






Hidden Above Church Vaults: The Design Evolution of Early Iron Roof Trusses in Mid-Nineteenth-Century Belgium

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ABSTRACT

This article sets out to assess the first phase of iron roof construction in Belgian churches, from the 1840s to the 1860s, and the evolution of iron roof structures in this period, through an in-depth analysis of four case studies, located in Brussels, Antwerp, and Ghent. The article is based on fieldwork as well as archival and literature research. The cases are contextualized within the architectural, technical, political-economic, and intellectual environment of the time when structural iron was introduced in Belgium: a country that industrialized at an early date, with an iron industry that developed rapidly. The Belgian findings are put into an international perspective. By providing new insights into the early use of iron and the evolution of new construction principles in churches, this study seeks to encourage researchers, architects, and heritage assessors to climb above the vaults of churches and consider the hidden roof structures with greater care.

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1. Introduction

For centuries, timber was the only material used for building roof trusses (Binding 1991; Hoffsummer 2009 and 2011; Holzer and Kock 2008; Janse 1989). In Belgium, although iron was gradually introduced in composite assemblies, trusses made entirely of iron only became common after the middle of the 19th century. At that time, timber structures did not show major improvement in Belgium (Vandenabeele 2018), but iron constructions were innovative (Baele and De Herdt 1984). However, recent studies on iron heritage show a lack of knowledge about the beginnings of complete iron roof trusses in Belgium compared to those in other countries, like France, England, or Russia (Espion et al. 2018). Furthermore, while it is commonly known that iron was used at an early date in the architecture of bridges, covered markets, railway stations, and large public buildings (Baele and De Herdt 1984, Espion et al. 2018), at the same time innovation also occurred in less visible places, such as the attics of churches (Wibaut, Wouters, and Coomans 2019). This article focuses on churches, a building type in which milestones of architectural and construction history in Belgium are represented. Architectural

modernity had an important place in the Religious Revival movement in early 19th-century Belgium (De Maeyer 2000, 19–27).

The construction techniques used in 19th-century church roofs have not yet been investigated systematically, and the heritage value assessment of churches often ignores the roof structures when they are hidden above roof vaults. 19th-century architectural history and heritage conservation of churches focus more on styles and other aesthetic aspects than on the construction of roof structures (Coomans 2003, 64–65). Recent inventories of 19th-century parish churches in Belgium pay little attention to the materials and techniques applied to their construction (Bertrand, Chenut, and Genicot 2009–2011; OEVL 2018; PIRBC 2018). In other countries, except the Netherlands (Stenvert 2013), general studies of the construction history of 19th-century church roofs are missing. This lack of knowledge hinders the recognition of their historical value. Therefore, the four individual cases analyzed in this article provide insight into the construction history of church roofs in Belgium as well as assessments of the historic construction features and the inherent qualities of structural components. A thorough knowledge of historical contexts, and construction materials and techniques, are prerequisites for evaluation and practical conservation.

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In addition, this article investigates the building actors and their backgrounds in the complex transition period when Belgium emerged as a young nation-state (1830). The introduction of new materials in architecture and construction was almost always accompanied by debates and controversy, because it upset the established order. Arising from technical and political-economic issues, these debates also involved the intellectual framework and interests of the different actors. What were the technical, theoretical, educational, and professional backgrounds of the patrons, architects, iron-construction workshops, and engineers? How did these individuals interact during the design process? Who decided to introduce innovative materials and principles in the roof structures?

The evolution in design and construction of early iron roof structures has been traced from an in-depth analysis of, and study of literature pertaining to, the four cases (Figure 1) put into an international perspective. When and how was iron as a primary material introduced in roof construction in churches? To what extent were the shape and connections in these iron trusses influenced by traditional timber carpentry and by emerging iron technology? First, the transition from traditional timber to iron trusses is addressed with the analysis of St. Joseph's Church in Brussels, designed by architect Tilman-François Suys (1783–1861) and built c. 1845. Second, the improvement in the use of iron through a new truss morphology is illustrated with St. George's Church in Antwerp, designed by architects Léon-Pierre Suys (1823–87) and François-Héliodore Leclef (1811–78) and built 1849–50. Third, the optimization of iron trusses through the use of a rational Polonceau configuration is considered in the case of St. Anne's Church in Ghent (1859–60), designed by architect Louis Roelandt (1786–1864) and built by architect Jacques Van Hoecke (1802–62). Fourth, St. Catherine's Church, Brussels, built 1854–66 and designed by architects Joseph Poelaert (1817–79) and Wynand Janssens (1827–1913), recapitulates this evolution through successive stages of the design process.

2. Documenting cases

When assessing 19th-century church roof structures, fieldwork is of utmost importance: the information obtained cannot be found in historical sources and literature. These hidden roofs have rarely been visited by scholars, and data on roof typology as well as on modifications, alterations, and actual conditions are lacking. The information collected on-site allows scholars to better understand the evolution of roof construction and supports future structural assessment. During on-site visits, the trusses were

photographed and the main dimensions of the trusses, including the assemblies and the overall dimensions of the roof, were documented. The measurements were carried out using a laser distance meter, a folding meter, and a sliding calliper (for small thickness, diameters and depths). Because not all the parts of the structure were accessible, good pictures of the roof parts (made possible in dark attics by battery-operated spotlights) were taken, and the trusses were reconstructed photographically using Hugin, an open-source photo-stitching and HDR-merging program. The unmeasured parts of the roofs could then be calculated given the measured dimensions in the drawing software AutoCAD. This work resulted in plans and sections of roof constructions that include the overall dimensions, truss and vault types, the materials and connections, sizes of structural members, and information on the overall conditions of the trusses.

Aside from some minor deterioration, including local deformation and surface corrosion, the roof structures of the 4 churches are well preserved and overall the stability of these 150-year-old structures is sound. Therefore, this article does not deal with specific conservation issues, but aims to put forward practical information and contextualize early iron structures in order to facilitate the work of heritage experts during assessments.

Besides fieldwork, archival research has proven to be a major source of complementary information about the design and construction process. Archival sources included sketches to final designs of the churches, architectural and construction plans, building specifications, cost estimates, and correspondence between different parties (patrons, architects, contractors): all were valuable for understanding the design process and evolution of mindsets. Relevant material was found in the archives of the St. George's parish (in Belgium, each parish has a church council—*fabrique d'église*—that manages its material assets); in the city archives of Brussels and Ghent; as well as in the archives of architect L. Roelandt, preserved at the University of Ghent. Yet, for the most part, documents about the design process and construction of the churches are scarce. Specific information about the roof structures is especially scarce and, in these case studies, varied from nothing (St. Joseph's in Brussels) to exceptionally complete documentation (St. Catherine's in Brussels).

3. The building actors

3.1. Architects

The first generation of Belgian architects were trained during the Napoleonic time at the *École Spéciale d'Architecture*

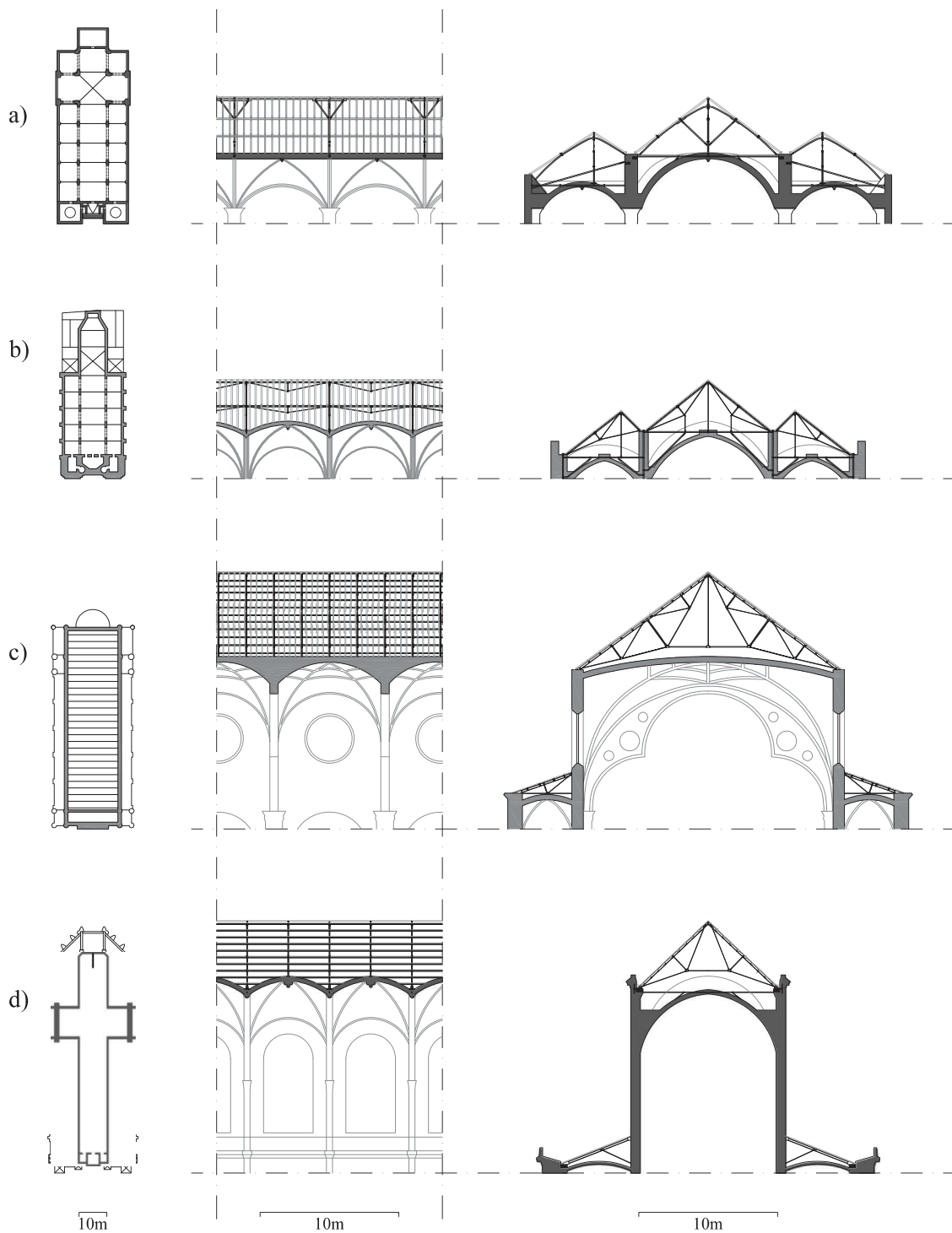


Figure 1. Plans and sections of the attics of: (a) St. Joseph's Church (1842–49) in Brussels. (b) St. George's church (1847–53) in Antwerp. (c) St. Anne's Church (1853–62) in Ghent. (d) St. Catherine's Church (1851–66) in Brussels (recorded and drawn by R. Wibaut, 2018).

in Paris, which later became the architectural section of the *École des Beaux-Arts de Paris*. Both T.-F. Suys and L. Roelandt frequented the atelier of Charles Percier (1764–1838), Napoleon's renowned architect, respectively, in 1806 and 1809, and they were the first Belgian architects to be hosted at the famous Paris school (Pinon 1989). It is

striking that several professors at this school experimented with iron in the early nineteenth century, such as François-Joseph Bélanger (1744–1818), who opted for a cast-iron dome in the construction of the *Halle aux blés* in 1811; Éloi Labarre (1764–1833), who designed the trusses to cover the *Bourse de Paris* in 1823; and Pierre-Alexandre Vignon

(1763–1828), who designed the *Marché de la Madeleine* in 1824. Later, other student-architects of the generation of Suys and Roelandt also experimented with iron in the construction of church buildings, in France, Russia, and Germany (see [Section 4.2](#)).

On the eve of the birth of the Kingdom of Belgium in 1830, architectural academies existed in Antwerp, Brussels, Bruges, Ghent, Malines, Liège, Mons, Leuven, and Tirlemont. Their educational programs were based on the study of classical orders and copying architectural examples (Verpoest 1984). After 1830, these academies were reorganized, and the government asked the Belgian architects trained in Paris to become heads of the departments of architecture (Faber 1989). Among others, T.-F. Suys was appointed head of the school in Brussels and L. Roelandt in Ghent. Although the academies continued to offer an aesthetic-oriented education inspired by the *Beaux-Arts* of Paris, they were also the cradle of innovation in Belgian architecture (Faber 1989).

Most of the Belgian architects of the second generation, mainly active in the second half of the 19th century, were educated in the reorganized local academies (Bertels 2008, 138–140). Hence, for instance, Joseph Poelaert and Wynand Janssens, the architects of St. Catherine's Church in Brussels, followed Suys' classes, as did Jean-Pierre Cluysenaar (1811–80), who experimented with iron in the architecture of St. Hubert's Galleries in Brussels in 1847. In Ghent, Roelandt was the teacher of Louis Van Overstraeten (1818–49), the architect of St. Mary's Church in Schaerbeek, who later became his son-in-law. Other architects of this generation made successful careers without any academic education, such as Léon-Pierre Suys, who made his apprenticeship in his father's architecture office and designed the Gothic Revival St. George's Church in Antwerp.

3.2. Iron-construction workshops

19th-century Belgium was tremendously impacted by the Industrial Revolution, especially its iron industry. Iron ore and coal constituted the fundamental resources of industrial development in the Walloon region—a development fostered by workers skilled in traditional metal trades. Rapidly, expertise, technologies, and capital were imported from England. Some English visionaries, who immigrated and tried their fortunes in Belgium, actively contributed to the growth of the iron industry. Hence, in 1814, the sons of the Lancashire mechanic William Cockerill (1759–1832) started one of the most advanced ironworks on the continent at Seraing near Liège (Halleux 2002). Another English engineer, Thomas Bonehill (1796–1858), partnered with the Belgian Puissant family to create in 1838 the *S.A. des Laminoirs, Hauts-*

Fourneaux, Forges, Fonderies et Usines de La Providence near Charleroi, which made products that were used to a large extent in the construction sector (Roffiaen 1858, 371; Halleux 2002, 28–29). Moreover, the realization of a dense network of State railways, after 1835, encouraged production throughout the whole country and the mobility of workers, allowing them to gain experience and knowledge.

Besides the reorganization and development of foundries, forges, and ironworks, new workshops for iron construction were created. Most of them manufactured locomotives or other machinery, but some also contributed to building construction. In Ghent, for example, the workshop of Charles-Louis Carels focused mainly on steam-powered engines and pumping stations but was also active in the building sector. Carels, as we will see, was appointed to manufacture and erect the iron roof trusses for St. Anne's Church in Ghent. Other workshops soon specialized in the production and implementation of iron components for buildings. These developments are part of the rise of a new kind of contractor in the building sector, who relied on their own engineers to handle technical issues. The workshop of Charles Marcellis (1798–1864)—a former poet and lawyer who became one of the most prominent iron industrialists of Belgium—formed one of the first iron workshops to specialize in production for the building sector. Amongst other realizations, Marcellis was entrusted to build the iron roof of St. George's Church in Antwerp. His partner, engineer Valery Duval, handled technical issues (Verswijver et al. 2011). In 1834–35, in the province of Liège, Marcellis acquired a forge (Raborive, Aywaille), a furnace (Ferot, Ferrières) and a foundry (La Boverie, Liège), which he transformed into a workshop for architectural iron. Until now, there has been little information about such workshops, and it is not easy to identify the projects with which they were involved. However, it is obvious that some of these workshops had a large influence in the building sector.

In 1844, driven by the idea of replacing timber with cast and wrought iron in buildings, Ch. Marcellis submitted to the Chamber of Representatives of the Belgian Parliament a request that had huge repercussions in the construction sector. Benefiting from his political experience as a past member of the Chamber (1833), Marcellis argued for the necessity of using cast iron instead of Baltic timber to make trusses for the State-subsidised public warehouse in Antwerp (Chambre des Représentants de Belgique 1844). He argued that cast iron would have two main positive impacts. First, it would improve the fire safety of both the building and the stored goods. Second, it would help to protect local industry, because iron was

produced in Belgium (Chambre des Représentants de Belgique 1845a). The first argument does not seem to have awakened much interest, but the second struck a hornet's nest. Several owners of blast furnaces, collieries, foundries and forges in the mining area of Charleroi supported Marcellis' request (Chambre des Représentants de Belgique 1845a and 1845b). In only a few months the debate shifted from one building in Antwerp to the whole public construction sector in Belgium. From that point on, using iron in the construction of buildings was seen as the best way to protect the national iron industry, which had suffered during the 1838–39 industrial crisis. The public warehouse of Antwerp was finally completed in 1851 by Marcellis' workshop using structural cast and wrought iron.

3.3. Engineers

Although no engineers were found to be involved with the four churches—except at St. Catherine's, where the city engineer intervened mainly as a construction site supervisor—they must have had an impact on the transmission of technical knowledge. It is not easy to discover how the concepts of iron roofs spread and how the understanding of the material could have affected their design. In order to get insight into the engineers and architects' knowledge about iron trusses, historical construction manuals and treatises that circulated in Belgian architectural circles in the 1840s–60s were consulted. In addition to the few books written by Belgian authors, some English, French, and German publications were available in school libraries and in the private libraries of architects or engineers.

Belgian architects and engineers, at the crossroads of intellectual ideas from England, France, and Germany, learned from international publications that circulated easily. In 1816, the Frenchman Jean Rondelet (1743–1829), in the fourth volume of his notorious *Traité théorique et pratique de l'art de bâtir*, which L. Roelandt referred to as a necessity (Cierkens 2018, 45), discussed the current knowledge on iron works and illustrated the use of structural iron (Rondelet 1816). The growing interest in structural iron is reflected in the two treatises by Charles Eck devoted to the use of iron in the construction sector (Eck 1836, 1841). Charles-Armand Demanet (1808–68), a Belgian lieutenant-colonel of military engineering, refers to Eck's books in his own manuals (Demanet 1847b, 1850). Among numerous examples of iron trusses, Eck published the three proposals made for the reconstruction of the roof trusses of the Cathedral of Chartres, respectively designed by ironmasters Mignon, Roussel, and Leturc (Eck 1841, 32–38 and pl. 21–29). English and German literature also influenced Belgian authors. For example, in addition to the previously

noted manuals and treatises, publications of Thomas Tredgold (1840) and Karsten (1830) also were mentioned by Demanet (1847b, 1850) and Roffiaen (1858).

Shortly after Belgian independence, three state-subsidised schools were created to rectify the lack of engineering education, namely the Military School in Brussels (*École militaire*, 1834), the School of Civil Engineering in Ghent (*École du génie civil*, 1836) and the School of Arts, Manufactures and Mines in Liège (*École des arts et manufactures et mines*, 1838). The private Hainaut Provincial School of Mines also opened in Mons (*École provinciale des mines du Hainaut*, 1837) (Linssen 2013, 275–284).

It was therefore not until the 1840s that theory and practice came together in Belgian construction manuals. This literature is rare and never exclusively dedicated to iron structures. However, all the manuals deal with iron trusses in at least one section and agree on the advantages of iron: it is a lightweight, durable and relatively affordable material, which also has decorative possibilities and is easy to assemble and set up (Demanet 1847b, Roffiaen 1858). In his *Cours de construction professé à l'École Militaire de Bruxelles (1843 à 1847)*, Demanet presents iron trusses as derivative of timber trusses in all respects: dimensioning (Demanet 1847b, 409–430), assemblies (Demanet 1847b, 328), and typologies (Demanet 1850, 153). Nonetheless, he pleads for a rational use of iron in trusses according to its properties: cast iron should be used in compression and wrought iron in tension (Demanet 1847b, 327). His two-volume manual was used at the Brussels Military School for 30 years. It is also said to have been popular in Belgian architectural schools—Roelandt owned the two volumes (Cierkens 2018, 383)—as well as in Spain and Russia (Siret 1868, 153). By 1858, when Eugène Roffiaen (1821–65), a Belgian captain of military engineering, wrote a treatise on the strength of construction materials (*Traité théorique et pratique sur la Résistance des matériaux dans la construction*), conditions evidently had changed. Only one kind of iron truss is discussed, specifically “*les fermes à une ou plusieurs bielle(s)*,” which corresponds to the (multiple) Polonceau trusses.

3.4. The Royal Academy of Belgium

Leopold I (1790–1865), the first king of Belgium, wanted to preserve, study, and promote the national past as well as to enliven the intellectual life of the young country and stimulate scientific research. For the first aim, he created archival institutions and, in 1835, the Royal Commission for Monuments, which advised and approved restorations of and new projects for public buildings, including churches. The architects T.-F. Suys and L. Roelandt were among the founding

members of this commission (Stynen 1998, 13–117). For the second objective, the king created museums and, in 1845, the class of Fine-Arts (*classe des Beaux-Arts*) in the Royal Academy, in addition to the already existing classes of Letters and Sciences. T.-F. Suys and L. Roelandt were the only architects to be designated as initial members of this class, and they were joined by other professors from Belgian academies (Faber 1989).

From its early days, this new class attached great importance to the construction of churches and the use of new technologies from the industrial age. In 1846, the Royal Academy issued a question on architecture, asking respondents to discuss the construction of churches considering Belgium's climate, resources and technological progress, and in particular the capabilities of the country's flourishing iron industry (Hayez 1846, 230). The first accepted dissertation, published in 1847 under the title *Mémoire sur l'architecture des églises*, was written by engineer Charles-Armand Demanet. He argued for greater use of innovative materials: cast-iron columns, walls in concrete instead of stone (as was done in England), wrought-iron sheets for roofing (as in Russia), and chemically fireproofed timber. Writing about vaulting, he advocated for iron ribs to be used in the construction of lightweight brick vaults. With respect to roof trusses, he recommended the use of wrought iron because of its great fire resistance and relatively low cost (Demanet 1847a, 70). The second dissertation, written by architect L. Van Overstraeten, was completed by L. Roelandt in 1850, after the author's sudden death. Although it contained little about iron, a long paragraph in the book was devoted to the St. Mary's Church, which he recently designed for Schaerbeek, a booming suburb of Brussels. Writing about the church's dome, he justified building it in iron as a way to reduce the amount and thereby cost of structural materials required (Van Overstraeten 1850, 189). In 1845, replying to a board of experts, who argued that the dome would not withstand its self-weight, Van Overstraeten described his design as a solid skeleton of wrought iron ("*une carcasse inébranlable de fer laminé*"), which would be anchored and riveted to the walls by means of cast-iron plates (Samuel-Gohin 2012). This dome was finally built much later (c. 1885) using riveted steel elements.

4. Rise of structural iron

4.1. Iron in the construction of roofs

Internationally, it is only from the 18th century that complete iron structures gradually started to appear as a result of the rising industrialization of metalworking. It seems

that the first trusses built entirely of wrought iron emerged in Russia during the first half of the 18th century (Lorenz and Heres 2015). In Western Europe, although the use of wrought- or cast-iron structural elements (tie rods, plates, and columns) became more common in the 17th and 18th centuries (Addis 2007, 245–248), the *Théâtre Français* in 1788 and the *Salon carré du Louvre* in 1789, both in Paris, are commonly considered as the first examples of complete (wrought) iron roof trusses (Addis 2007, 255; Holzer 2018). However, the real start of using iron trusses in Western Europe occurred in Paris with the construction of the *Bourse de Paris* in 1823 and the *Marché de la Madeleine* in 1824 (Holzer 2018), both of which used iron for fire-safety reasons (Lemoine 1986). Along with Russia and France, Great Britain also played a key role in the development of iron trusses. The trusses designed by engineer William Murdoch (1754–1839) to cover the Soho Foundry in 1810 and a mill in Manchester in 1815 are the first known fully triangulated combinations of wrought and cast iron in the construction of roof trusses (Addis 2007, 311). In these trusses, the tie rods are wrought iron, foreshadowing the commonly called "*ferme à la Polonceau*" invented in 1839 by engineer Rudolf Wiegmann (1804–65) in Germany and Camille Polonceau (1813–59) in France. This type of truss was widely adopted during the second half of the 19th century.

In Belgium, structural iron was first applied to the construction of bridges. The wrought-iron suspension footbridge of Wissekerke (Kruibeke), designed in 1824 by engineer Jean-Baptiste Vifquain (1789–1854) (Wouters, de Bouw, and Verdonck 2015), and the cast-iron arch bridges of Martelange and Ortheuville, built 1827 (Espion 2018), are early examples. Iron was also largely used in the construction of the Brussels Botanic Garden's greenhouses, built 1826–29 according to the plans of T.-F. Suys (Baele and De Herdt 1984). In 1839, architect L. Roelandt commissioned Ch. Marcellis to manufacture and supply cast-iron beams for the construction of the courthouse in Ghent. It marked the beginning of a fruitful collaboration between the architect and the industrialist (Cierkens 2018, 394–395). After 1840, iron was also used in the construction of public warehouses (Royal Depots) in Brussels (1842–44), Ghent (1845–46), and Antwerp (1844–51). In the Brussels public warehouse, architect Louis Spaak (1804–93) used cast-iron columns and beams, masonry walls, brick-vaulted floors, and wrought-iron roof trusses, inspired by the English "fireproof mills" (Wouters 2002). In Ghent, the interior structure was timber but the warehouse featured an innovative wide-span, cast-iron roof construction ("*C'est le premier travail de ce genre qui aura été fait et placé en Europe,*" un abonné 1846). Ch. Marcellis and V. Duval proposed a system of prefabricated cast-iron trusses,

which they patented (Cierkens 2018, 399–402). In the same vein, but better known for its “extraordinary span” and “remarkable ornamentation,” Roelandt’s military riding hall in Ghent (1851–53) was covered by 22-m-long prefabricated cast-iron trusses (Schayes 1852, 672). In Antwerp, after long political debates (see Section 3.2), Marcellis was entrusted to complete the enlargement of the public warehouse, and he replaced the planned timber elements with ones made of wrought and cast iron. Finally, after about 1855, the self-described “engineers-constructors” Joseph Pâris and Pierre Wolff realized numerous trusses in Belgium (Roffiaen 1858, 371), mainly based on their “*système breveté des charpentes de la Providence*” (Marchienne-au-Pont, Charleroi). Although the patent for their concept has not yet been retrieved, it appears from built structures that their trusses are simply slightly modified Polonceau trusses (e.g., La Monnaie Theatre and St. Peter’s Hospital in Brussels, Sury Carousel in Mons, and Artillery Shed in Charleroi). Unfortunately, many of these early Belgian iron roofs have been demolished, which makes it difficult to learn their details. In contrast, most churches built in this period are still standing, and some of them include very innovative trusses.

4.2. Iron in the construction of churches

When it comes to church roofs, primitive examples of iron roofs have yet to be documented, and Aleksandra Kosykh (BTU Cottbus-Senftenberg, *Pioneers of modern construction. Building with iron in 18th-century Russia*) is currently investigating iron church roofs in 18th-century Russia. In Great-Britain, the three cast-iron churches built 1813–16 in Liverpool, by architect Thomas Rickman (1776–1841) in collaboration with John Cragg’s foundry, are probably the first examples of churches with complete iron frames in the world (Clarke 2014, 259). Later, in Western Europe, architects

who followed classes at the *École Spéciale d’Architecture* at the same time as T.-F. Suys and L. Roelandt also experimented with iron in churches. In Paris, for instance, architect Jean-Jacques-Marie Huvé (1783–1852) and François-Christian Gau (1790–1853) respectively covered the Madeleine Church (c. 1830) and the St. Clotilde Basilica (1846–57) with iron roofs. Moreover, still in Paris, Adrien-Louis Lusson (1788–1864) together with Louis-Auguste Boileau (1812–1896) designed St. Eugene’s Church, built 1854–55, which was the first in France to have a full iron frame (Duvignacq and Fouqueray 2009; Lemoine 1986). This church largely fuelled the quarrel between L.-A. Boileau and Eugène Viollet-le-Duc (1814–79) about the ability of iron to generate a new type of architecture (Marrey 2002). Graduates from the *École Spéciale d’Architecture* were also active outside France. In 1838–39, Auguste Ricard de Montferrand (1786–1858) designed St. Isaac’s Cathedral in St. Petersburg, Russia, with a complete iron dome (Fedorov 2015). In Belgium, complete iron trusses were introduced into churches for the first time in the 1840s.

5. Early iron roofs in Belgian churches

5.1. From timber to iron: St. Joseph’s church in Brussels (1842–49)

As far as is known, full-iron trusses appeared for the first time in Belgian church construction in the roof of St. Joseph’s Church (Figures 1a and 2), a Renaissance-Revival style church erected in Brussels in 1842–49 as the main monument of the first urban extension of the capital. The new *Quartier Léopold* was a neoclassic grid-plan neighbourhood for the elite, developed by the private company *Société civile pour l’agrandissement et l’embellissement de Bruxelles* (Demey 1992, 22). Architect T.-F. Suys, who was in charge of urban planning of this new district, was commissioned by Count Ferdinand de Meeûs (1798–1861), the



Figure 2. St. Joseph’s Church (1842–49) in Brussels. Exterior, interior and trusses (c. 1845) (pictures R. Wibaut and I. Wouters).

principal shareholder in the company, to design the St. Joseph's Church. Count de Meeùs was directly connected to the iron industry: he invested in the *Société générale*, a financial company that supported and promoted Belgian metalwork industries. Both the architect and the builder were acquainted with the iron industry. However, no sources were found that explained why iron was adopted for the roof trusses or named the iron-construction workshop.

St. Joseph's is a hall church with three naves of similar height, each covered by a saddle roof with a slope of approximately 35° (Figure 1a). The trusses were constructed c. 1845, using wrought iron for all the bars and the nodes of the trusses, as well as for the purlins. Only the common rafters are timber. The trusses of the main nave have a span of 10 m. They are composed of two curved principal rafters, a tie-beam to prevent these elements from spreading apart, a king post and two struts supporting the principal rafters from the king post. The trusses are braced longitudinally by means of two members that link the king post to the ridge. All the members are flat rolled bars with a rectangular section varying from 50 × 20 to 70 × 25 mm. They are connected with square-headed bolts, mainly using the configuration that Ch.-A. Demanet called "assembled with flat joints" (*assemblage à plat-joint*) which, he wrote, replaces the traditional mortise and tenon assemblies of timber trusses (Demanet 1847b, 328) (Figure 3a). One exception is the iron-wedge assembly that connects the curved rafters to the roof purlins (Figure 3b). This type of connection had been used since at least the 15th century and derives from typical timber connections. Perhaps this connection was used at St. Joseph's in the final in-situ assembly at roof level because wedges were easier to introduce, while bolted connections were used to pre-assemble trusses at ground level. It was common to pre-assemble timber and iron trusses at that time (Demanet 1847b, 331).

As suggested by the use of wedges, this first application of (wrought) iron in the construction of roof trusses in Belgian churches shows the influence of traditional timber carpentry. An interesting feature of this transition is the assembly marks hammered and carved into the wrought-iron elements (Figure 3c). This derives from the practice of carpenters who marked all the unique handmade timber elements in order to facilitate assembly at their final positions in the roof. At St. Joseph's, as the different wrought-iron members were manufactured, the ends of each element were adjusted by hand. The overall geometry of the wrought-iron trusses also appears to be a traditional timber king-post truss typology. At that time, mimicking timber truss typologies was common practice, as Demanet suggested: "all combinations of timber pieces [...] can be reproduced in metal (iron or cast iron)" (Demanet 1850, 153). Although the wrought-iron bars are indeed used analogously to timber, their sections are of course much smaller. This typology, which is not well-adapted for iron, was progressively abandoned in favour of other arrangements better suited to the properties of metal.

5.2. Improvement in form and dimensions: St. George's church in Antwerp (1847–53)

St. George's (Figures 1b and 4), erected in Antwerp from 1847 to 1853, belongs to the first generation of churches in Gothic Revival style in Belgium. Although architect F.J. Stoop won the church council's competition for the erection of a new church, his plans were not realized due to a last-minute extension of the land available for the project. The extended church was finally designed by T.-F. Suys and its realization entrusted to his son, L.-P. Suys (Bertels 2000, 17–18). However, due to disagreement between the latter and the church council, he was dismissed in 1853 before the completion of the towers and the interior decoration. These were assigned to architect

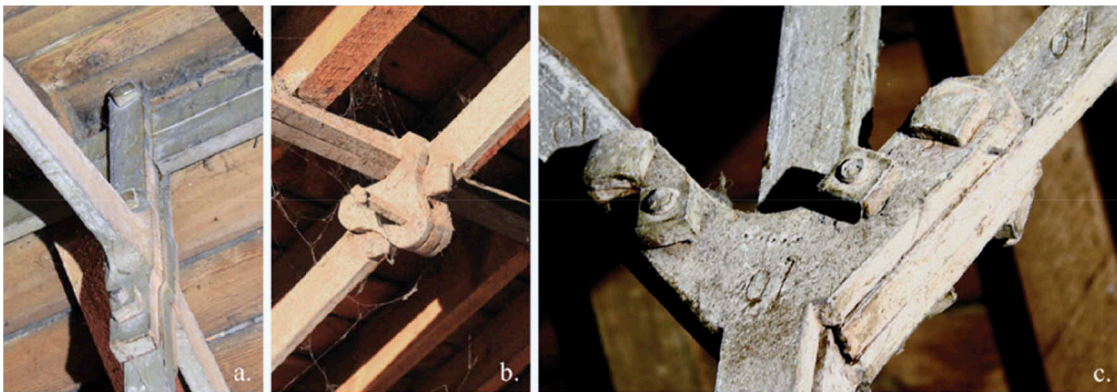


Figure 3. St. Joseph's construction details. (a) *assemblage à plats joints*, (b) iron-wedge assembly, (c) assembly mark: "10" and 5 dots (pictures R. Wibaut and I. Wouters).



Figure 4. St. George's Church (1847–53) in Antwerp. Exterior, interior, and trusses (1849–50) (pictures R. Wibaut).

F.-H. Leclef. St. George's is a hall church with three naves of similar height, covered by three parallel saddle roofs (slope of approximately 37°) formed by iron trusses. A large quantity of iron was also used to reinforce the stone construction (Bertels 2000, 17). This structural use of iron in an early Gothic Revival church was in line with Augustus W.N. Pugin's (1812–52) ideas about Gothic architecture: "When viewed with reference to mechanical purposes, it [iron] must be considered as a most valuable invention, but it can but rarely be applied to ornamental purposes" (Pugin 1841, 29). Promoted by Baron Jean-Baptiste Bethune (1821–94), Pugin's theories exerted a great influence on Belgian Catholic architects in the 1850s, particularly those in the circle of radical Catholics (Ultramontanes).

St. George's trusses (Figure 1b) were realized by the *Atelier de Construction* of Ch. Marcellis, in 1849 and 1850 (Bertels 2000, 15). The trusses of the middle nave span 9 m and are each composed of two trussed beams made of wrought iron. These beams consist of two ties extending from a round-profiled compression strut to each end of the principal rafter. The compression struts, situated at mid-span and perpendicular to the principal rafters, stiffen and

strengthen the rafters. The outward thrust of the two trussed beams on the walls is restrained by a rectangular, wrought-iron tie rod between the two lowest parts of the trusses. This tie rod is supported by three vertical ties, one hanging from each trussed beam and one hanging from the ridge connection. The trusses are longitudinally braced by trussed beams that serve as purlins and span between the trusses (Figure 5a). The only parts of the truss that are not wrought iron are the connections between the raked struts and the purlins. Here, the wrought-iron compression strut is screwed into a cast-iron connection element, which connects the purlins and the rafters using the same hexagonal-headed bolts that are used in all the other connections (Figure 5b). Assembly marks similar to those carved on bars used at St. Joseph's are present on the iron bars at St. George's (Figure 5c).

This second known iron roof in a Belgian church shows a clear evolution. Rather than a form influenced by traditional timber construction, the truss is a new type whose form and dimensions are better adapted to the properties of iron. The shapes of the sections also evolved: both principal rafters and purlins are constructed in wrought-iron T-sections (60 x 70 mm). Nevertheless,



Figure 5. St. George's construction details. (a) trussed-beam bracing, (b) screwed assembly, (c) assembly mark: "B" and 6 dots (pictures R. Wibaut and I. Wouters).

some influences of timber trusses remain, such as the presence of a king post and rectangular, rolled tie beam (whose section is the same as used at St. Joseph's: approximately 20×70 mm), which could have been replaced by a horizontal tie linking the two trussed beams together, as usually found in Polonceau trusses. Hence, although they do not have the Polonceau form, the trusses at St. George's already show a first step toward realizing this more efficient configuration.

5.3. Optimization: St. Anne's church in Ghent (1853-62)

St. Anne's Church (Figures 1c and 6) was erected in Ghent from 1853 to 1862 in a kind of eclectic Rundbogenstil. The church was designed by L. Roelandt, at the time city architect of Ghent. However, he resigned in 1854 following a disagreement with the church council concerning the stability of the foundations. He was replaced by architect J. Van Hoecke, who completed the church and toned down Roelandt's design (Bekaert and De Meyer 2007; Van Driessche 2007). The Royal Commission for Monuments evaluated Van Hoecke's project as "a banality without style" compared to Roelandt's design: "architect Roelandt presented his project as a new type by which he wanted to make the most use of products from the metallurgical industry" (Cierkens 2018, 409). Indeed, between 1835 and 1850, Roelandt presented several designs with hidden timber and cast-iron trusses (Figure 7a) (Ghent, City Archives). He even proposed a project with a visible cast-iron structure (Figure 7b) (Ghent, Archives of the University Library) reminiscent of the exceptional cast-iron interiors built by foundry owner John Cragg in Liverpool in the 1810s (Clarke 2014, 259). After discussing these various projects, the church council finally opted in 1851 for an innovative single-nave church with a large, column-free inner space and lateral chapels between the buttresses. To

cover such a large nave, Polonceau trusses were selected. In 1858, the iron-construction workshop of Ch.-L. Carels (Ghent) was appointed to construct the roof and assemble all the trusses following the completion of the vaults, and finish the work before September 1859 (Ghent, State Archives of Belgium). Installing the roof frame after the ceiling vaults were built was unusual; in the two previously discussed churches, the roof trusses were positioned before the vaults were constructed, which was common practice since the Middle Ages.

St. Anne's nave is twice the width of the middle naves of St. Joseph's and St. George's. Therefore, a double Polonceau truss (*ferme à trois bielles*) was used for this 20-m-wide span. This combination better supported the long rafters. Hence, Roelandt designed for an optimal use of the different components. Because of their length (11 m), the principal rafters were made by riveting two rolled I-section beams end to end (Figure 8a). This assembly was probably made in the workshop, unlike all other connections, which were made on the ground at the construction site using hexagonal-headed bolts (Figure 8b).

As stated by C. Polonceau in the *Revue Générale de l'Architecture et des Travaux Publics*—a journal Roelandt owned (Cierkens 2018, 382)—this configuration required the minimum quantity of materials, which resulted in a very light and cheap truss (Polonceau 1840). At that time, the cost of an iron structure was mainly determined by the amount of material, since labor costs were comparatively low. In this type of truss, all the members are (in theory) loaded purely in tension or compression. Recognizing the different strengths of wrought and cast iron, Roelandt used traditional cast-iron cruciform sections, thickened toward their mid-length (an optimal section to avoid buckling), for the struts and wrought-iron bars for the ties. The trusses at St. Anne's thus display a better understanding of the different properties of the materials.

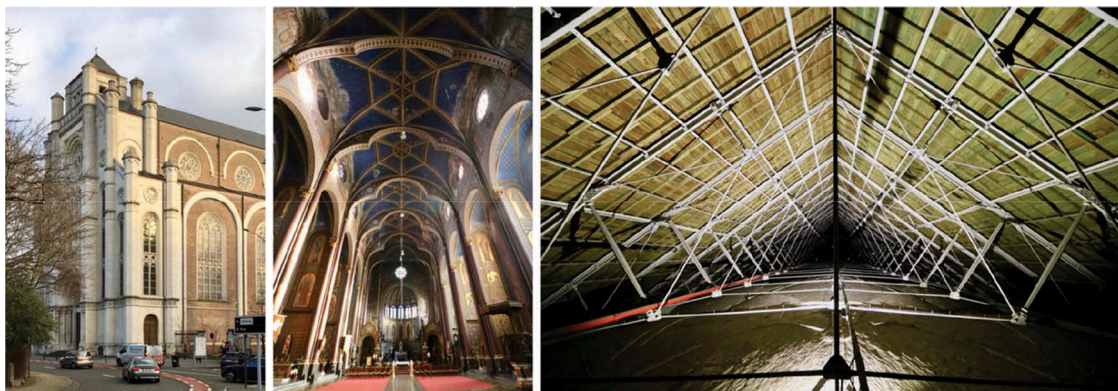


Figure 6. St. Anne's Church (1853–62) in Ghent. Exterior, interior and trusses (1858–59) (pictures THOC and R. Wibaut).



Figure 7. L. Roelandt's preliminary design for the St. Anne's Church. (a) Hidden cast-iron trusses (City Archives of Ghent, Atlas Goetghebuer, L135/11). (b) Visible cast-iron structure (Archives of the Library of the University of Ghent, BIB.ARCH.003566).

From that time forward, the Polonceau configuration was widely used in roofs of large churches in Belgium: e.g. St. Catherine's in Brussels (1854–74), St. Amandus in Antwerp (1869–74), St. Servatius in Schaerbeek (1871–76), and the Sacred Heart in Bruges (1879–85). Whereas in 1847–50, Ch.-A. Demanet depicted several typologies for trusses, E. Roffiaen, writing in 1858 about iron roofs in his *Traité Théorique et Pratique*, only mentions the simple and multiple Polonceau trusses (“*fermes à une ou plusieurs bielles*”) (Roffiaen 1858, 348 ff.). In his handbook *Cours de*

construction donné de 1864 à 1874 à la section du génie de l'école d'application de Bruxelles, Major N. De Vos, a military engineer, explained Roffiaen's focus: “many different devices have been used or proposed in the past; only two have remained in use because of the great advantages they offer: the *ferme à bielle normale* or Polonceau truss for small spans and the *ferme à bielle oblique* for the larger ones” (De Vos 1879, 56). Use of these types of trusses declined only at the very end of the nineteenth century, when steel began to be widely adopted in Belgian construction.

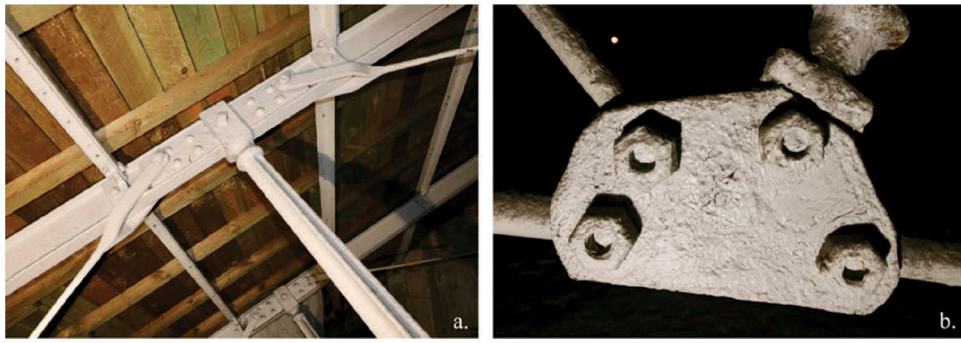


Figure 8. St. Anne's construction details. (a) riveted I-sections, (b) hexagonal bolts (pictures R. Wibaut).

5.4. Evolution of the truss design at St. Catherine's Church in Brussels (1851–66)

St. Catherine's Church is a large, Eclectic-style aisled basilica located in the historic center of Brussels. The nave is covered with simple Polonceau trusses, built 1865–66 (Figures 1d and 9). However, the truss type and construction details changed several times during the design process, which started as early as 1851. The analysis traces this 15-year evolution of the trusses—an evolution similar to that in the three previous cases. Documentation regarding this church, whose construction was undertaken by the Brussels Public Works Department, was found in the Archives of the City of Brussels.

In 1851, J. Poelaert, architect of the Brussels Public Works Department, was asked to develop several alternative proposals for the new St. Catherine's Church for submission to a public enquiry (Brussels, City Archives, B.C. 1851, 33). After the enquiry, in 1852–53, Poelaert designed the so-called “final” plans of the church, and Victor Jamaer (1825–1902)—at that time a draftsman in the department—developed the preliminary cost estimate (Brussels, City Archives, B.C. 1852, 397). In this first project, the roof structure of the main nave was composed of 10 trusses made entirely of wrought-iron bars (Figures 10a and 11a). Similar to St. Joseph's,

the truss typology was largely influenced by the traditional king post configuration from timber carpentry. Even the longitudinal bracing system and the distance between two trusses (approximately 6.5 m) were similar in both churches.

In 1854, the *Société Générale*, which helped fund the project, required some improvements to the initial design (Brussels, City Archives, B.C. 1854, 85–86). Although a small transept and a new entrance were added, the typology of the roof structure was not modified. On September 25, construction of the foundations started according to these plans (Brussels, City Archives, B.C. 1854, 143).

No information about the roof structure was available for the period between 1854 and 1859. Nevertheless, as stated by the communal council, all the detailed plans were completed in 1859 (Brussels, City Archives, B.C. 1859, 175). Some are still conserved in the Archives of the City of Brussels and are signed by J. Poelaert, then City Architect, and Pierre Schmit, *contrôleur-général* of the Public Works Department. The drawings illustrate precisely the evolution of the roof trusses from timber-influenced trusses toward more rational Polonceau trusses (Figures 10b and 11b). The material also evolved: the struts, the assembly plates and the truss shoes were designed in cast iron, while the ties and rafters were in wrought iron.



Figure 9. St. Catherine's church (1851–66) in Brussels. Exterior, interior and trusses (1865–66) (pictures R. Wibaut).

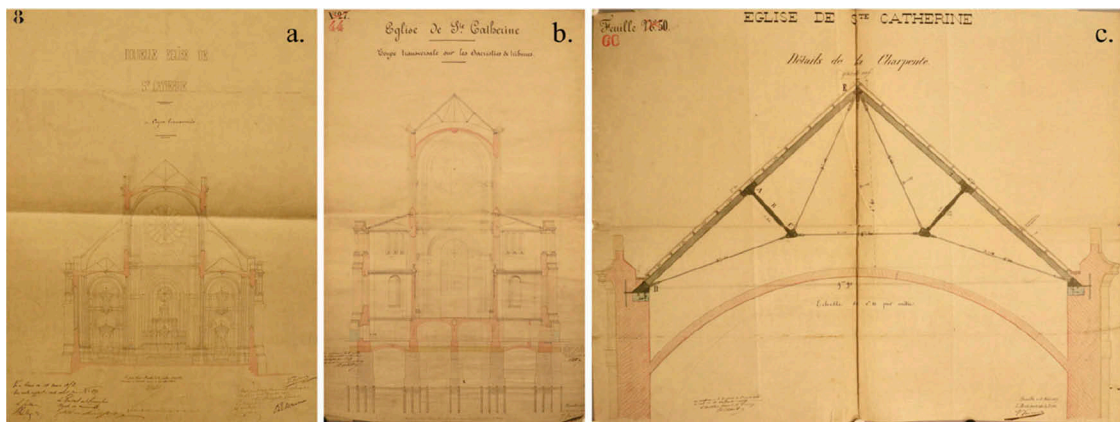


Figure 10. J. Poelaert's design for St. Catherine's church (Brussels, City Archives, *Nouveaux Plans Portefeuilles*, C22). (a) Preliminary design from 1852. (b–c) Detailed plans from 1859.

For the same building length, the number of trusses increased considerably, from 10 to 22. The trusses, however, were never built according to these drawings because later in 1859, Poelaert resigned from this position to fully devote himself to the construction of the Brussels Palace of Justice.

Schmit continued to supervise the construction of St. Catherine's following Poelaert's design. However, from 1863 up to the completion, another architect became involved: W. Janssens, an architect who was not part of the City Administration. He wrote the building specifications for the last construction phase, including those for the roof trusses, but never drew new detailed plans (Brussels, City Archives, A.A. 1865). The cost estimate appended to

the specifications gives detailed information about the trusses to be built. Although the overall geometry of the trusses corresponds to Poelaert's design, the use of cast iron is mentioned only in the construction of the truss shoes. The struts are described as round wrought-iron bars and the assemblies are made of wrought-iron thin plates. The vertical tie from the 1859 configuration was removed (Figure 11c). For the construction of the trusses, the general contractor Jean-Baptiste Docq, a *maçon-entrepreneur* from Brussels, had only the description given in the cost estimate. It is therefore not surprising that the final realization of the trusses (Figure 11d) was contested in 1866 by the City engineer Théophile de Jamblinne de Meux (1820–1912),

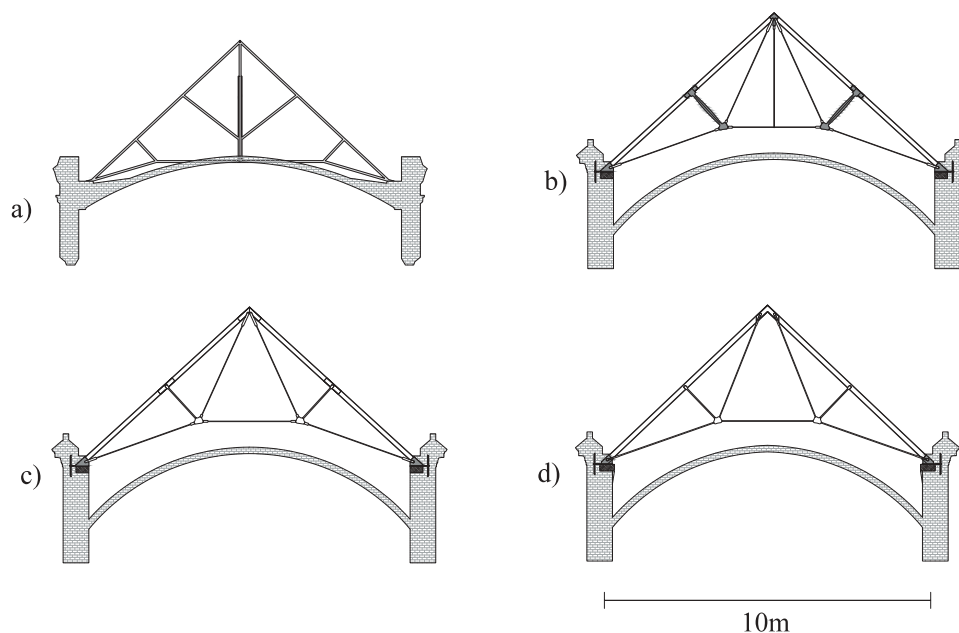


Figure 11. Evolution of the truss design at St. Catherine's church (drawings by R. Wibaut, 2019). (a) 1852: according to the preliminary design by architect J. Poelaert (Brussels, City Archives, *Nouveaux Plans Portefeuilles*, C22). (b) 1859: according to the detailed plans by architect J. Poelaert (Brussels, City Archives, *Nouveaux Plans Portefeuilles*, C22). (c) 1865: according to the cost estimate established by architect W. Janssens (Brussels, City Archives, A.A. 1865). (d) 1867: as built by contractor J.-B. Docq (recorded by R. Wibaut, 2017).

who reported that the assembly plates were not consistent with the cost estimate, nor were the ties and rafters, and that the longitudinal tie rods were simply deleted (Brussels, City Archives, C. 1866). On-site assessment of the church shows that these discrepancies only affected the contractor's income, as no change was made to rectify the construction. Visual examination confirms the 1866 observations.

6. Conclusions

This article sheds light on the roots of the design and construction of iron roof trusses in Belgian churches through a careful examination of four 19th-century examples and by placing early trusses in their historical contexts. It explains that between 1840–60, Belgium benefitted from a favorable context for the introduction of structural iron in construction. From a technical point of view, national knowledge about iron construction developed through actors educated at the most advanced schools in Western Europe, as well as through technical publications and realizations. At the political-economic level, the use of iron in public construction sector was seen as a way to promote the national iron industry. Moreover, a new intellectual framework in the field of architecture was growing, which favored innovations in materials and design. A small group of architects, engineers, and industrialists stood out of the crowd, positioning themselves as advocates for the use of iron in the construction sector. Not coincidentally, it was members of this group who were involved in the early introduction of structural iron in the churches that are the subjects of this article. These cases also show the emergence of new contractors in the building sector and give insight into the collaboration they may have had with architects. At St. George's and St. Anne's, the realization and positioning of the roof trusses were entrusted to industrialists, owners of iron-construction workshops that specialized in the building sector.

Within this global context, the article gives an overview of the tangible evolution that occurred in the design and construction of these four churches. This evolution goes from timber-influenced iron trusses (St. Joseph's, c.1845), via the use of a hybrid system (St. George's, 1849–50), to the use of the more rational Polonceau configuration (St. Anne's, 1859–60 and St. Catherine's, 1865). Due to a lack of standard solutions for the construction of iron roofs in mid-19th-century Belgium, a continuing search for suitable designs and experimentation were necessary. Yet in less than 15 years, designs evolved from entirely wrought-iron trusses to composite cast-iron and wrought-iron trusses, where the materials were placed in the structures according to their respective properties. The connections also give evidence of this rapid evolution. Although bolts

and nuts were used for most of the connections in the four case studies, some specific assemblies are remarkable. Hence, at St. Joseph's, wedge connections inherited from traditional carpentry were used, while at St. George's screw threads were introduced in the cast-iron connections. When it comes to St. Anne's, the principal rafters were connected using a hot riveting technique. The sections of the structural elements also evolved within these 15 years. For St. Joseph's trusses, only rolled, rectangular wrought-iron profiles were used, while a few years later with the construction of St. George's, round bar-iron (for both ties and struts) and rolled T-sections (for the rafters and the purlins) were used. At St. Anne's Church, struts were made of cast-iron with cruciform sections, to increase their buckling resistance, while rolled I-sections were used for the rafters. Therefore, the period between 1840 and 1860 appears as a transition during which architects, industrialists, and engineers came to understand the characteristic properties of wrought and cast iron, and learned from each other through experimentation and discussions. Moreover, the impressive amount of archival documentation retrieved for St. Catherine's confirmed this evolution of iron trusses through the design history of one single church, from its preliminary project (1851) to its realization (1866).

Finally, from a heritage protection point of view, this article provides new information to facilitate the structural and heritage assessment of historic iron roofs in Belgium. It is intended to encourage researchers, architects and heritage experts to climb above the vaults and study the construction of church roofs and place them in a broad historical context. Understanding the developments in the use of iron as a roof construction material allows one to identify the characteristics, as well as, from the perspective of conservation, the strengths and weaknesses of these structures. On-site investigations have shown that the iron roofs do not suffer from inherent structural issues, but better-informed assessments of conditions could be beneficial for future maintenance or renovation. Further research based on on-site investigations will be undertaken to gain more precise insights into the evolution of timber, iron, steel, and concrete roof constructions in Belgian churches from the 1830s to 1940s (Wibaut, Coomans, and Wouters 2018; Wibaut, Wouters, and Coomans 2017).

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