentation or whether and how much they conform with main types or not. Regarding restoration work, roof truss typologies have an influence on the type of scaffolding used to strip and repaint the metallic roof structure.

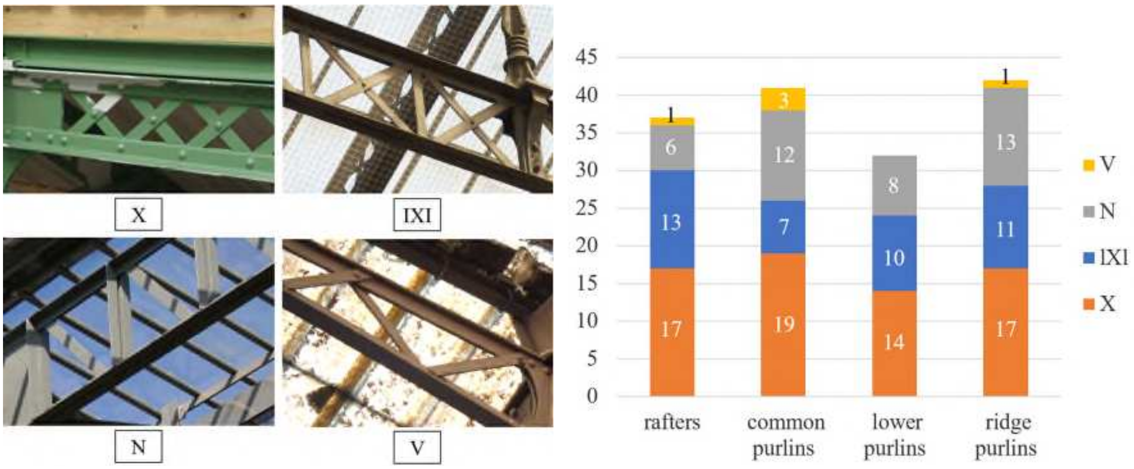


(a) (b)

Figure 9: (a) Largest spans featured by sheds of railway stations built between 1840 and 1940 in France, Germany, United Kingdom and United States, according to the date of construction; (b) Statistical distribution represented as box-and-whisker chart.

4.3. Rafters and purlins

Rafters and purlins are “secondary” structural elements compared to the main roof trusses and were therefore largely neglected by the literature. They were constructed either as solid web girders or as lattice girders. In France, lattice girders were prevalent. Based on recent photographs, the survey of surviving train sheds revealed that about 70% of them feature lattice girders, mostly serving as purlins or rafters. Lattice purlins and rafters were designed using the same truss types first developed for bridges. Given the dimensions and the loads, the lattice girders used as secondary elements in roof structures have the specificity of being very simple assemblies of flat and angle bars, jointed with single rivets. Displaying a wide variety of geometries based on a narrow range of basic elements, these girders bear witness to the morphological type-based understanding of trusses by designers, as opposed to a structural understanding, as evidenced by Rinke and Kotnik (2013). Using a classification based on the geometry of the webs (Cordeau 1901; Klasen 1876), lattice purlins and rafters from French train sheds fall into 4 categories, that can be named after their inventor or after their closest related shape: the Town type with or without vertical elements (lXl or X-shaped), the Howe or Pratt type (N-shaped), the Warren or Neville type (V-shaped). Examples are displayed on Figure 10(a). Figure 10(b) details the number of surviving sheds featuring lattice girders, differentiated according to their function. A distinction is made between common, lower and ridge purlins as some sheds feature lattice girders only for the ridge or the lower purlins while all other purlins are laminated profiles. Figure 10(b) shows that the X and lXl types are in the majority, despite representing a more intricate structural system.



(a) (b)

Figure 10: (a) Examples of the 4 types of lattice purlins and rafters: X (Gare de Cerbère, Cerbère, France), lXl (Gare de Paris-Austerlitz, Paris, France), N (Gare d'Etampes, Etampes, France), V (Gare d'Agen, Agen, France) (Pictures from SNCF-AREP). (b) Number of sheds featuring rafters or purlins of each truss type.

Lattice girders were in competition with solid web girders, made of laminated profiles or of plates riveted together. Laminated profiles had the advantage of being easy to manufacture and of making structural calculations straightforward. Riveted solid web girders required more manufacturing effort but offered more flexibility in height. Lattice girders were used as a structural alternative conforming to beam behaviour (Rinke and Kotnik 2010). They necessitated a lower quantity of material and of rivets and were easy to transport and to assemble on site. In France, they were also favoured for their aesthetics, giving the structure a lighter appearance. In 1863, an engineer wrote in the journal *Nouvelles Annales de la Construction* about rafters in roof trusses: “when a lattice is used [instead of a solid web beam], it is because economy must be sacrificed to ornamentation” (Mathieu 1863). The ornamental quality of X and lXl type-beams was sometimes enhanced by the addition of non-structural elements at the crossing of diagonals (Figure 11).

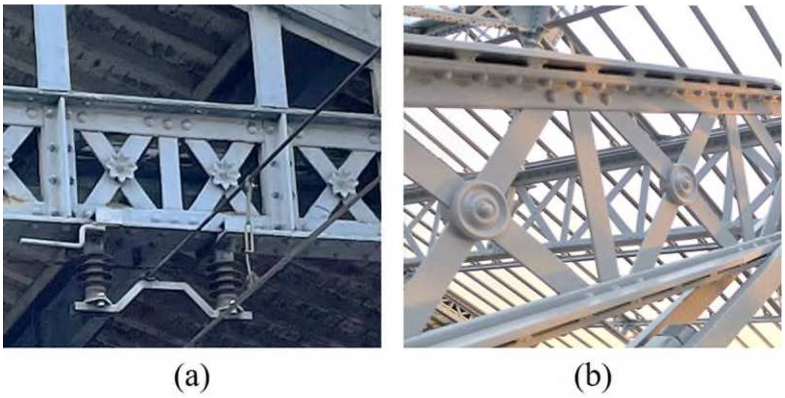
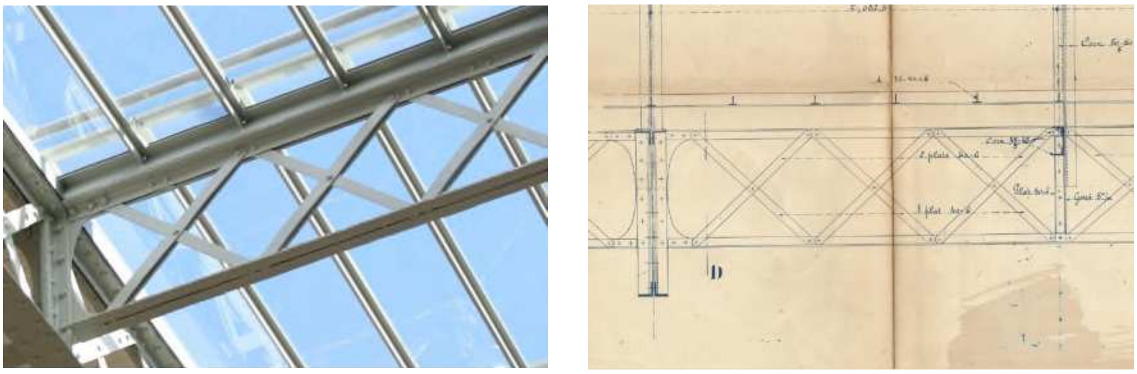


Figure 11: Examples of ornamental additions on lattice lXl-type beams (Pictures from SNCF-AREP). (a) Gare de Blois, Blois, France (picture: H. Franz). (b) Gare de Paris-Austerlitz, Paris, France.

Unlike the ones in France, German metallic train sheds seem to have favoured solid-web girders, thus featuring less ornamental structures, which enhanced their engineering quality compared to their architectural one. This idea was supported by the early Austrian architectural theorist Josef August Lux in 1910 in his work “Engineering aesthetics”, as described by (Krings 1985): “it is the absolute adequacy and utility, the expression of extreme material economy, of strict intellectual discipline, which secures these creations the right to aesthetic recognition.” In German train sheds, trusses were rather used for monumental purposes – for example to create 3-dimensional arches like in the railway stations of Bremen, Cologne, Dresden and Leipzig.

Back to France, lattice purlins and rafters also contributed to the territorial identity discussed for roof trusses. Railway companies regularly employed the same contractors to build several train sheds. Consequently, not only the architectural shape, especially the roof truss typology, was repeated, but also construction details. This is particularly visible on lattice girders. Taking again the example of the Compagnie du Midi, the contractor Daydé et Pillé built train sheds for at least six railway stations around 1900. When comparing the sheds of the Gare de Montauban and the Gare de Bédarieux, not only the general aspect of their metallic structure is similar (see Figure 8), but several details also appear to be the same. The lattice purlins feature diagonals made out of flat bars with rounded extremities, which is original. Also, in the three crosses closest to the support, the diagonals pointing downwards towards the support consist of two flat bars instead of one (see Figure 12). This last detail was a constructive measure against buckling, as these diagonals work in compression but were not formally verified against buckling in the calculation notes (Franz et al. 2022).



(a) (b)

Figure 12: Repeated construction details in train sheds built by same contractor Daydé et Pillé (Picture from SNCF-AREP, archive plan from SNCF archives). (a) Gare de Montaubau, detail of a lattice purlin, Montauban, France; (b) Gare de Bédarieux, detail of a lattice purlin from an archive plan, Bédarieux, France.

Gustave Eiffel also worked for the Compagnie du Midi. With his company, Eiffel built train sheds for the railway stations of Toulouse in 1864 and Agen in 1866. Here again, the architecture is very similar between the two sheds. The roof trusses are Polonceau type with lattice rafters, which was common at the time. The lattice purlins, however, are very specific to these two sheds. The geometry of their webs corresponds to the Warren (V-shaped) type and the chords are T-sections instead of double angles. Both of these features are highly unusual.

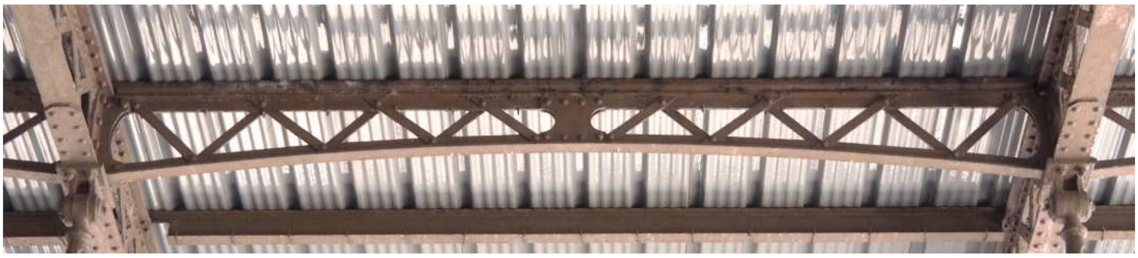


Figure 13: Lattice purlin of the Gare d'Agen, Agen, France (Picture from SNCF-AREP).

Typologies of lattice rafters and purlins bear more subtle witness to French construction practice than roof truss typologies. They played a major ornamental role, characteristic of the French industrial aesthetics. Also, their construction details provide a structural identity related to the contractors. Lattice rafters and purlins are therefore a vector of structural authenticity to be preserved. Strengthening measures implemented on those elements in train shed restorations since 2005 stand in the focus of this article in Section 6.4.

4.4. Skylights and glazed gables

While the roofs of train sheds provided shelter against sun and rain, skylights along the ridge (see Figure 4 and Figure 14(a)) ensured the evacuation of locomotive smoke and glazed gables (Figure 14(b)) prevented excessive wind from being engulfed inside the shed. Skylights were commonly used for ventilation purposes in other types of metallic halls such as market and industrial halls (Lemoine 1986). The structure of glazed gables consisted first of a metallic frame directly supporting the glass panels. The vertical bars of the frame had to transmit the horizontal wind loads to the roof girders on the top and to a trussed girder at the bottom. This bottom girder also supported the weight of the glazing.

As skylights and glazed gables had clear functional roles when they were constructed, their preservation is important for the authenticity of train sheds.

Figure 14 : (a) Skylight along the ridge (Gare d'Evian, Evian, France) (Picture from SNCF). (b) Glazed gable (Gare de Tours, Tours, France) (Picture from H. Franz).

5. Evolution of the roofing

Train shed roofs had an opaque part and a translucent or transparent part. The ratio between the opaque and the translucent parts was chosen to provide enough luminosity while avoiding a greenhouse effect (Lemoine 2022). This ratio varied a lot amongst different train sheds and was often modified as renovations were undertaken. In the shed of the Gare de Nice, opaque and translucent parts were even inverted in the restoration of 1968. This section gives an overview of roofing materials used in the original constructions and in restoration projects over time (Figure 15). It also gives an indication of corresponding loads, to highlight the impact on the metallic structure.

Figure 15 : Example of complete replacement of the roofing: aerial view of the restoration of the shed of the Gare de Tulle in 2019, Tulle, France (Picture from SNCF). Right side: old fibre cement panels. Left side: new steel decks and polycarbonate panels.

5.1. Overview of roofing materials

Throughout the construction period of interest, from 1850 to 1930, the opaque part of original roofs consisted almost always of a zinc roof on timber boarding (see Figure 16(a) and (b)) or of corrugated iron sheets. Corrugated iron sheets were lighter and more economical but despite being galvanized they were sensitive to the corrosive action of locomotive smoke. Some historical sources suggest that railway companies thus preferred zinc roofs protected by their timber boarding (Deharme 1890; Moreau 1898). A few train sheds featured slate or tiled roofs.

The translucent part was made of glass, more or less transparent. Archives or periodical articles related to train sheds did not say much regarding the characteristics of the glass. The first train sheds probably used sheet glass made with the cylinder process, following the trend of the famous Crystal Palace built in 1851 (Hollister 1974) (Kefallinos 2013). The "cylinder process" consisted of a mass of glass hand-blown into a cylinder, then split open and flattened out. Rolled plate glass was patented in 1847 in England and produced in France by Saint-Gobain from 1854. It was produced by pouring molten glass onto a plate and rolling it into a sheet. Because of its greater thickness, its larger dimensions and its favourable price, it quickly prevailed over sheet glass for the roofing of industrial constructions (Carré 2010). In 1893, Léon Appert patented wire glass, in France and Germany. Wire glass was produced mechanically, by pouring molten glass, rolling it into a sheet and then rolling wire netting into it. It became a widespread product in the late 1890s (Kefallinos 2013) and must therefore have been used for the last train sheds built at the beginning of the 20th century (Figure 17(a)).

Little information is available as to what happened to roofs of train sheds between the time of their construction and about 1960. Internal SNCF historical reports, gathered for 34 railway stations, show that an important wave of restoration took place in the 1970s and 1980s[8]. This wave was characterized by the replacement of the original materials by cheaper and lighter materials, that were being produced industrially since the middle of

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[8] Amongst the 34 railway stations of the dataset, 28 were renovated between 1970 and 1990. The restoration dates of the whole dataset range from 1957 to 1995.

the 20th century. Regarding the opaque part of the roofs, slate and tiled roofs were usually preserved but zinc roofs and corrugated iron sheets were often replaced by steel decks (Figure 16(c)), polyester panels (Figure 16(d)), or fibre cement panels. Figure 18(a) indicates the prevalence of each material. Material alternatives to zinc roofs were easier to implement as they did not require different layers of construction and offered bigger spans. For the translucent part, glass was sometimes preserved, sheet glass being replaced by wire glass. However plastic materials, such as polycarbonate, polyester (reinforced with glass fibres), Plexiglas or PVC were favoured (Figure 18(b)). Again, their implementation was easier since ribbed or corrugated plastic panels offered much bigger spans than glass panels. Moreover, they had a safety advantage over glass, being less brittle and avoiding the hazard of potential glass shards.

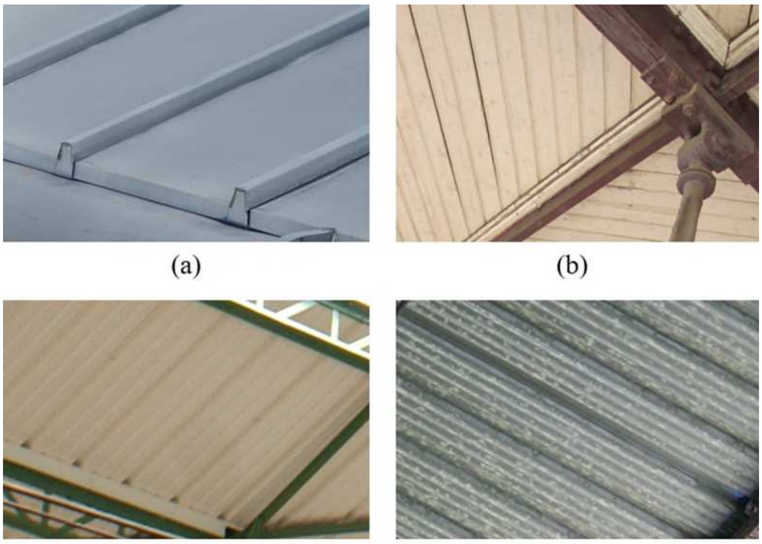
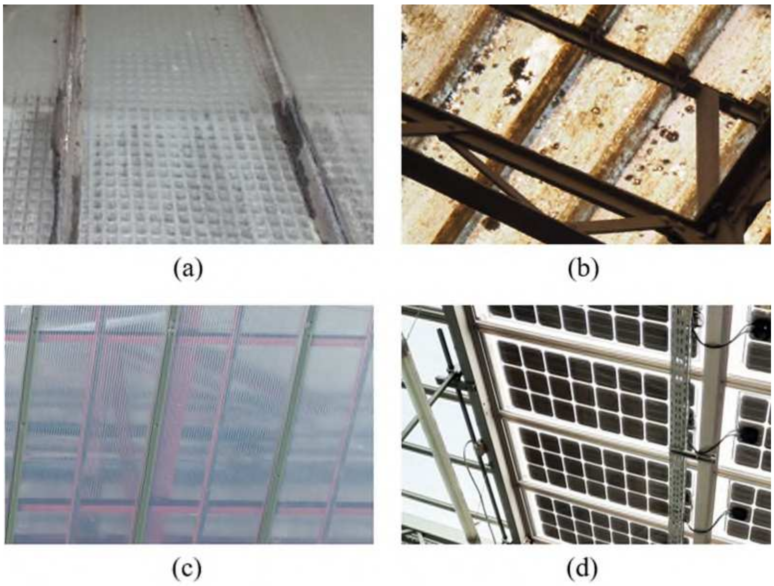
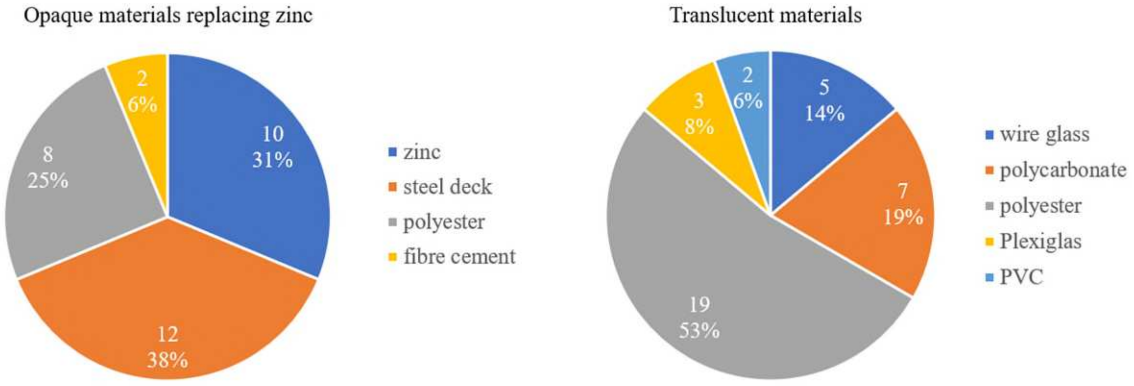

(a) (b) (c) (d)

Figure 16 : Opaque materials used for roofing (Pictures from SNCF). (a) Traditional roll cap zinc roof, seen from above (Gare de Bayonne, Bayonne, France); (b) zinc roof supported by timber boarding, seen from below (Gare de Bayonne, Bayonne, France); (c) steel deck (Gare de Perpignan, Perpignan, France); (d) polyester panels (Gare de Pau, Pau, France).



(a) (b) (c) (d)

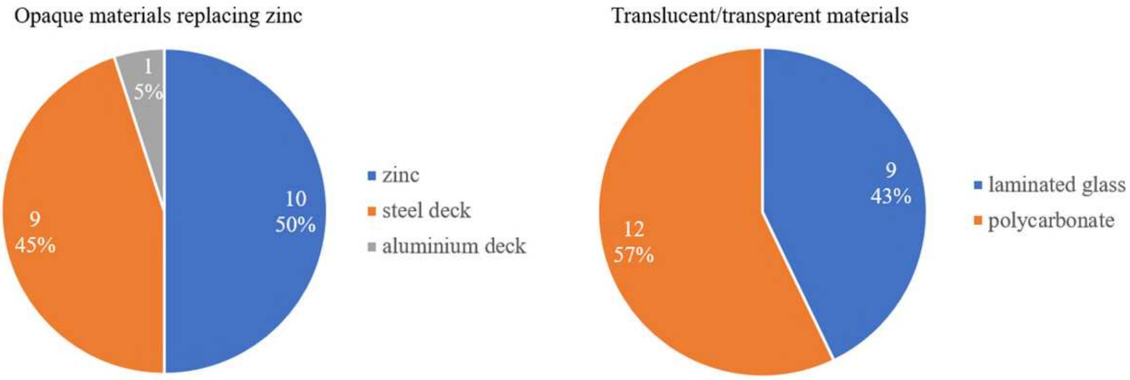
Figure 17 : Translucent/transparent materials used for roofing (Pictures from SNCF). (a) Wire glass (Gare de Lyon, Paris, France); (b) aged polycarbonate (Gare d'Agen, Agen, France); (c) new polycarbonate (Gare de Tulle, Tulle, France); (d) glass panels with embedded photovoltaic cells (Gare du Bourget, Le Bourget, France) .



(a) (b)

Figure 18 : Proportional amounts of roofing materials used in the restoration wave of the 1970s-1980s (the absolute amounts correspond to the number of railway stations in which those roofing materials were implemented).

The longevity of translucent plastic materials proved to be much less satisfying than glass (Figure 17(b)). Since 2005, restoration projects have tended to restore the original roofing, at least for prestigious train sheds. Data was gathered from plans and notes for the restoration of train sheds of 20 stations since 2005. It appeared that, proportionally, the original materials zinc and glass reclaimed their place (Figure 19). Zinc roofs were rebuilt with the traditional roll cap system, even though standing seams are much more common today. Sometimes steel decks were implemented with timber boarding underneath, to preserve the original aspect seen from below. Glazed parts made use of laminated glass. Fixation systems were developed to preserve the existing glazing bars or to replace them with similar profiles, while ensuring waterproofness according to current standards. Even though they restore a sense of authenticity, zinc roofs and glazing are still a minority because they are more expensive than metal decks and plastic panels. Moreover, improvements were made in the manufacturing technology of polycarbonate sheets (Figure 17(c)), in the form of protection from environmental degradation by UV radiation, so that their suitability as an alternative to glass has increased (Schwartz 2014). Future restoration projects might implement glass panels with embedded photovoltaic cells, to exploit the vast surface of train shed roofs for energy production. Such panels have been used for example for a shed of the newbuilt railway station of Le Bourget in 2008 (Figure 17(d)).



(a) (b)

Figure 19 : Proportional amounts of roofing materials used in restoration projects since 2005 (the absolute amounts correspond to the number of railway stations in which those roofing materials were implemented).

5.2. Technical details and permanent loads

5.2.1. Opaque roofing

Original zinc roofs were built using the roll cap system. Zinc sheets were fixed on wood rolls with a trapezoidal cross section which were themselves supported by timber boards. In the train sheds for which data was available, the weight of historical or reconstructed roll cap zinc roofs varied between 20 and 40 kg/m² depending on the thickness of the layers of timber boarding beneath the zinc sheets. The first layer of timber boarding, used to fix the wood rolls, had a thickness varying between 18 and 27 mm. Either this layer was left apparent or another layer was added below. This additional layer, between 27 and 34 mm thick, had its boards oriented diagonally. In the original design, this layer was probably meant to contribute to the bracing of the structure. Corrugated iron sheets weighed about 10 kg/m², much lighter than zinc roofs, while slate and tiled roofs were much heavier. Based on Cordeau (1901), the weight of slate roofs including timber boarding can be estimated at 40 kg/m² and the weight of tiled roofs at 60-100 kg/m² depending on the type of tiles.

In the 1970s-1980s, the opaque polyester panels used to replace zinc roofs or corrugated iron sheets were about 3 kg/m², while fibre cement panels were about 20 kg/m². Steel decks were usually around 7-8 kg/m².

In recent restoration projects since 2005, reconstructed zinc roofs tried to reproduce the original constructive pattern, yielding a similar weight. When steel decks were used, they were the same weight as those used since the middle of the 20th century. However, in some projects, timber boarding was added beneath the steel deck to keep the original aspect from below. The resulting weight was 30 kg/m², and so, compared to a zinc roof, it represented only an economic gain, with no structural benefit. Also the authenticity of this variant is questionable.

The study of the weight of opaque roofing materials shows that the restorations of the 1970s and 1980s tended to reduce the permanent loads supported by the metallic structure of train sheds, while the more recent restorations of the 21st century yielded comparatively higher loads (Figure 20). The study of the weight of glazing materials is now presented to confirm this tendency.

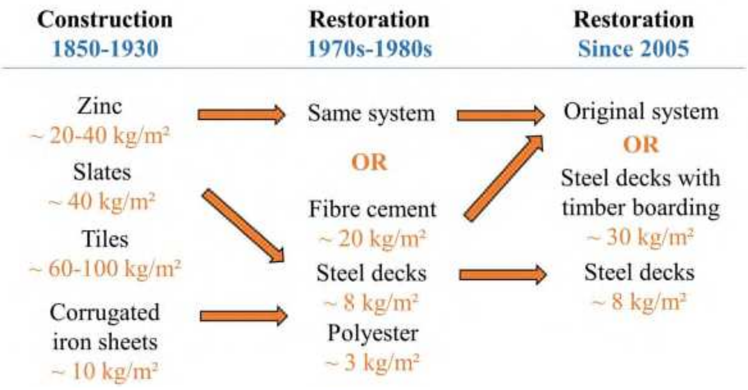


Figure 20: Overview of the evolution of the loads associated with opaque roofing materials.

5.2.2. *Glazing*

The permanent load associated with roof glazing born by the metallic structure results from the weight of the glazing panels and the weight of their metallic frame. Little data can be found regarding the thickness of original glazing in train sheds built between 1850 and 1930. In the Crystal Palace, sheet glass panels were 2 mm thick, spanning 25 cm. This choice was apparently consistent with the practice of the time, as these dimensions had been used for the glazing of railway stations built in the 1840s in England (Hollister 1974). In French train sheds, glass panels were about 50 cm wide, so that the glass thickness must have been closer to 4 to 6 mm. These were typical dimensions for sheets of rolled plate glass (Carré 2010). In Belgium, glass plates used for roof coverings were usually “verre double”, with a thickness of 3-4 mm (Lauriks, Wouters, and Belis 2018).

The French journal *"Le Génie civil"* indicated in 1886 that the new train sheds under construction for the Gare St-Lazare in Paris had a glazed roof using 5 to 6 mm thick glass panels supported by specially designed glazing irons spaced every 58 cm (Boca 1886). The total weight was then 22 kg/m². Original design reports and plans were available to the authors for the present article on the stations of Bordeaux Saint-Jean built in 1898 and Bédarieux built in 1903. In Bordeaux, the glass panels were 4 mm thick, accounting for 10 kg/m², and the frame was constituted of metallic T-sections 45 mm x 35 mm x 5 mm spaced every 42.1 cm. The total weight was 17 kg/m² then. In Bédarieux, the glass panels were 6mm thick and the frame was made of T-sections spaced every 41.6 cm, total weight was 22 kg/m² then. From the end of the 19th century, wire glass was employed, with a traditional thickness of 6 to 7 mm (Carret 1909). Overall, assuming glass panels between 4 and 6mm thick and a frame weighing a maximum of 10 kg/m², original glazing for train sheds built between 1850 and 1930 weighed about 25 kg/m².

In the restoration wave of the 1970s-1980s, the plastic panels used to replace the glazing led to a significant load reduction, dividing the roof weight by almost ten. The panels themselves were lighter than glass, but they also offered larger spans, so that the metallic frame structure was removed. A calculation note edited in 1983 for the station Gare de Tours took 2 kg/m² as a load assumption for the new polyester panels[9]. For other railway stations, restoration plans indicated the profile of the corrugated polyester panels, for example NERVESCO 1000TS (Gare d'Aurillac, restoration of 1985) or C25 (Gare d'Angoulême, restoration of 1976). The associated weight could be extracted from

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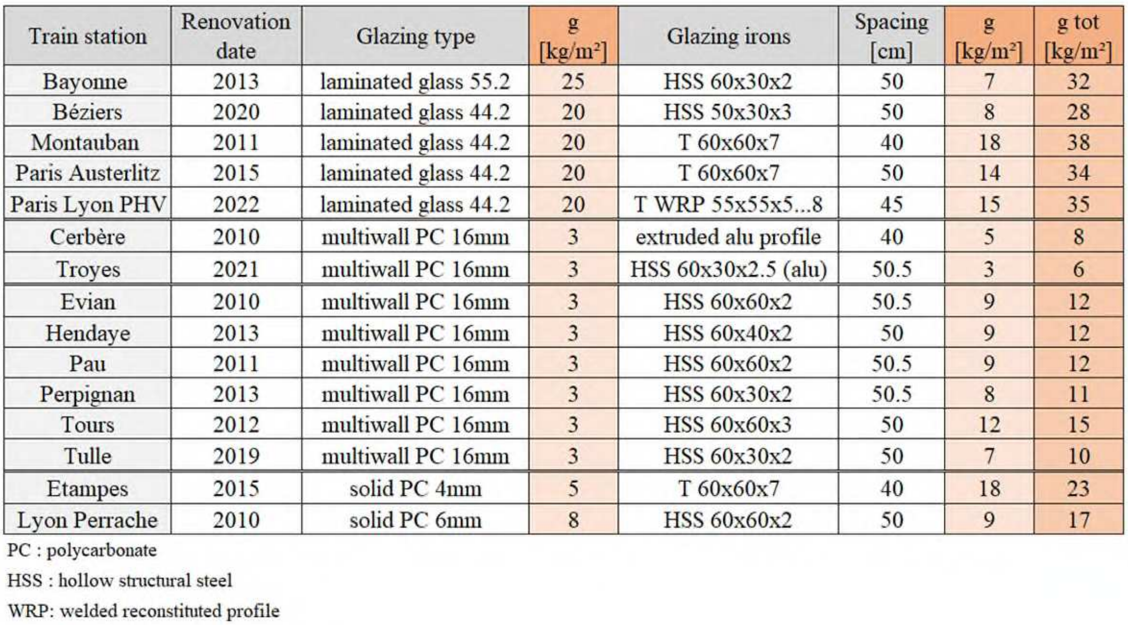
[9] Société industrielle SMI. 1983. Gare de Tours – Réfection verrière – Adjonction d'une panne. [Calculation note for a new purlin]. Box B00203966 D00860383. Centre national des archives de la SNCF, Le Mans, France.

technical data sheets of today's equivalent products. The weight of plastic panels, whether polyester, polycarbonate or PVC, was about 2-3 kg/m², depending on the thickness of the sheet.

Since 2005, restoration work has kept or re-established the original spacing between glazing irons, whether the translucent part of the roof was renovated with laminated glass or with polycarbonate. The safety glass panels were usually type 44.2 or 55.2, which means an assembly of two glass plates of 4 mm thickness (or 5 mm respectively), with an interlayer of two translucent PVB films of a total thickness of 0.76 mm. These panels weighed 20 kg/m² and 25 kg/m² respectively, the weight of the interlayer being negligible. Regarding polycarbonate, different products were favoured, either multiwall sheets of 16 mm thickness, weighing 2.5-3 kg/m², or solid sheets of 4 to 6 mm thickness, weighing 5-7.5 kg/m². Precise characteristics of the glazing have been gathered from recent train shed restorations over the last 15 years and are presented in Table 1. This table shows that the weight of glazed roofs with glass ranged roughly from 30 to 40 kg/m², while the weight of polycarbonate roofs was between 6 and 23 kg/m². The use of multiwall polycarbonate sheets led to a maximum weight of 15 kg/m². Regarding the glazing irons, they were usually made of steel. Two projects used aluminium profiles, probably more expensive, but leading to a substantial reduction in weight. It can also be noted that when rectangular hollow profiles were used, they were lighter than when open T-shaped profiles were used. This is presumablybecause hollow profiles are more resistant to buckling. The choice of T-shaped profiles over hollow ones could be related to their thinner appearance, closer to the original aspect. However heavier roofs were more likely to require strengthening of the metallic structure.

Table 1: Glazing characteristics and associated weights for recent train shed restoration projects.



Train station	Renovation date	Glazing type	g [kg/m^2]	Glazing irons	Spacing [cm]	g [kg/m^2]	g tot [kg/m^2]
Bayonne	2013	laminated glass 55.2	25	HSS 60x30x2	50	7	32
Béziers	2020	laminated glass 44.2	20	HSS 50x30x3	50	8	28
Montauban	2011	laminated glass 44.2	20	T 60x60x7	40	18	38
Paris Austerlitz	2015	laminated glass 44.2	20	T 60x60x7	50	14	34
Paris Lyon PHV	2022	laminated glass 44.2	20	T WRP 55x55x5...8	45	15	35
Cerbère	2010	multiwall PC 16mm	3	extruded alu profile	40	5	8
Troyes	2021	multiwall PC 16mm	3	HSS 60x30x2.5 (alu)	50.5	3	6
Evian	2010	multiwall PC 16mm	3	HSS 60x60x2	50.5	9	12
Hendaye	2013	multiwall PC 16mm	3	HSS 60x40x2	50	9	12
Pau	2011	multiwall PC 16mm	3	HSS 60x60x2	50.5	9	12
Perpignan	2013	multiwall PC 16mm	3	HSS 60x30x2	50.5	8	11
Tours	2012	multiwall PC 16mm	3	HSS 60x60x3	50	12	15
Tulle	2019	multiwall PC 16mm	3	HSS 60x30x2	50	7	10
Etampes	2015	solid PC 4mm	5	T 60x60x7	40	18	23
Lyon Perrache	2010	solid PC 6mm	8	HSS 60x60x2	50	9	17

PC : polycarbonate
HSS : hollow structural steel
WRP: welded reconstituted profile

Finally, as mentioned earlier, glazing can be used to generate energy. Some restoration projects of the last 5 years have included studies to integrate photovoltaics. Two main options exist for photovoltaic glazing: crystalline silicon (c-Si) cells or amorphous silicon (a-Si) cells, encapsulated inside two glass panes with translucent resin. C-Si modules (like the ones presented on Figure 17(d)) are less translucent than a-Si modules but produce more energy (Casini 2016). According to some SNCF studies, the weight of such photovoltaic modules would be about 50 kg/m². They have not been implemented yet in restorations.

The study of the weight of transparent or translucent roofing materials confirms and even enhances the results obtained with opaque materials. The suggested tendency becomes even clearer: through restorations of the 1970s and 1980s, permanent loads supported by the metallic structure of train sheds decreased, while through restorations since 2005, permanent loads increased (Figure 21). This questions the authentic character of recent restorations. They strived to restore the original aspect of the roofing while filling today's requirements in terms of safety and durability. However, by doing so, they overloaded the metallic structure, which led to more strengthening measures. In turn, these strengthening measures harmed the authenticity of the restored train sheds, by modifying the appearance of the structure or by introducing irreversible changes. Structural interventions are discussed in detail in the next section.

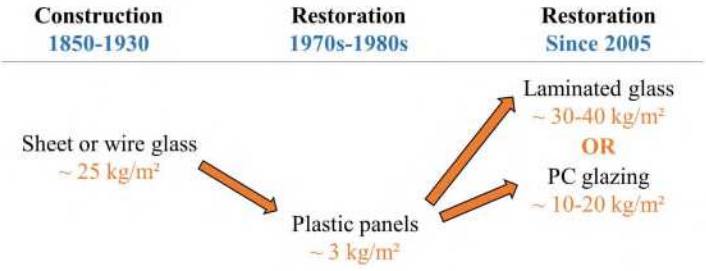


Figure 21: Overview of the evolution of the loads associated with transparent/translucent roofing materials.

6. Structural interventions

6.1. Skylights and glazed gables

6.1.1. Removal and reconstruction

In the course of restoration projects in the 20th century, skylights were often removed. A historical note from the SNCF archives dating back to 1981 indicated that skylights were mandatory installations when trains were still powered by steam but were no longer needed after the end of steam locomotives[10]. Their removal could moreover minimise subsequent maintenance expenses, because the metallic structure would then be better

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[10] 1981. Note d’argumentation pour le financement de la rénovation des grands halls métalliques. [Note about the funding of train shed restorations]. Box 0823LM1024. Centre national des archives de la SNCF, Le Mans, France.

protected from the weather. There are also a few examples of modified skylights. In the railway station of Etampes, the original double-pitched skylight built in 1911 was replaced in the second half of the 20th century by a curved skylight made of curved polycarbonate panels, thus eliminating any waterproofing problems at the ridge. The original metallic structure of the skylight was removed. In the restoration projects since 2005, skylights have usually been reconstructed with dimensions close to the original, for heritage reasons but also for the purpose of ventilation. The new metallic structures were built according to the current construction practice, using bolted or welded laminated profiles.

The original glazed gables lost their prevalence in the 20th century. Sometimes glass panels were replaced by plastic panels, but in many cases, broken glass panels were simply removed, while the metallic frame or at least the bottom trussed girder were left in place. In some cases, the metallic structure of the glazed gables was removed completely. This results in very different impressions of originally similar structures: in the railway station of Bordeaux Saint-Jean the glazed gables with their glazing were completely preserved and renovated in 2017, while in Bédarieux, only the bottom girders and some vertical bars were preserved (Figure 8(b)), and in Montauban and Mont-de-Marsan, the gable structure was completely removed (Figure 8(a)). In some railway stations, the structure of the extreme roof trusses, deprived of glazing, was modified, as in the station of Carcassonne in the 1960s. Only the bottom girders of the glazed gables were preserved. New metallic struts, reminiscent of the geometry of the Polonceau roof trusses inside the shed, were added to transmit the load of the higher roof.

6.1.2. Influence on wind loads

Wind loads started to be taken into account in design calculations around 1840 (Holzer 2006) and were integrated in design regulations in Europe starting from 1880

(Schueremans et al. 2018). In France the first design regulations regarding train sheds were released in 1902 (‘Circulaire Du Ministre Des Travaux Publics Aux Préfets Du 25 Janvier 1902 (Halles à Voyageurs et à Marchandises Des Chemins de Fer)’ 1904) and recommended the assumption of a wind load of 150 kg/m², in a direction inclined 10° to the horizontal. This assumption, that does not reflect any real aerodynamical behaviour, had already been developed in the 1850s. Wind uplift was not considered in design practice until the 1930s, even though this phenomenon had been highlighted by Navier almost a century before (Holzer 2006). The integration of wind uplift in the structural assessment of train sheds built between 1850 and 1930 led to strengthening measures for some structural elements, as the reversal of the sign of wind loads sometimes caused elements designed in tension to work in compression and thus be exposed to buckling.

Beyond the evolution of regulations, the effect of wind uplift was physically increased by the removal of glazed gables, as wind would then act on both the upper and lower surfaces of the roof. According to today’s Eurocode regarding wind actions (EN 1991-1-4, 2005), train shed roofs can usually be regarded as “canopy roofs” because two or three of their sides are open (*ibid* §7.2.9(2)). The removal of glazed gables means a reduction of the degree of blockage φ of the wind as defined for the design of “canopy roofs” (EN 1991-1-4 2005) from about $\varphi=0,5$ (50% of the gable surface is closed) to $\varphi=0$. For wind blowing in the longitudinal direction, this leads to an increase of the estimated wind force of 40%.

Maintaining, removing or reconstructing the skylights and the glazed gables has therefore an influence not only on the architectural appearance but also on the structural authenticity. Removing or modifying those substructures changes the loading conditions related to wind. Thus, it modifies the structural behaviour and the functionality of train sheds, namely ensuring a good ventilation while protecting from wind gusts.

6.2. Maintenance equipment

In the course of restoration projects, equipment was added to train sheds, to provide more safety for the workers carrying out inspection and maintenance tasks. Some equipment such as lifeline systems have negligible weight, but maintenance platforms must usually be taken into account. This type of equipment installed over the roof is discrete and does not have any impact on the aspect of the train shed for passengers (Figure 22(a)). A counterexample is given by the stairs that were added below the roof surface in the railway station of Bordeaux Saint-Jean in 1928, with a relatively massive railing system to allow the stairs to move in the longitudinal direction. Such invasive measures were avoided in more recent restoration projects. However, in the restoration of Bordeaux Saint-Jean in 2016, the stairs and rails of 1928 were left in place, thus endorsing a profound modification of the original aspect.

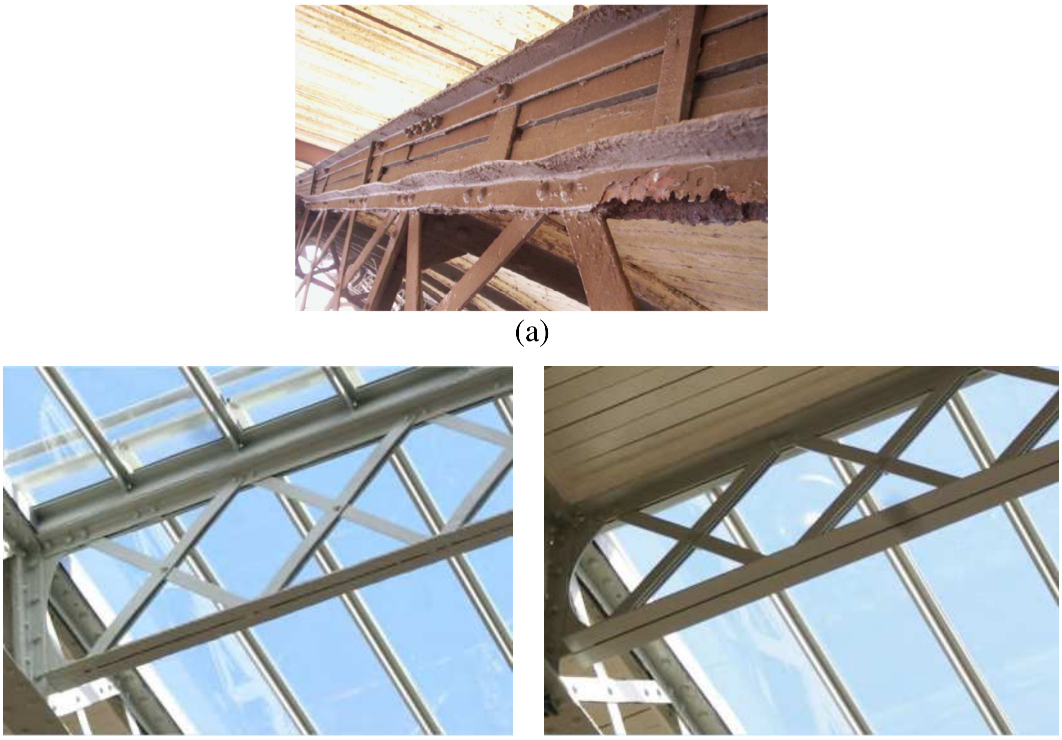

(a) (b)

Figure 22 : Maintenance equipment added on the course of restoration projects in the train shed of Bordeaux Saint-Jean, Bordeaux, France (Pictures from SNCF and by H. Franz). (a) Maintenance platform and lifeline system over the roof, added in 2016 (picture: SNCF); (b) Metallic stairs and rails below the roof, added in 1928.

6.3. Repair or replacement of structural elements

The main pathology of the metallic structures of train sheds is corrosion. In restoration projects since 2005, when the section of some structural elements was too seriously reduced because of corrosion, those elements were either repaired or replaced. Repairs often consisted in locally adding metallic plates. Figure 23 shows the example of the local riveted repair of the bottom chord of a roof truss in the railway station of Troyes, after restoration in 2021. When damaged areas were too large, structural elements were replaced, while aiming to preserve the original aspect as far as possible. Figure 24 shows the example of the purlins of the train shed of Montauban. Some of them were heavily corroded, especially their top chord (Figure 24(a)). They were then replaced (Figure 24(c)), keeping a similar aspect to the original preserved purlins (Figure 24(b)).

Figure 23: Local repair of a chord with added riveted plates in the train shed of Troyes renovated in 2021, Troyes, France (Picture from SNCF).



(a)

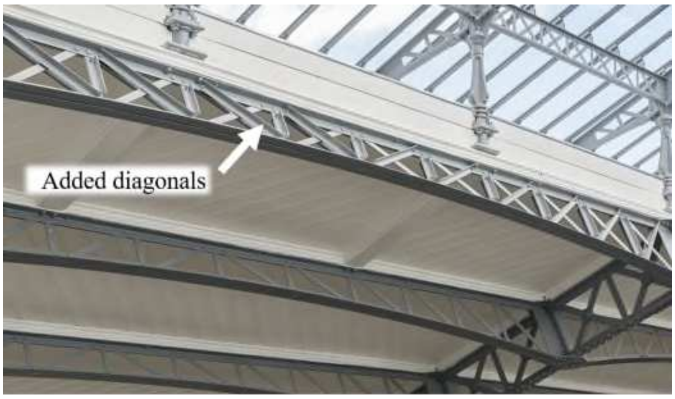
(b) (c)

Figure 24 : Replacement of purlins in the train shed of Montauban, France (Pictures from SNCF). (a) Corroded purlin in 2007 before restoration; (b) Original non-corroded repainted purlin after restoration of 2011; (c) Corroded purlin replaced by a new purlin after restoration of 2011.

6.4. Strengthening measures

Whether it was because of the effective increase in the dead loads of the roof or because design criteria became stricter, strengthening measures were often carried out during restoration projects. Little data could be found regarding restoration projects of the 20th century. Apart from the addition of bracing systems, the strengthening measures implemented seemed to disregard the original functionality and the visual impact. In Bordeaux Saint-Jean, probably around 1980, the lattice rafters of the skylight were reinforced with tension ties, transforming them into underspanned beams (Figure 25(a)). This strengthening measure modified the functionality of the rafter, from a beam working in bending to a compression element. In Paris Austerlitz, the lattice purlins supporting the skylight were reinforced in 1983 with added diagonals (Figure 25(b)). The original lattice purlins had only diagonals pointing upwards towards the middle of the span, thus working in compression. The added diagonals made of corner plates transformed the original lattice girders into girders with crossed out sections, thus changing their aspect considerably. Furthermore, the new diagonals worked in tension and had a much larger section than the original diagonals, so that the latter probably did not contribute to the bearing capacity anymore. These examples of strengthening measures went against the idea of authenticity: beyond being visually invasive, they modified the structural behaviour of the reinforced girders.

(a)



(b)

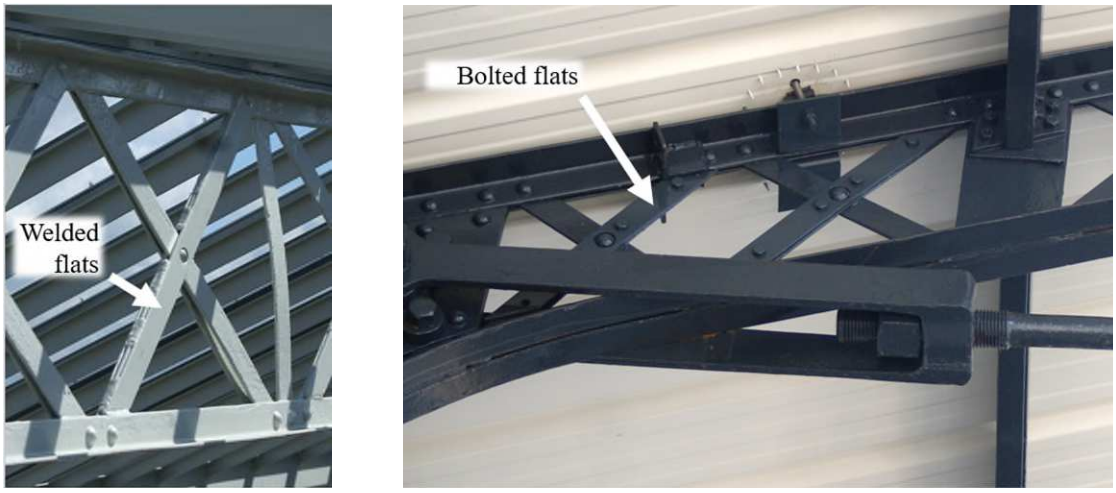
Figure 25: Invasive strengthening measures of the end of the 20th century (Pictures: SNCF). (a) Gare de Bordeaux Saint-Jean: underspanned lattice rafters, Bordeaux, France; (b) Gare de Paris-Austerlitz: diagonals added to lattice purlins, Paris, France.

In restoration projects since 2005, strengthening measures have been less invasive. Technical details were analysed by the authors for eleven restoration projects involving strengthening measures. The interventions could be classified in two categories: interventions increasing the section of existing structural elements, or interventions adding elements to the structure. Lattice purlins and rafters were often reinforced by increasing the section of their web or chord members, to prevent them from buckling. Flat or L-shaped plates were added to the original elements with welds or bolts (Figure 26(a) and (b)). Welds were visually better integrated than bolts but did not obey the principle of reversibility recommended for the restoration of heritage structures (ICOMOS 2003). Bolts created holes in the existing elements, while welds probably induced residual stresses. These variants did not significantly change the load distribution in the existing elements. On the contrary, in the railway station of Cerbère, laminated HEA100 profiles were added on top of the lattice purlins to create a new cross-section far more rigid than the original one and with a displaced neutral fibre (Figure 26(c)). The restoration of the railway station of Béziers in 2020 took it a step further by adding new tubular purlins on top of the original ones and structurally independent from them, thus completely deactivating them. This solution favoured the preservation of the aspect of the structure over its structural functionality (Figure 26(d)).

As an alternative to the increase of existing sections, added structural elements also aimed at preventing buckling issues. In some projects, tension rods were added to link the purlins together, either at the level of the top chord or through the web. These tension rods had thin circular or L-shaped sections (Figure 27(a)). To provide buckling restraints for the bottom chord of lattice girders, small brackets were sometimes added (Figure 27(b)).

Overall, the survey of strengthening measures in the eleven recent restoration projects providing relevant data showed that no intervention type stands out. The strengthening measures carried out were extremely varied, both in their principle and their constructive implementation. It appears that there is no common practice as to how the metallic structure of train sheds should be reinforced.

Strengthening measures from the two last decades strived to remain discrete. Still, their impact on the authenticity of the original structures is non negligible. The less discrete variants, involving sections reinforced by bolted plates or added structural elements, can profoundly change the appearance of the structure when they accumulate. Figure 1 provides a good example. The end result of the restoration is aesthetically satisfying (Figure 1(b)). However, when compared to the original structure, it can be noticed that the restored structure, with added brackets and tension ties, has lost some of its lightness. This results in a loss of authenticity, as lightness was a key characteristic of metallic structures in the 19th century. As to the most discrete variants, they are also questionable. Welded added sections are non reversible. The addition of new purlins on top of the original ones changes the load distribution or even deactivates some structural components. A loss of functionality means a loss of authenticity.



(a) (b)

(c) (d)

Figure 26: Interventions increasing the cross-section of existing elements or replacing them (Pictures from SNCF-AREP). (a) Welded flats, Gare de Montauban, Montauban, France; (b) Bolted flats on existing diagonals, Gare d'Hendaye, Hendaye, France; (c) Added HEA100 laminated profile on top of existing lattice purlin, Gare de Cerbère, Cerbère, France; (d) Added tubular purlins effectively replacing the existing ones, Gare de Béziers, Béziers, France.

(a) (b)

Figure 27: Interventions adding structural elements to provide buckling restraints (Pictures from SNCF-AREP). (a) Tension ties between purlins, Gare de Pau, Pau, France; (b) Bracket restraining the bottom chord of a lattice purlin, Gare de Montauban, Montauban, France.

7. Conclusion

Based on an extensive survey of surviving train sheds, this article establishes the specificities of their metallic structures and gives insight into the impact of restoration projects on these structures. Regarding structural specificities, the study went beyond the roof truss typologies traditionally used to classify the architecture of train sheds. In comparison with other countries, French train sheds mainly featured double-pitched roofs, with smaller spans, and their aesthetics relied on ornamentation, to which the metallic structure itself contributed with lattice rafters and purlins. The typicality observed not only in the architecture but also in construction details enhanced the technical value of train sheds, that can be traced back to the preferences of engineers or contractors.

Regarding restoration practices, until the 1980s, the choice of roofing materials and the elaboration of structural interventions disregarded the preservation of the original appearance. Since 2005, in the framework of the restoration program carried out by SNCF, train sheds have been restored with a definite sensitivity towards heritage preservation. Roofing materials and techniques have strived to reproduce the original impression, removed skylights were reconstructed, repairs and strengthening measures stayed discrete. However, this article demonstrated that current restoration practices have led to an increase of the permanent loads supported by the structure, which have made further structural interventions necessary. It was also shown that the strengthening measures carried out were extremely varied, both in their principle and their constructive implementation. This suggests that an optimisation of strengthening measures could be possible by comparing criteria such as their structural efficiency, their ease of implementation, their visual impact or their “authenticity”. Some strengthening measures, despite being visually well integrated, significantly changed the load distribution in existing structural members, or even deactivated them.

It is interesting to note that the tendency observed for recent restoration projects in France does not necessarily apply to other countries. For example, in 2006, a completely different strategy was adopted for the restoration of the train shed of Dresden in Germany. Instead of restoring the roofing with original materials, the metallic structure of 1898 was covered with a PTFE-coated glass fibre membrane (Vitzthum, Voland, and Foster & Partners 2006). The idea was to increase the natural daylight and "reveal" the metallic structure. The notion of "revealing" was biased. Since the membrane decreased the dead loads but generated high compression loads in the existing arches, the load-bearing system was deeply modified and it was rather the architecture than the structure that was revealed. It could be argued that the authenticity of historic metallic train shed structures lies in their functional role and their power to impress, relying on state-of-the-art construction techniques. These are the qualities that inspired the new generation of metallic train sheds built in the 21st century, like the railway station of Orléans (Figure 28). However, in order to best preserve the spirit of historic metallic structures, a slightly different perspective might beapt: for the structure to serve the architecture, restoration should serve the structure.

Figure 28: Gare d'Orléans, built in 2009, Orléans, France (Picture from SNCF-AREP by D. Boy de la Tour).

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