Joining techniques in nineteenth- and early twentieth-century Belgian timber roofs

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ABSTRACT: An intimate knowledge of joining techniques is crucial for the documentation and restauration of old timber structures, yet these assemblies are often overlooked in historical studies or during on-site assessment. To help bridge this gap, this paper provides an overview of the joining techniques used in Belgian timber roof structures during the nineteenth and early twentieth centuries. Based on the author's on-site observations of over 50 roofs, four types of joint are described and analysed: (1) timber-to-timber joints, (2) nailed and bolted layers of timbers, (3) iron straps, stirrups and plates, and (4) connections between timber and iron members. Thus, this study intends to help researchers and heritage specialists to better interpret connection details during investigations of nineteenth- and early twentieth-century timber roofs.

KEYWORDS : 1820-1920, Belgium, Timber Structures, Joint, Roof

1 INTRODUCTION

During the nineteenth century, the industrialization of the construction sector brought alternatives to centuries-old practices in European timber carpentry. Whereas builders used to rely on techniques passed from generation to generation with little variation, the rapid technological evolutions in the nineteenth century forced them to develop new techniques rapidly in order to build larger, lighter, faster and cheaper structures. Consequently, joining techniques used in the assembly of timber structures underwent important changes.

Although the main traditional joining techniques used until the late eighteenth century have been studied by various scholars (Holzer 2015; Hoffsummer 2009; Yeomans 1992), the connections and connecting devices introduced during European industrialization received little attention. To address this, on-site observations and measurements of over 50 roofs have been undertaken, providing an overview of the assemblies used in Belgian timber roofs during the nineteenth and early twentieth centuries. In this paper, the different assemblies are categorized in four main types, varying from traditional to innovative: timber-to-timber joints, nailed and bolted layers of timbers, iron straps, stirrups and plates, and connections between timber and iron members. For each group, the main developments prior to the nineteenth century are briefly reviewed and form the basis for the analysis of the subsequent period. Each group is illustrated by means of 15 exploded views of representative examples. This study is embedded within a broad historical framework including evolutions in the timber trade, developments in iron engineering, sawing techniques, typological evolutions, collaboration between the building actors and, their practical and theoretical knowledge.

2 TIMBER-TO-TIMBER JOINTS

A multitude of timber-to-timber joints has been developed since prehistoric times, but contrary to the primitive stone or metal tools that were used to make them, practically no evidence of the earliest joints has reached us. Nevertheless, exceptional archaeological discoveries have shown that elaborated connections (wedged tusk tenon joints and interlocking corner joints) were already used by the first farmers some 7,000 years ago (Tegel et al. 2012). Timber used in Antiquity suffered a similar fate: only a few artefacts have been preserved thanks to wet subsoils or dry climates. Fortunately ancient Greek and Roman literature allows a better understanding of woodworking technology from that time (Ulrich 2007). As a matter of fact, the first-century Roman carpenter used practically the same assemblies as his early nineteenth

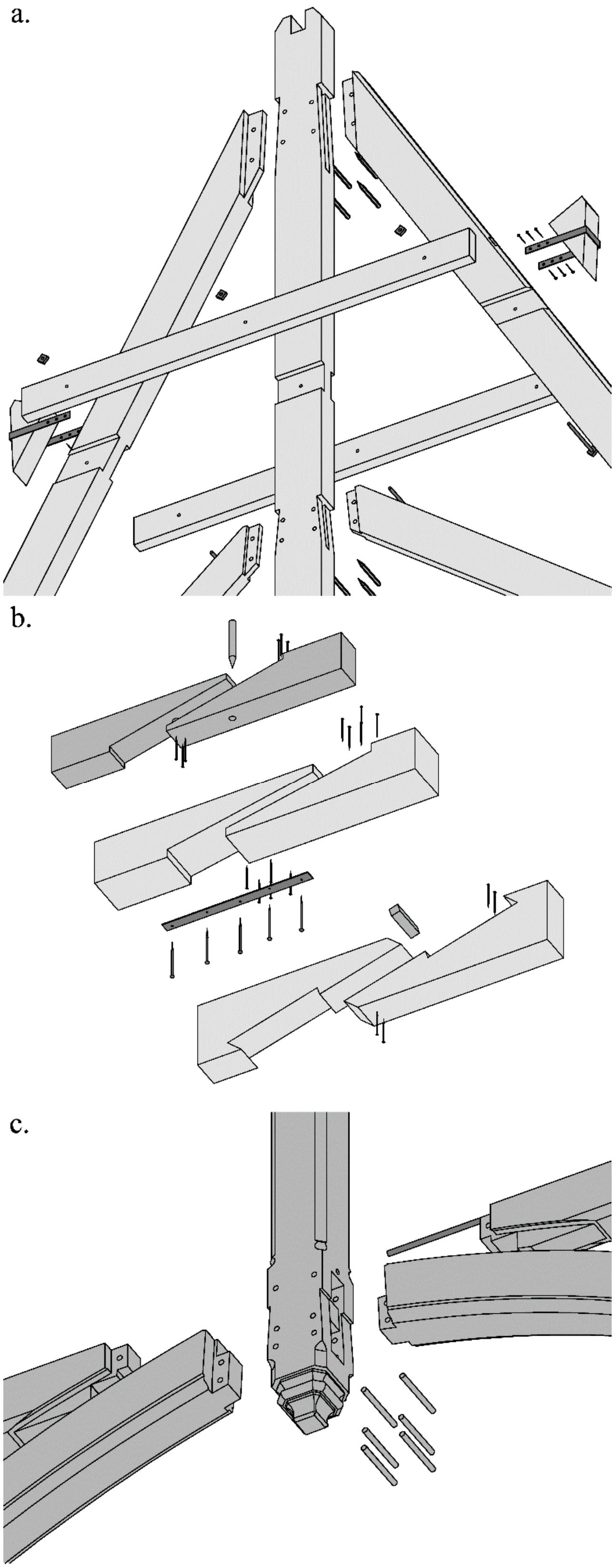


Figure **1.a**. Mortice and tenon joints (top and bottom connections) and lap joints (middle connection). Span: 7 m (St-Pierre church, Jette, 1878). **1.b.** Stop-splayed scarf joint with wooden peg (Grand Hospice, Brussels, 1825); with iron strap (Immaculée Conception church, Brussels, 1856); Trait de Jupiter with wooden key (St-Josse church, St-Josse-ten-Node, 1864). 1.c. Mortice and tenon joints. Span: 8.5 m (Maison du Roi/Broodhuis, Brussels, 1883).
Colour code: white = Populus sp.; light grey = Pinus Sylvestris L.; grey = Quercus sp.; dark grey = wrought iron/cast iron/steel.

century successor (mortice and tenon joints, lap joints and scarf joints) and shared the same toolkit (frame saw, axe, adze and chisel).

In France, Belgium and the Netherlands, roof structures were typically assembled with lap joints (and wooden pegs) until the thirteenth century, when mortice and tenon joints moved to the forefront (Hoffsummer 1995; Janse 1989; Hoffsummer 2009). However, mortice and tenon joints had already been introduced much earlier in other regions: the oldest still-standing roof, built in the sixth century on the Sinai Peninsula (Egypt), was constructed with such assemblies (Koufopoulos 2004). In Belgium, mortice and tenon joints remained in common use until the twentieth century, especially for two typical compressive connections: between rafters and king-posts and between rafters and tie beams; secured with one, two or three oak pegs, according to the size of the connection. (Fig. 1.a.)

Lap joints also found their way into nineteenth-century carpentry through the replacement of wooden pegs by iron bolts, allowing builders to easily connect double members (e.g. collar beam, scissor bracing, interrupted tie beam) on each side of single elements (e.g. rafter, king-post, tie beam). (Fig. 1.a.) Although lap joints with iron bolts and iron pins (without nuts) were recorded in Orleans (France) as early as the late fifteenth century (Alix and Noblet 2009), these assemblies (with threaded bolt and nuts) were apparently introduced in Belgium only in the 1820s.

Scarf joints were typically used for longitudinal joints in purlins and, less frequently, in long posts and tie beams (though iron ties often replaced the latter from the 1850s). Different ways of fastening scarf joints coexisted: wooden pegs, wooden keys (forming a *trait de Jupiter*), nails, or iron plates. (Fig. 1.b.) Keys and pegs, often combined with iron nails, became less frequent from the 1870s onwards when the sole use of nails and plates replaced these more labour-intensive techniques.

As a general trend, timber-to-timber joints became increasingly simpler in order to speed up building processes and reduce labour costs at the same time. Early nineteenth-century building specifications indicate that carpenters would sometimes receive additional payment for the cutting of joints (e.g. two florins per scarf joint during the construction of the *Grand Hospice* in Brussels, 1825), a practice that thereafter disappeared. For economic reasons, later contractors were thus more likely to avoid laborious assemblies whenever possible unless it was specified by the architect. In the last quarter of the nineteenth century, complex timber joints were thus on the brink of extinction, and were used only in exceptional projects such as the Gothic-revival roof of the *Broodhuis/Maison du Roi* (Brussels, 1883), for which finding competent craftsmen was a major challenge (Vandenabeele, Bertels, and Wouters 2017). (Fig. 1.c.)

3 NAILED AND BOLTED LAYERS

Implementing innovations to reduce the cost of carpentry work is clearly not exclusively a nineteenth-century practice. A noteworthy example is provided in the mid-sixteenth century by Henri II's architect Philibert De l'Orme (c.1514-70), who gave his name to a system of vaulting using thin timber arches built with vertically layered planks. One main advantage of these roofs was that they could be constructed by joiners and therefore dispense with traditional carpenters' knowledge, rates and powerful guilds (dismantled in France in 1791 and four years later in Belgium). When the system re-emerged in the 1770s, after a century of apparent oblivion, guilds still strongly opposed it: in 1777, carpenters from Tours (France) filed a suit against a merchant for using De l'Orme's system. Yet they could not prevent its popularization in late eighteenth- and early nineteenth-century Europe after the construction of famous roofs such as the *Halle au Blé* (Paris, 1782), praised for the "visual manifestation of the technical feat" (Nègre 2015). In 1825, a second much-discussed timber arch system was first applied by the French *Colonel du Génie* Armand-Rose Emy (1771-1851). In order to use the full length of timber planks and thereby avoiding curved cuts and timber scraps, Emy proposed bending straight, flat boards along their weak axis, stacking them horizontally on top of each other, and locking them in an arch shape with iron bolts and straps. The spacing between the arches was much larger (about 3 m) than in De l'Orme's system (about 60 cm). The sole use of straight elements and simple lap joints offered a clear advantage: highly skilled craftsmen were not required for the construction.

Being ubiquitous in nineteenth- and early twentieth-century carpentry handbooks, the systems of De l'Orme and Emy plainly inspired Belgian builders. After the abolition of the traditional craft guilds, the sharp distinction between carpenters and joiners was lost (many timber workers combined both crafts), and so too was the pure economic advantage of De l'Orme's vaults. Yet De l'Orme roofs remained popular for other reasons. The first known Belgian example was constructed for the *Grand Hospice* (Brussels, 1827) by architect Henri Partoes (1790-1873). (Fig. 2.a.) Although referenced as "*fermes circulaires à la Philibert De l'Orme*" in the building specifications, the oak arches display characteristics of both De l'Orme and Emy's systems: they are composed of three vertical curved planks, but are spaced at 2.8 m and assembled using iron bolts and square nuts. Most of the planks were sawn by hand but several straight boards show traces of mechanical sawing (reciprocating saw). It is noteworthy that the labour required for these oak arches was priced higher than for the rest of the traditional carpentry work but it is not clear whether this extra cost was justified by the advantage of having an open attic (ideal for storage) or if visual

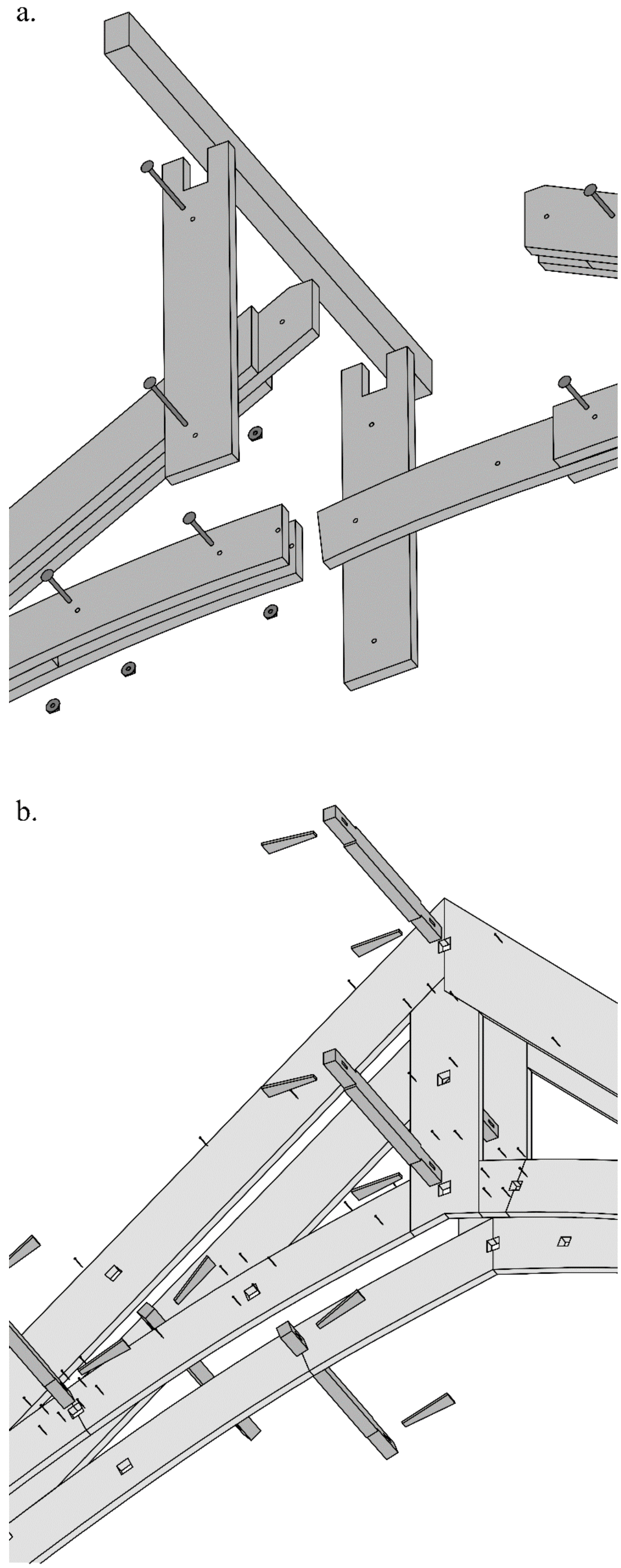
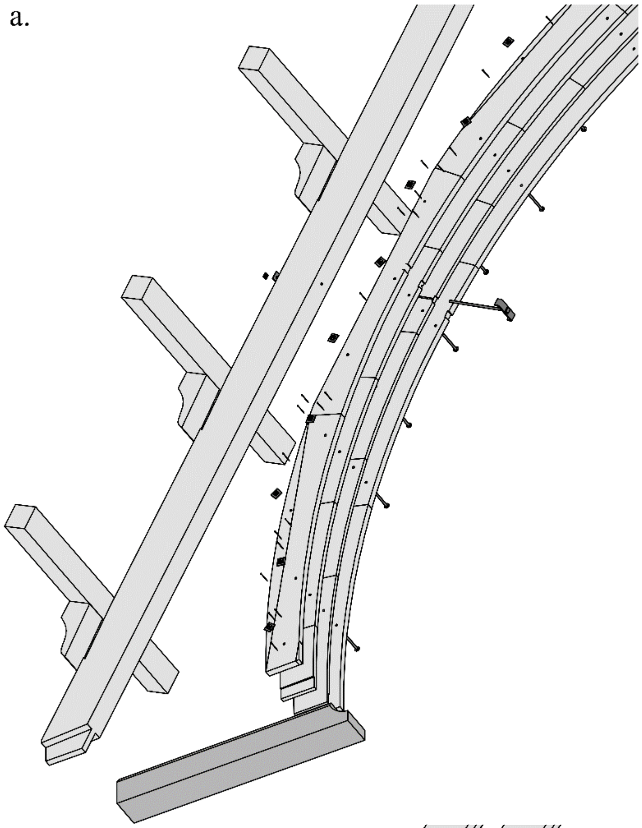


Figure **2.a.** Top connection between (preassembled) half-arches and king-post. Span: 11 m (*Grand Hospice, Brussels, 1825*).
2.b. Top connection of De l'Orme's arches, assembled with nails and liernes. Span: 10 m (Hospice des Indigents, Tournai, 1842).

a.



b.

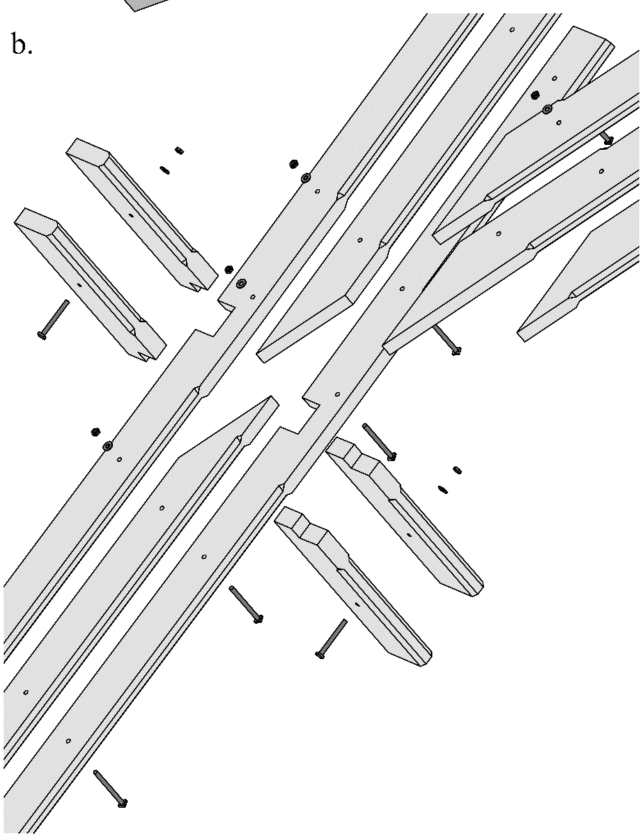


Figure **3.a.** Half-arches made from straight planks, assembled with nails and bolts (*Porte de Hal/Hallepoort, Brussels, 1871*). **3.b.** Straightforward assembly of standardized joists. Span: 14.6 m (*Institut Saint-Jean-Baptiste de la Salle*, *Saint-Gilles, 1911*).

appearance prevailed over economy. The technical achievement is more striking in the roof of the *Hospice des Indigents* (Tournai, 1842), designed by architect and drawing teacher Bruno Renard (1781-1861), which is almost an identical copy of De l'Orme's timber vaults. (Fig. 2.b.) Although the price of the roof is unknown (the building archives were lost in a fire in 1940), the impressive amount of sawing, nailing and joining undoubtedly made it an expensive piece of work. To limit material costs, the arches were made from mechanically-sawn softwood boards (reciprocating saw) while the *liernes* and keys were in oak. Interestingly, two wings were added around 1878 by Renard's former student, architect Justin Soil (1816-80), who realized a carbon copy – except for the nailing pattern – of what had been built by his eminent mentor.

Until the 1840s, military engineers were particularly enthusiastic about timber arches. Similar systems to those erected in the *Grand Hospice* were applied to much larger roofs covering military riding halls like those of the *Rijschool* (Leuven, 1837) and the *Caserne des Annonciades* (Brussels, 1844) which respectively spanned 16 and 23.5 m (none of which have survived). On the other hand, Emy's system was applied in the (still-standing) riding hall of the *Caserne Fonck* (Liège, 1837) with a span of 25 m. Here, both the general layout and the assemblies (bolts, straps and lap joints) were directly inspired by Emy's second roof built in Libourne (France) in 1826.

After the mid-nineteenth century, the success of both systems diminished when their real structural effectiveness was brought into question and when iron structures became more widespread. Nevertheless, nailed or bolted layers of planks remained a common way to deal with curved shapes. For example, lath and plaster ceilings in churches were often nailed to two or three-layered arches suspended from the tie beams of roof trusses. Remarkable arrangements of planks were also designed, primarily for architectural purposes, by architect Henri Beyaert (1823-94) for the exposed roof structure of the *Porte de Hal/Hallepoort* (Brussels, 1871). (Fig. 3.a.) To avoid timber waste, four vertical layers of softwood planks (some mechanically sawn) were wisely cut in such a way that the pieces removed from the intrados could be reused at the extrados. Another interesting design was conceived by William Hanssen (1848-1936), architect of the *Pavillon des Petits Jeux* (Spa, 1879): three vertical layers of planks make up the arches whose price could be reduced by using a cheap species of wood (poplar) and boards sawn mechanically with a circular saw. (Fig. 4.b.) In this last example, the planks were bolted together with iron bolts, whereas the arches of the *Porte de Hal/Hallepoort* were held together by a combination of nails and bolts.

The standardization of timber sizes paved the way towards more economical building methods, not only with planks but also larger timbers. Indeed, after the swift rise of the Norwegian and Baltic imports of sawn softwood in the 1860s (partly made possible by the investment in steam-powered sawmills in the preceding decade), roofs built by assembling standardized joists (usually 3 x 9 inches – about 7.5 x 23 cm) appeared more frequently in the 1870s and became widespread after the turn of the twentieth century. The workmanship required for the construction of such trusses was significantly reduced, woodworking being limited to the cutting of beams to the desired length and lap joints not being necessary.

The roof structures of the *Institut Saint-Jean-Baptiste de la Salle* (Saint-Gilles, 1911) or the *Panorama de la bataille de Waterloo* (1911) are two such examples where the elements are simply overlapped without additional cutting. (Fig. 3.b.) Nevertheless, relying entirely on bolts for the transfers of loads in connections resulted in high stress concentrations at the interface with timber and often led to local crushing of the timber. Belgian builders after the turn of the twentieth century did not really address this issue because it occurred mainly in large spans (over 20 m), which, by then, were usually built in iron. By contrast, in the Germanic world larger timber roofs were built more often and innovative connections had to be engineered to avoid these problems. In the interwar period, some of these systems, such as oak ring fasteners developed around 1920 by Karl Kübler AG (Stuttgart), were introduced in Belgium and used, for example, in the roof of the factory *Den Ammoniak* (Willebroek, *c.*1926) for a span of 32 m.

4 STIRRUPS, STRAPS AND PLATES

Stirrups and straps attached with iron nails, or iron pins and pegs, had been part of Belgian carpentry since the thirteenth century; short wrought-iron ties appeared in the fourteenth century, whereas there is not yet evidence of threaded bolts and nuts in Belgian carpentry before the nineteenth century (Maggi 2014). Previously encouraged by the abundance of Walloon iron ore, the use of iron in timber carpentry significantly increased in the first decades of the nineteenth century, before booming from the 1840s onwards with the development of the iron industry.

Since their introduction, the most common function of stirrups and straps had been to suspend tie beams to king-posts, where timber-to-timber joints would not have coped with the tensile forces. Sometimes they were also used at the joints between rafters and tie beams. In the nineteenth century, this role was usually still insured by these same elements which, especially in churches, were highly comparable to those used since the Middle Ages. However, stirrups and straps were progressively applied more frequently to all kinds of joints to strengthen connections and to ease the assembly process. For example, the

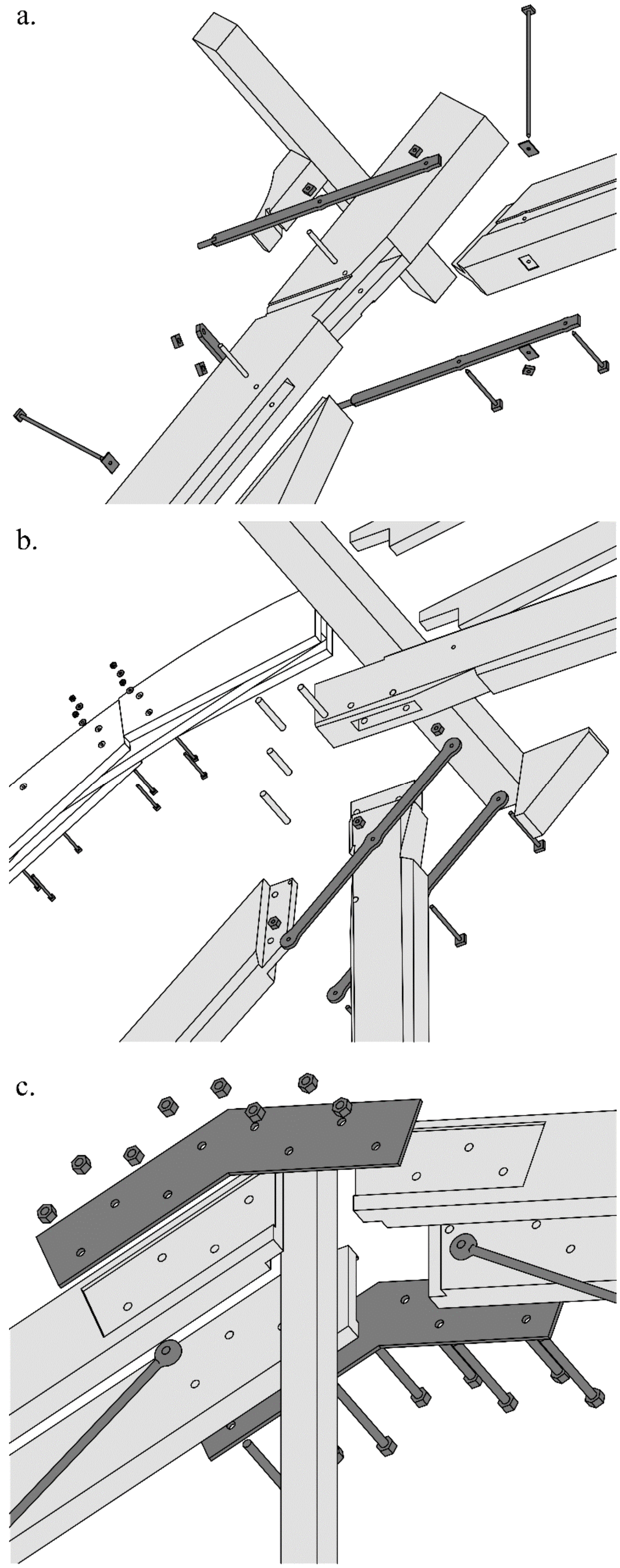


Figure **4.a.** Iron straps and bolts fastenings. Span: 13 m (*Immaculée Conception church, Brussels, 1856*).
4.b. Joint secured by iron straps; the arches were added after hoisting the trusses. Span: 12.5 m (*Pavillon des Petits Jeux, Spa, 1879)*.
4.c. Top connection with steel plates and bolts in a Polonceau truss. Span: 20 m (*Hangar Fort V, Edegem, 1912*).

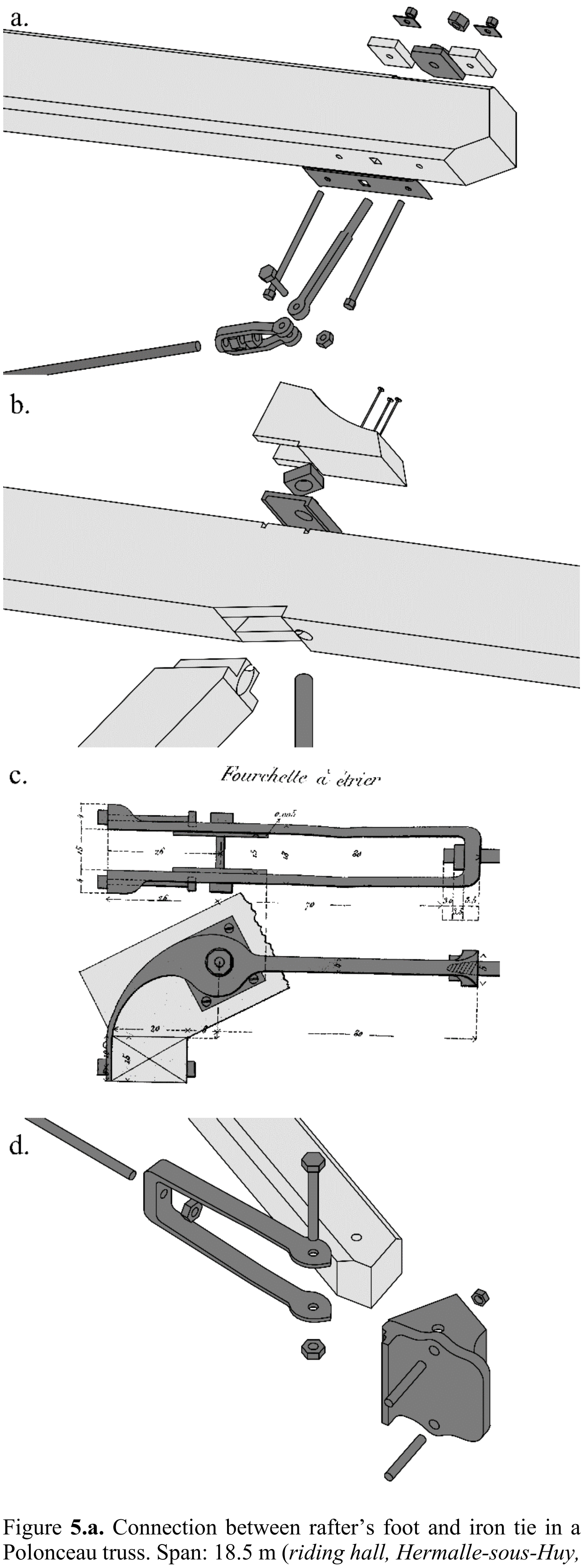


Figure **5.a.** Connection between rafter's foot and iron tie in a Polonceau truss. Span: 18.5 m (*riding hall, Hermalle-sous-Huy, 1856*).
5.b. Connection between rafter and vertical tie. Span: 11 m. (*Centrale werkplaatsen, Leuven, 1863)*
5.c. Rafter's foot connection to iron tie. Span: 12 m (*machine shed, Charleroi, 1857*) (Roffiaen 1858, fol. 16).
5.d. Connection between rafter's foot and iron tie in a Polonceau truss. Span: 12.2 m (*Centrale werkplaatsen, Leuven, 1864*).

trusses of the *Immaculée Conception* church (Brussels, 1856) were not only reinforced with straps at the base of the king-post but also at other places like where collars meet rafters. (Fig. 4.a.) Roman numerals corresponding to the carpenters' marks in the trusses components were engraved on some of these straps, attesting to the small scale and custom manufacturing of these pieces of iron. In this activity, blacksmiths obviously worked hand in hand with carpenters.

Iron elements attached to joints also played an important role during the construction stages: they avoided the dislocation of these connections due to unusual loads and could, for example enable a preassembled truss to be hoisted in one piece by attaching a rope around the king-post, as was the case of the trusses of the *Pavillon des Petits Jeux*, of which the joints were secured by straps and bolts. (Fig. 4.b.)

From the 1890s onwards, the role of iron elements in timber carpentry increased as steel plate assemblies were more widely adopted. A typical example of this kind of joint, which fully relies on metal, are the Polonceau trusses of *Fort V* (Edegem, 1912): numerous bolts were placed in a zigzag pattern through two steel plates – a technique borrowed from iron engineering – as this is more efficient at transferring loads while reducing stress concentrations. (Fig. 4.c.)

5 TIMBER-IRON CONNECTIONS

High stress concentrations in connections were encountered in Belgian timber carpentry as early as the 1840s in another situation: when metal elements (wrought-iron ties and cast-iron struts) were first used on a large scale to create lightweight composite structures. Transferring forces effectively from timber to iron had already been achieved when suspending tie beams from king-posts, but connecting iron ties to the feet of timber rafters was an unprecedented challenge as it involved dealing with forces about ten times larger.

The most successful type of a lightweight truss with timber rafters and iron ties was first built by French engineer Camille Polonceau (1813-59) (Polonceau 1840). In Belgium, the oldest known application of this combination is the above-mentioned roof of the riding hall of the *Château de Hermalle-sous-Huy* (1856). (Fig. 5.a.) All assemblies are identical to those illustrated by Polonceau in 1840, except for the lowest connection where the bevelled cast-iron washer is not placed behind the wall plate but on the upper face of each rafter. This modification provided the advantage that the trusses were independent from each other and could be fully assembled on the ground and lifted in one piece, but caused some crushing due to the square bolt's tendency to align with the tie. Similar bevelled washers were also used in several trusses of the *Centrale Werkplaatsen* (Leuven, 1863) to suspend vertical ties to the rafters. (Fig. 5.b.) Another early attempt to connect ties to the feet of rafters was implemented in a (now demolished) machine shed of the Saint-Martin station (Charleroi, 1857): it consisted in inserting screwed plates in order to improve load transfer. (Fig. 5.c.)

Around the mid-nineteenth century, cast-iron shoes – possibly first used in 1817 for the 45 m roof truss over the Moscow Manege, designed by the Spanish engineer Augustin Bétancourt – were first used in Belgium, especially in industrial buildings that were usually designed by engineers. Although many of such roofs have been demolished, an early example dating from 1863 has survived: the *Polonceau* trusses of the *Centrale Werkplaatsen* (Leuven, 1864) designed by railway engineer Maurice Urban. (Fig. 5.d.) The use of cast-iron shoes had three main advantages: they allowed for a much better force transfer; they isolated the timber elements from the masonry and avoided decay due to moisture; the assembly of such trusses was also fast and inexpensive as it required little carpentry work. The standardization of timber sections might have led to uniform cast-iron shoes but, apparently, it did not occur: they always differ from one roof to another and were seemingly manufactured as bespoke items for each project. Although cast-iron shoes were still occasionally used in the early 1910s, they were soon replaced by bolted steel plate assemblies.

6 NUTS AND BOLTS

Almost all joining techniques discussed in this paper involved the use of iron nuts and bolts. As a final point, it is worth tracing the evolution of these elements as they were also strongly influenced by the industrialization of the building sector. The oldest bolts recorded in the scope of this study are those in the *Grand Hospice* (Brussels, 1825); they show a round head and are tightened by a large square nut with washer. (Fig. 2.c.) In Belgian timber carpentry, the transition to hexagonal nuts started about 25 years later in the early 1850s, and was completed in the 1880s. The first hexagonal nuts were systematically observed in structures making use of large quantities of iron such as in the *Musée Antoine Wiertz* (Ixelles, 1851) or the riding hall of the *Château de Hermalle-sous-Huy* (1856), suggesting that the contact with larger industries – in opposition to local blacksmiths – encouraged their introduction. This assumption is supported by the fact that during the last decade of this shift, square nuts were recorded only where traditional practices survived longer to industrialization: church roofs. Compared to square nuts, hexagonal nuts needed less iron to produce, less space to be tightened (60°) but required perfectly adapted wrenches. From the end of the 1870s, their widespread adoption was thus accompanied by a reduction in size and a standardisation of their dimensions (width across corners of 38 mm).

7 CONCLUSION

The 50 surveyed roofs, representing a selection of nineteenth- and early twentieth-century Belgian timber carpentry, clearly bear witness to the birth of the industrial age. Three main reasons can enlighten this sinuous, yet one-way path from craftsmanship to engineering. Firstly, the industrial developments in the timber and iron industries allowed the drastic reduction, especially after the mid-nineteenth century, in the efforts required for shaping and assembling structural members. Secondly, engineering sciences flourished from the 1820s and provided new ways to predict the behaviour of structures and thereby, not only make a better use of resources, but also encourage change – novel ideas that were quickly disseminated across borders through the booming technical literature. Thirdly, the progressive shift, initiated in the last decade of the eighteenth century, from a traditional craft controlled by guilds and master carpenters, to a trade by general contractors and less skilled workers, inevitably brought about both simplification and optimization.

Despite these trends, timber joints should nevertheless always be assessed on a case-by-case basis as local circumstances – architectural concerns, a designer's background or available workmanship and material – were prone to the persistence of traditional practices. After the focus of Belgian engineers had shifted from timber to iron around 1840, there was a period of limbo in the second half of the nineteenth century; timber carpentry absorbed technical progress from other fields, and while joining techniques were adapted, roof types remained largely untouched. This situation changed in the first decades of the twentieth century when the engineering approach to using iron and the introduction of foreign systems (mainly from Germans) clearly made their mark on Belgian timber carpentry.

The combination of old designs of truss with new industrial products, and of craftsmanship with engineering principles, together with the resulting variety of structures are therefore probably the most distinctive feature of Belgian carpentry in the nineteenth and early twentieth centuries. The evolution of joining techniques should be seen not only as a transition from fine craft tradition to mechanised modern engineering (as the comparison of Figs 1.c. & 4.c. may suggest), but also as a testimony of the inventiveness and the capacity of individuals to combine old and new know-how, to transfer knowledge beyond borders and to transpose man's oldest building material into the modern industrial world.

ACKNOWLEDGEMENTS

The present research could be realized thanks to the funding of the *Fonds Wetenschappelijk Onderzoek* (FWO).

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