Cast-iron girder bridges of Belgian industrialist Charles Marcellis (1798–1864)

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Abstract

In 1840 the Belgian industrialist Charles-Henri Marcellis (1798–1864) and his partner V. Duval developed a cast-iron girder bridge to replace traditional arch or suspension bridges. When 3 years later the town council of Ghent decided to connect the new railway station with the old Saint-Peter's quarter, two areas that were divided by the Scheldt River, it became its first Belgian test. The 20-meter long 'Marcellis Bridge' as it would soon be called, consisted of two pairs of cast-iron pierced plates, each pair forming a box girder and serving as a parapet. The trump card of this bridge was its straight line that did not impede river navigation nor did it create a 'mountain' for horses and coaches crossing the bridge.

When looking closely at the development of Marcellis' bridges in books, plans and building permits one notices a striking resemblance between his projects and Robert Stephenson and William Fairbairn's successive bridge designs in England. Both the Belgians and the English started with cast-iron girders in the 1830s-40s, developing into more complex box and tubular bridges in the 1840s-50s. A clear path of knowledge transfer is not yet identified, but dating the different designs makes it clear that Marcellis was inspired by England's trial and error testing of this new and also momentary type of bridges. In the second half of the 19th century these bridges would be built using wrought iron and steel due to cast iron's lack of tensile strength and ductility, and its risk of fatigue.
Keywords: Belgium, bridges, cast iron, foundries, Marcellis, 19th century.

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1 Introduction

1.1 Intentions and context of this research

In 1835, Belgian lawyer Charles Marcellis (1798–1864) bought a foundry in the city of Liège and suspended his writing and political activities. From then on he would become a determined defender of cast-iron architecture, much less from an artistic or architectural point of view, but mostly to support his own workshop and the Belgian metallurgical industry. Marcellis wrote and built extensively which makes him a worthy case to examine middle 19th century cast-iron architecture and engineering. His written work obviously calls for critical evaluation, since he hardly ever came up with quantitative data to support his designs.

As a prelude to an exhaustive study on Belgian foundries in the 19th century, this paper examines the cast-iron girder bridges developed by Marcellis' workshop in Liège between 1830 and 1860, and compares them with parallel projects in England by civil engineers William Fairbairn (1789–1874) and Robert Stephenson (1803–1859).

1.2 Historiographical reflections

Canonical architectural history shows that Marcellis is best known for two (cast-iron) constructions, the Marcellis Bridge in Ghent (1844 – pulled down in 1865) and the covering of the Antwerp Stock Exchange (1854 – burnt down in 1858). Since these structures were demolished rather rapidly, it is thanks to Marcellis' vivid writings and their contemporary polemics that they are still remembered and remain a solid subject of scholarly work. Though at the same time they also relegated Marcellis' other realizations, such as steam machines and pumps for the mining industry exported to The Netherlands and Germany, to the background.

Current literature is not very unanimous on Marcellis' profession or background. Lode De Clercq has probably written the most discerning article on Marcellis when he studied Belgian 19th century heating technology [2]. However when discussing Marcellis' background he too could not draw any substantial conclusions due to a lack of decisive sources. Only further archival and literature research can expand our knowledge and give greater accuracy on the extent of Marcellis' activities. Consequently this research mostly depends on the combination of multiple types of documents and combining sources with literature to check accuracy. Especially Marcellis' books, along with building permits and specifications, will provide additional information on the exact details of his constructions.

2 A shifting career: from literature to industry

2.1 Charles Marcellis as a poet and a politician

Charles-Henri Marcellis (Antwerp, 1798–Liège, 1864) was a prolific writer, as a poet, a politician and as an industrialist. In 1822 he had obtained a law degree at the University of Liège but in the first years of his professional career he was mainly occupied with literature and poetry. In 1829 Marcellis published *Les Germains*, his best-known work of poetry. This poem of 4 cantos over 125 pages was Marcellis' imaginary description of a Roman camp besieged by Germanic tribes. After the Belgian revolution in 1830 Marcellis published only occasional books as he got more interested in politics. He was a member of parliament for a few months in 1833 and for three years he also wrote for *Politique*, a journal published by the Belgian unionist movement which advocated the union of Catholics and liberals against the policies of William I of The Netherlands.

2.2 Cooperation at the foundry between Marcellis and V. Duval

In 1835 Marcellis bought the foundry of Mr Gomrée after already having purchased the furnaces of Raborive and Férot which he would transfer into the Gomrée foundry in the Boverie in Liège. In the Biographie Nationale it is stated that the Fonderies et Ateliers de Construction de Machines de M. Ch. Marcellis (fig. 1(b)) employed over 500 workers [3].

Figure 1: (a) Charles Marcellis and the Antwerp Stock Exchange on a commemorative medal of 1854 and (b) a lithograph of Marcellis' foundry and workshop in Liège, published in 1854 [1].

In only a few years time Marcellis was able to transform himself into an important industrialist. The technical aspect was looked after by his partner V. Duval, a man of whom little is known. Most works refer to him as a French (mining) engineer, though there is no real evidence for this and his name is only mentioned as a co-author of some of Marcellis' books. The large production of Marcellis' company and the fact that his name is next to Marcellis' when it comes to engineering aspects allow concluding that Duval was indeed well-trained in engineering.

After Marcellis' death in September 1864 his sons François and Charles Marcellis took over their father's company. In 1872 the company turned into the S. A. des Ateliers de Construction de la Meuse and moved to Val-Benoît.

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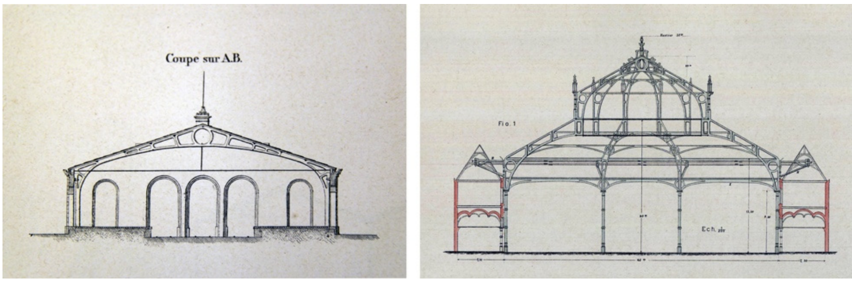


Figure 2: (a) Design of a cast-iron truss for an Antwerp warehouse of 1844 with a span of 25 m [4] and (b) the cover of the 1854 Antwerp Stock Exchange as drawn by Belgian engineer Arthur Vierendeel with a span of 30 m x 40 m [5].

3 On 'Belgian' bridges

3.1 Marcellis' first project for a cast-iron girder bridge

In February 1840, only five years after Marcellis had become active in the metal industry, Marcellis and Duval published his *Notice sur un nouveau système de ponts en fonte*, the first of a pair of notices – not to say pamphlets – on their so-called 'new' system to erect cast-iron bridges. In the introduction the authors appealed to the feelings of the readers by deploring that their native country Belgium was a close follower of England with respect to iron production whilst the use of this material remained unnoticed in building practice [6]. Marcellis regretted even more that the city of Liège had decided to reconstruct the recently demolished stone La Boverie Bridge by another stone bridge. Marcellis illustrated his system by redesigning this La Boverie Bridge (fig. 3).

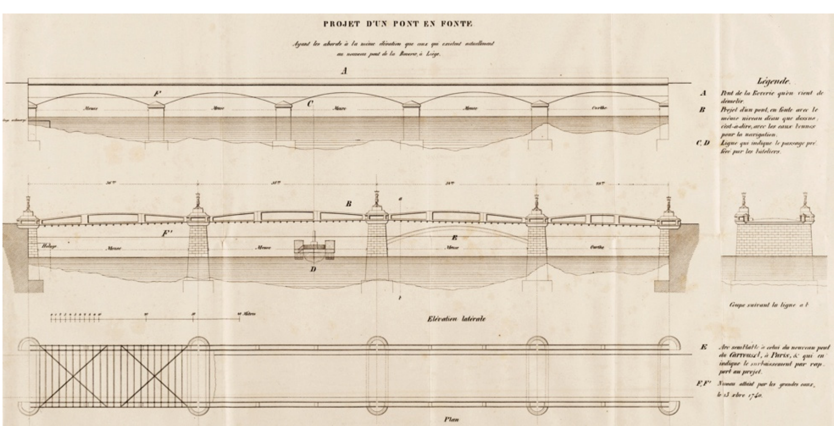


Figure 3: Marcellis' project for the cast-iron La Boverie Bridge in Liège with 3 stone pillars instead of 4 for the stone variant, and easier navigation for boats as shown in the middle drawing [6].

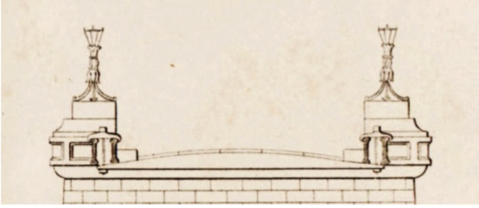
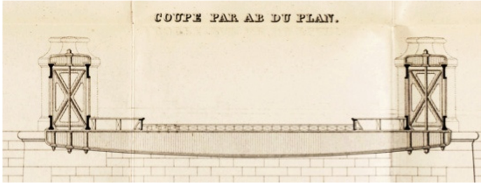
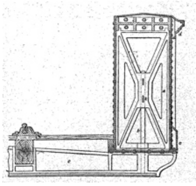
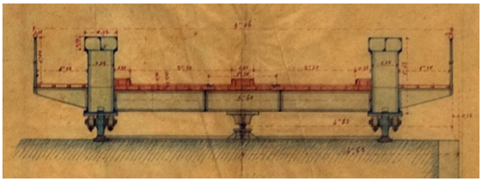
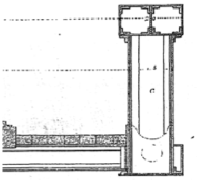
Marcellis argued that the bridge had to link the two borders while at the same time obstruct as little as possible the course of the river, i.c. the Meuse. Reading the *Annales des Travaux Publics de Belgique* of that period confirms the great importance that was attached by the government to ease river navigation. The recent demolition of this stone bridge convinced Marcellis that such a bridge lacked life span and security. The greatest disadvantage of stone bridges was their shape: many piles (obstacles in the water) are necessary to support the stone arches and when one tried to enlarge the distance between the piles, the arches needed to be higher, thus turning the bridge into a mountain, making it more dangerous for horses and coaches. When considering the opposite – putting the piles closer to each other – the passage of large boats would be more difficult and it would also decrease the section for the water to flow through.

Since Marcellis criticized the shape of stone bridges, it is logical that iron arches were not his favourite alternative either. So suspension bridges were the only solution left at the time. Their advantage to completely free the passage of the river below it, resulted in another problem: the discomfort they give people in case of a large live load on these bridges with low rigidity. Marcellis cited one empirical result of French engineer Joseph Chaley (1795–1861) who, when testing his suspension bridge in Swiss Fribourg (1834 – demolished in 1923) reached a deflection of one meter. Marcellis however forgot to mention the dimensions of the bridge, an at the time world record-breaking span of 273 m. Discussing relative deflections would have provided more accuracy.

Then Marcellis came to the next or 3rd step of construction bridges, using cast-iron beams. He was very sparing of technical details, only mentioning the main dimensions: 36 meters long, consisting of three parts bolted together, 8 cm thick and 2 meters high in the middle (following the line of equal resistance), its total weight being 39 000 kg. This type of beam could span up to 32 m and would be able to resist a maximum force in the middle of 213 000 kg. Four of these beams, two on each side, would thus give a strength of 852 000 kg, or almost 2 000 kg/m^2. Marcellis did not give any mathematical or mechanical explanations for these results, since "its extreme simplicity doesn't require it." [6] The two plates he added gave a better insight in the real structural character of the bridge, though they were hardly detailed (fig. 3). The most striking fact is that it is a simple girder bridge based on English examples, although the crossbeams that supported the bridge deck were not connected to the bottom flange of the girders but hung at the top by means of hangers, making it a perfect transition between early and later cast-iron bridges, respectively (trussed) girder and box girder bridges (table 1).

When it came to calculations only some experiments were mentioned deriving strengths from small samples that according to Marcellis had been proven equally correct for large elements. Marcellis stated that Ghent city-architect Louis Roelandt (1786–1864) had shown his faith in these results and that his applications in the Ghent courthouse had put its opponents in the wrong. In the courthouse the archives and an interior wall had to be supported by a set of cantilever beams. The load was estimated at 70 000 kg. Two connected beams of

Table 1: Comparison of Marcellis' bridges and English bridges of Robert Stephenson and William Fairbairn between 1840 and 1860.

Type of bridge	Marcellis' bridges in Belgium	Bridges in England
(Trussed) girder	 Boverie Bridge in Liège (without trusses) Designed in 1840 [6] s	 Dee Bridge (Stephenson) Executed in 1846 [12]
Box girder	 Marcellis Bridge in Ghent (with pierced plates) Executed in 1843 [7]	 Althorpe Bridge (Fairbairn), s.d. [10]
Tubular	 Swing bridge in Antwerp Designed in 1857	 Design (Fairbairn) Patented in 1846 [11]

55 cm high had a strength of 210 000 kg. For the La Boverie Bridge beams of 2 m high would be used, providing sufficient strength.

3.2 Bridge over the Scheldt in Ghent

In 1843, Marcellis was finally able to build his bridge. He convinced Charles Rogier (1800-1885), Belgian Minister of Public Works from 1840 till 1841, to grant him a subsidy to erect a cast-iron bridge over the Scheldt in Ghent. The Ghent council had agreed to build this type of bridge to link the new train station to the Saint-Peter's quarter. The bridge consisted of two pairs of cast-iron pierced plates of 20 m long, the members of each pair were combined by 6 struts, thus forming two box girders. Each of the plates was made out of 10 m long plates bolted in the middle by means of 8 smaller plates. Seventeen cast-iron

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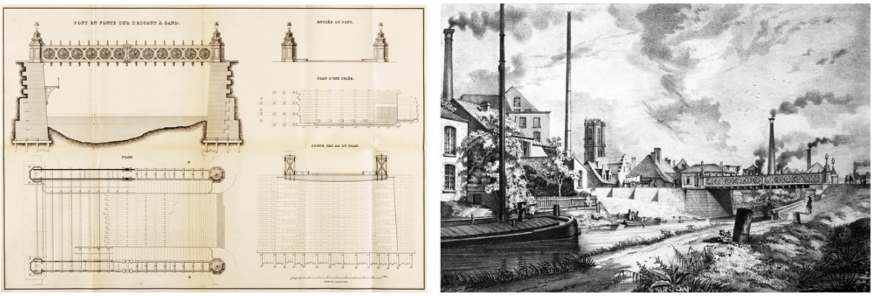
crossbeams of 11,4 m were connected at the bottom of the box girders and carried the bridge deck made out of wood. The crossbeams were connected to the box girders by 3 bolts at each end, 2 of which were connected to the plates and one by a tie-rod connected to a small crossbeam that connected the pierced plates at the top (fig. 4(a)).



(a) (b)

Figure 4: (a) Marcellis' bridge design for Ghent [7] and (b) a view over Ghent showing the Marcellis Bridge in front of an industrial landscape [8].

The official inauguration of the *yzeren Marcellis brug* (iron Marcellis Bridge) took place on 30th June 1844. Earlier that month Marcellis and Duval had published the most important features of the bridge in *Sur les ponts belges, nouveau système de ponts en fonte* [7]. The title gave away their ambitions. The horizontal cast-iron beam would be the base of a Belgian way of constructing bridges. However, Marcellis' large-scale ambitions have never been tested. His first design for the La Boverie Bridge combined a span of more than 30 meters with a very simple design whereas the Marcellis Bridge was a much more complex design having only a 20 m span. The bridge was pulled down in 1865 when Ghent decided to shift the road. Only the name of the bridge remains up until today in its concrete successor.

3.3 Testing the bridge

As will be discussed further in this paper, uncertainty about these girder bridges remained in Belgium, as well as in England. When on 13th June 1842 the contract between the city of Ghent and Charles Marcellis was signed, it clearly stated that before construction in Ghent the bridge had to be tested in the workshops of the contractor. The official report of these tests was described by Marcellis and Duval [7]. The bridge having a length of 19 m and a with of 9,2 m was charged with a load of 400 kg/m^2, which amounts up to a total load of 70 tons. Deflections measured at the large pierced girders were only 3 mm on the day of testing, and 4,5 mm after 24 hours. One can only conclude that the stiffness of the bridge is very firm with a relative deflection of less than L/4000.

An extra test to determine the load-bearing capacity was carried out on site when a loaded coach with a weight of 14 500 kg was placed in the middle of the bridge. A rope that had been stretched at the extremities of the bridge, and showed a natural deflection of 93 mm compared to a fixed point of the bridge, did not show a deflection of more than 1 mm when the weight was put on.

4 Marcellis' Bridge in a Belgian and European context

4.1 Foreign influences on Belgian bridge building

Referring to a Belgian system of building, Marcellis' cast-iron bridge designs were not his invention, nor of any other Belgian architect or engineer. In both England and France earlier examples can be found. Nevertheless Belgian developments (or developments on what was later to be Belgian territory) could have influenced his designs, since traces of iron bridges in Belgium are already found in the 1820s. We could mention for example Belgian politician Théodore Teichmann (1788-1867), an inspector-general for the national service of bridges and roads, who, according to Marcellis, had introduced cast-iron bridges in Belgium twenty years earlier in Antwerp, spanning a dockyard with an iron arch bridge.

When it comes to foreign influences French and English paths of knowledge transfer are plausible theories. During the French reign (1794-1815) many Dutch and Belgian public services followed their French counterpart's policies [9]. In addition, France was the country where engineering was highly theorized at the *Ecole Nationale des Ponts et Chaussées* from the end of the 18th century onwards. Looking closely however to French books, e.g. Antoine-Rémy Polonceau's *Notice sur le nouveau système de ponts en fonte suivi dans la construction du Pont du Carrousel* (1839) or André Guettier's *De l'emploi pratique et raisonné de la fonte de fer dans les constructions* (1861), no direct link between Belgian and French evolution in cast-iron girder bridges can be revealed. This may be due to a lack of exhaustive sources, but it is believed that France built more arch and suspension bridges, and later on lattice girders bridges. One French engineer who cited the Marcellis' Bridge was J. Chaix. In his book on the history of wooden, iron and steel bridges we read that "*Malgré les bons résultats obtenus, les ponts de ce système n'ont pas été reproduits, et nous croyons que c'est à cause des évidements pratiqués dans les parois, lesquels sont aussi peu favorables pour l'homogénéité de la fonte, que pour la transmission des efforts verticaux aux semelles*" [10]. Chaix was referring to both technical aspects with regard to casting the elements as structural disadvantages. The latter are due to cast iron's lack of tensile strength and ductility, and its risk of fatigue. According to Chaix bridges with horizontal beams were mainly used for railways and to span roads or smaller streams (2 to 7 m).

In England bridge building had developed mainly by pragmatic evolutions and these designs will be discussed in the next paragraph. Any Dutch influences – the United Kingdom of The Netherlands were reunified from 1815 until 1830 –

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would have to be put into perspective as the first iron bridge in The Netherlands is only believed to be built in 1837 in Rotterdam [9].

4.2 Charles Marcellis vs. William Fairbairn and Robert Stephenson

William Fairbairn (1789–1874) and Robert Stephenson (1803–1859), two of the most important figures in the iron industry in England in the first half of the 19th century, were contemporaries of Marcellis. Fairbairn's and Stephenson's (railway) bridges resemble Marcellis' design a lot. Even more striking is the parallel evolution of their bridges from simple cast-iron beams to more complex box girders (table 1).

It is said that in England the building of railways led to an "*unprecedented increase in the use of iron bridges and their introduction led to experimentation concerning the use of cast and wrought iron*" [11]. This means evolutions occurred for 2 reasons: bridges were needed to span rivers for railway traffic, but more important was the knowledge that was gained by erecting a network of railways, which increased familiarity with new materials and techniques. In England the first girder bridge was built in 1830 at the Water Street terminus of the Liverpool and Manchester Railway to a design by William Fairbairn, though sources remain vague and no visual material is able to determine the real characteristics of this bridge.

Charles Marcellis however hardly ever referred to English or any other specific construction he might have known. Since Robert Stephenson was so well known at the time throughout Europe it is very likely he knew his bridge designs. Both Robert Stephenson and his father George Stephenson, the latter renowned as being the *Father of Railways*, were for example present at the inauguration of the first continental railway between Mechelen and Brussels in May 1835.

The decade that began in 1840, and in which Marcellis was very focused on getting his plans pushed through, was one of the most exciting when it comes to iron bridge design in England [11] – it became for good reason known as the 'railway mania' [12]. It was a period of trial and error for both suspension bridges and horizontal beams. In this decade the birth and death of the (trussed) girder bridge were witnessed when the Dee Bridge at Chester collapsed in 1847 of which Robert Stephenson had been the engineer. The Dee Bridge is very similar to Marcellis' first proposition of February 1840. In both cases every girder was made by bolting together three smaller castings of equal length and four girders were used per span, the only difference being the presence of a wrought-iron truss as a reinforcement in Stephenson's design – since the Dee Bridge was built 6 years later than Marcellis' first design, it is logical to assume more knowledge.

Comparing the Marcellis Bridge in Ghent to an undated bridge of Fairbairn over the Althorpe Street in London (described by Chaix in 1891 [10]) resemblance is even more striking, and the same goes for a swing bridge Marcellis designed for the Antwerp harbour. The design is an almost exact replica of a type Fairbairn had patented more than 10 years earlier. These latter box girder bridges are however no longer in cast iron but made out of wrought iron. From the 1860s onwards cast-iron (box) girder bridges were demolished and cast-iron was replaced with wrought-iron composite beams formed by riveting sheets together, and then steel rolled beams, materials with higher values for both tensile strength and ductility.

In the end the few cast-iron girder bridges – of any form – were only granted a short life. In a handbook by Belgian engineer Armand Demanet (1808-1865) we read that *"Les ponts de ce système n'ont reçu qu'un fort petit nombre d'applications. Une entre autre a été faite à Gand sur un bras de l'Escaut"* [2].

Tom Peters wrote in his *Transitions in Engineering* in 1987 that the bridge in Ghent is a pierced plate member bridge resembling a Vierendeel [13] However, by combining two of these pierced plates, the beam tends towards a box girder. Furthermore cast-iron box girder bridges are of a different nature than steel framework beams, such as a Vierendeel. We also have to point out that Marcellis' motives were of economic nature whereas Vierendeel was on the one hand intrigued by the collapse of bridges where the diagonals had not failed (thus being superfluous) and its relation to the discussions on secondary stresses, and on the other hand by the aesthetic values of simple and solid forms without too many slender lines [14, 15].

5 Conclusion and discussion

The *Iron Bridge* near Coalbrookdale in England is the first, and probably the best-known cast-iron bridge worldwide. Built in 1779 by Abraham Darby III this arch construction had no precedent and thus was the method to erect and connect the structure based on carpentry. This particular bridge has been the subject of much investigation, but so far little is known on the history of cast-iron girder bridges, which existed between 1830 and 1860. Some aspects have been studied, but an exhaustive approach of its development does not exist. This paper tried to put two country's evolutions next to each other: the girder bridge designs of respectively Charles Marcellis from Belgium and William Fairbairn and Robert Stephenson from England.

Charles Marcellis was a multifaceted man. Considering his previous careers as a lawyer, writer and politician we can assume that he had developed his rhetoric qualities and built up a network when he took over the Gomrée foundry in Liège, and started casting and building machines and pumps on the one hand and columns, beams and larger plate girders on the other hand. Comparing him to his English contemporaries, a striking resemblance has been noticed, evolving from simple girder bridges, towards more complex box girder bridges and later even wrought-iron tubular bridges.

The documents that were studied gave a clear insight in the evolution and the international context of this type of span which got replaced by wrought iron and steel from the 1860s onwards, and is a characteristic example of a momentary construction element on the frontier between earlier wooden and later wrought-iron and steel trusses.

This paper is part of a broader research that lists all Belgian foundries in the 19^{th} century and examines their role in knowledge transfer on materials and structural design. It exposes the innovations that were developed, not only by architects and engineers, but also at foundries and workshops. This inventory of foundries and their buildings will help to preserve the few remaining large cast-iron artefacts that still exist today, next to the usual cast-iron suspects as columns and smaller cast objects. They remind us of our ancestors' first steps into industrialization when they expanded their one-man workshops into foundries.

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