Das lange 19. Jahrhundert (1780–1914)
Teil I: 1780–1850

Stefan M. Holzer, ETH Zürich

Jahrhundert des Eisens:
Die Voraussetzungen

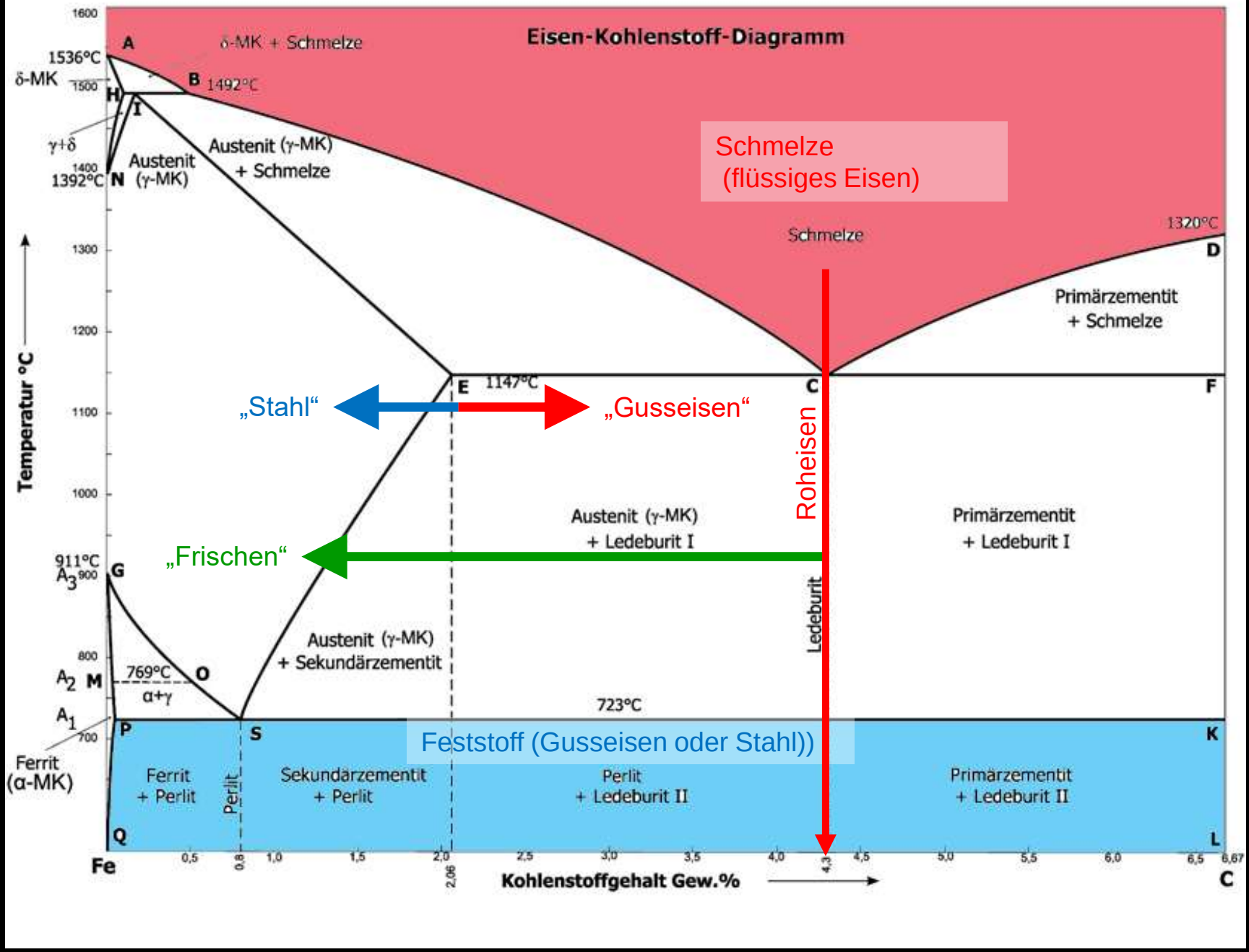
Rot-
eisenstein
(Hämatit)
Fe_2O_3

Brauneisen-
stein
(Limonit)
Fe(O)OH

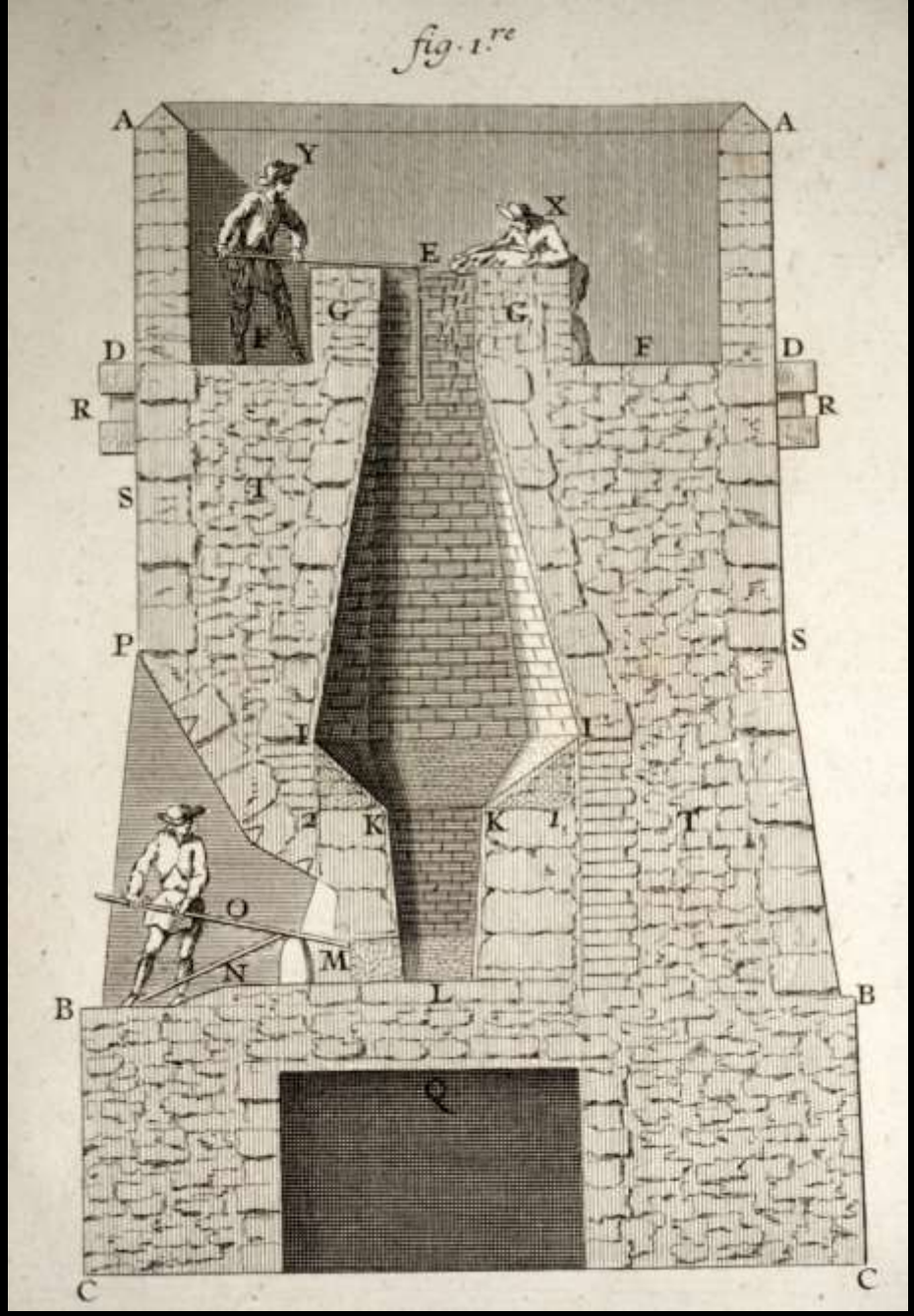
Spateisen-
stein
(Siderit)
$FeCO_3$

Pyrit
FeS_2

Eisenhaltige Erze (Fotos: WikiCommons)



Eisen-Kohlenstoff-Diagramm und Herstellungsschritte



Hochofen, Reduktion des Eisenoxids, ermöglicht Produktion von flüssigem Roheisen
etwa ab 17. Jh. allgemein gebräuchlich (Courtivron/Bouchu 1762)

Französische Ofenplatte aus Gusseisen

Bauteile aus Schmiedeeisen, 18. Jh.

Gusseisen vs. Schmiedeeisen

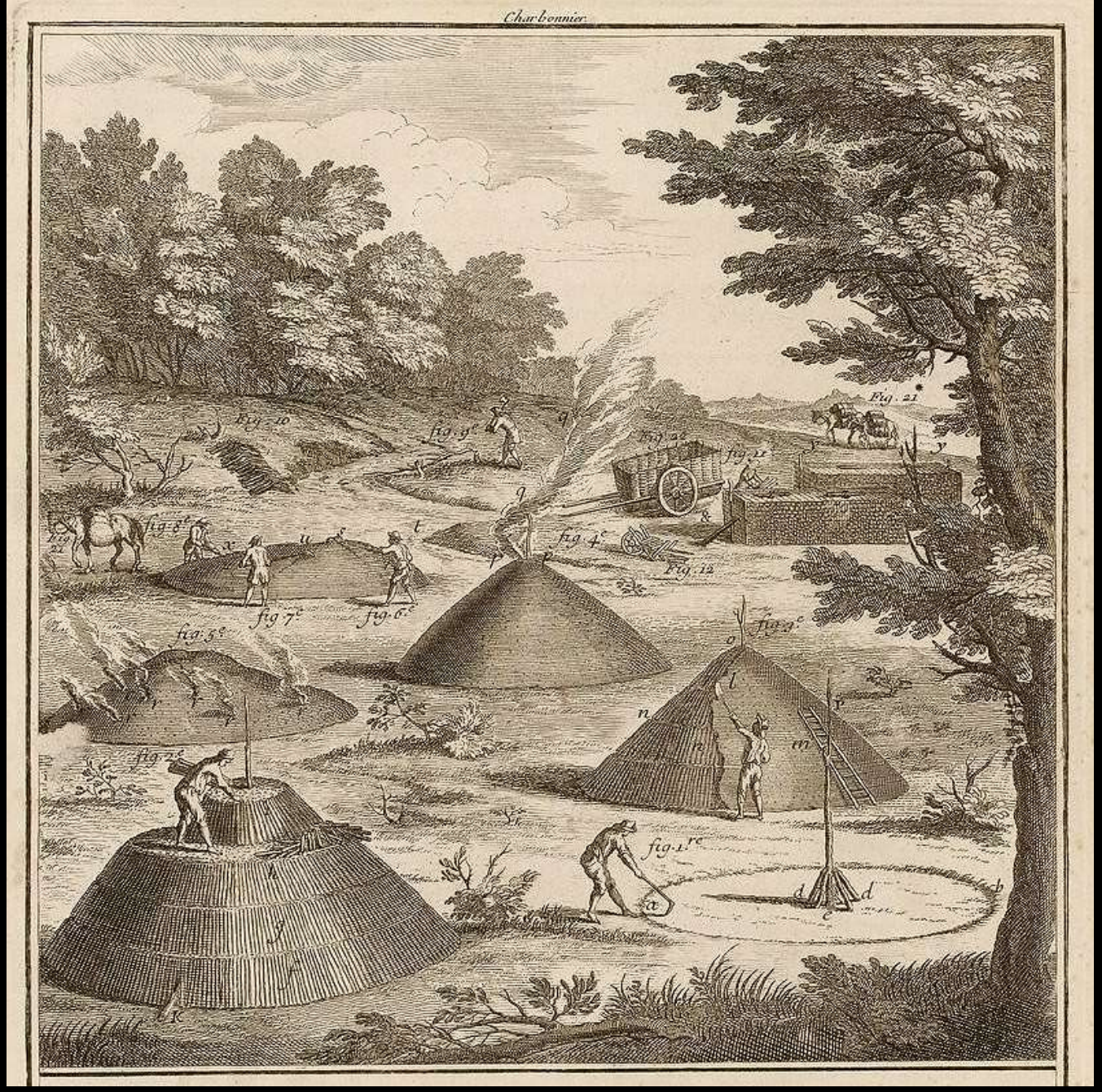
Gusseisen:

- Hoher Kohlenstoffanteil
- Formgebung: direkter Guss in Sandform
- Materialeigenschaften: hart, spröde, hohe Druckfestigkeit (vgl. Stein)
- Ggf. nur einstufiger Herstellungsprozess (Roheisen = Gusseisen)

Schmiedeeisen („Stahl“):

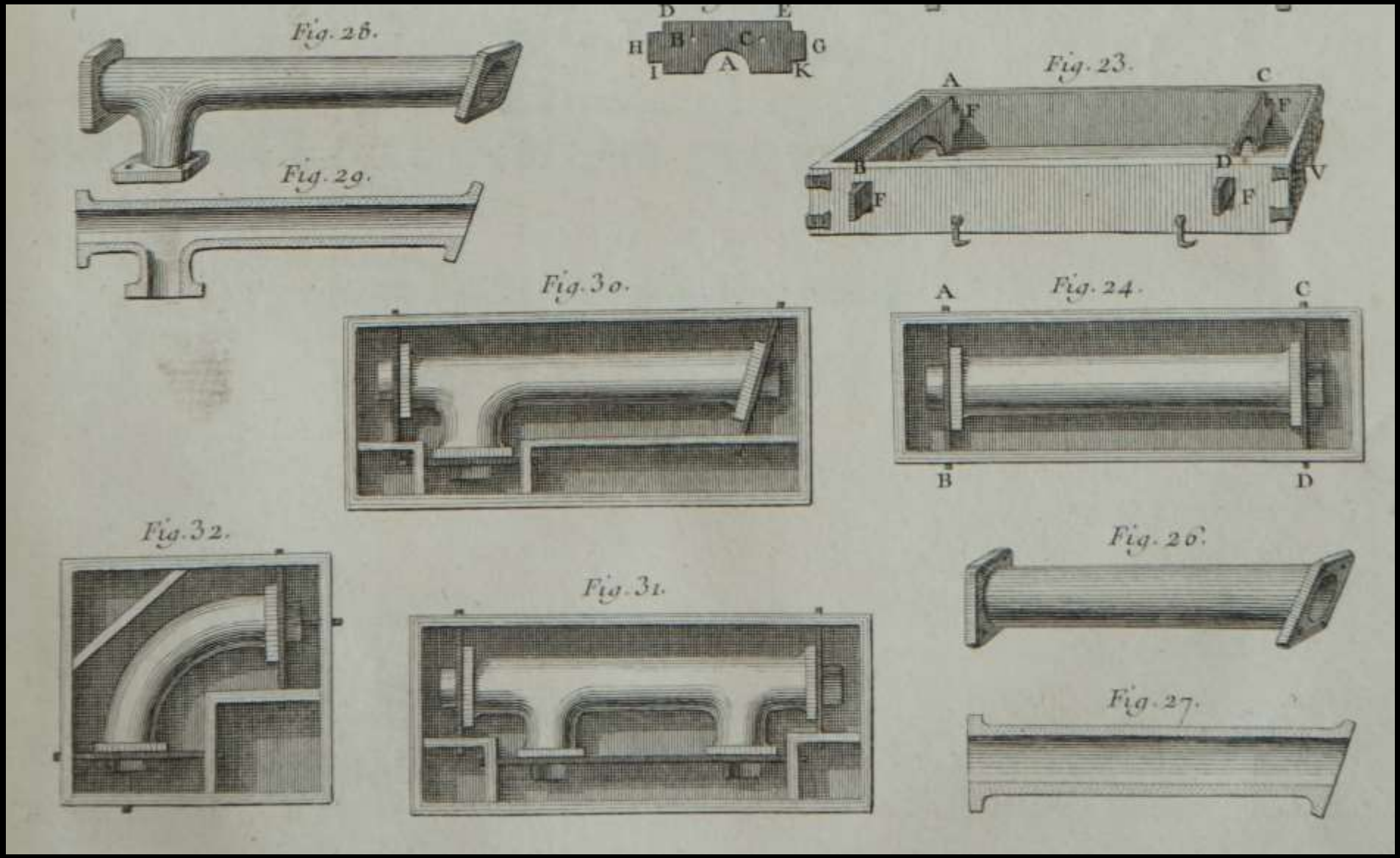
- Niedriger Kohlenstoffanteil
- Formgebung: Umformen durch Schmieden
- Materialeigenschaften: zäh, Druck- und Zugfestigkeit gleich hoch (vgl. Holz)
- Zweistufiger Herstellungsprozess (Roheisen -> Schmiedeeisen

Gusseisen vs. Schmiedeeisen

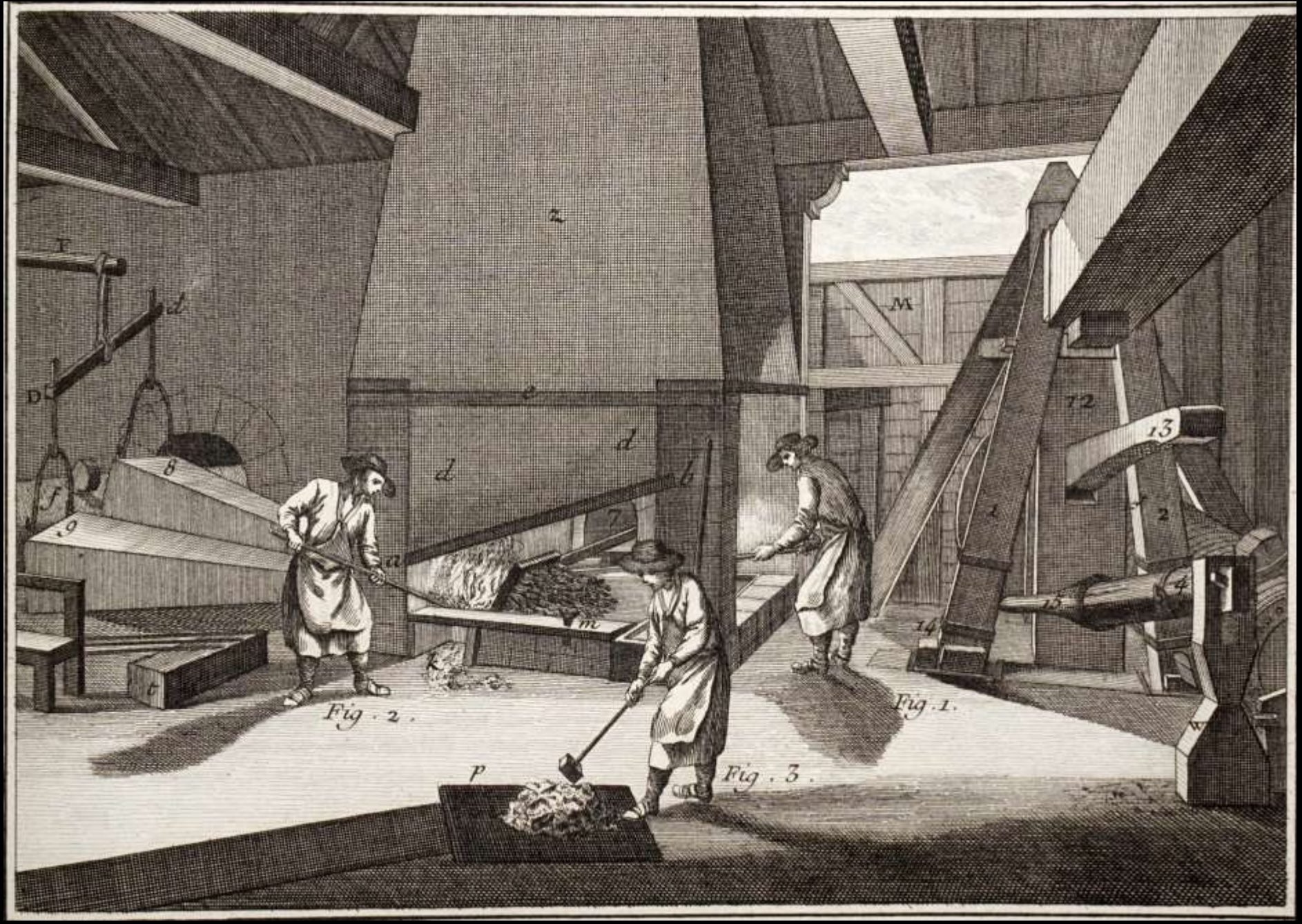


Herstellung von Holzkohle für die Eisenverhüttung in Meilern
(Duhamel du Monceau, *Art du Charbonnier*, 1770)

Direkter Guss von Roheisen aus dem Hochofen
(Encyclopédie 1765)



Typische Gusseisen-Produkte des 18. Jahrhunderts: Rohre
(Courtivron/Bouchu 1762)



Frischherd des 18. Jahrhunderts: aus Roheisen wird schmiedbarer Stahl („Schmiedeeisen“)
(Encyclopédie 1765)

Typische Schmiedeeisenprodukte: Nägel des 15.-18. Jh.

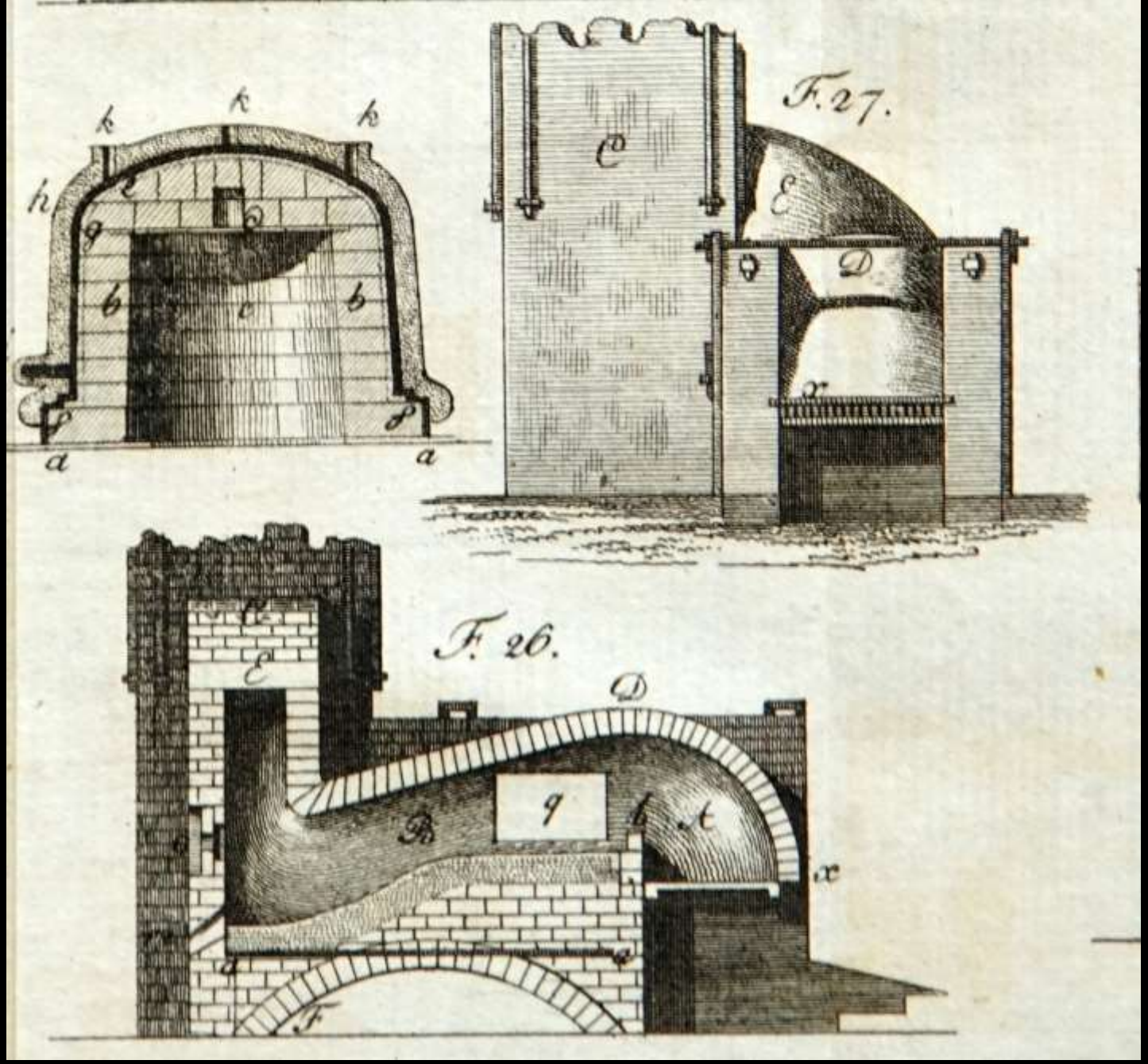
Industrialisierung der Eisenproduktion

1705 Innovationsschritt Kohlenkoks statt Holzkohle

1784 Innovationsschritt „Puddeln“ statt Frischherd

Roheisenproduktion mit *Koks* im Hochofen (Abraham Darby I, ab 1705)
(Francis Vivares, A View of the Upper Works at Coalbrook-Dale, Kupferstich, 1758)

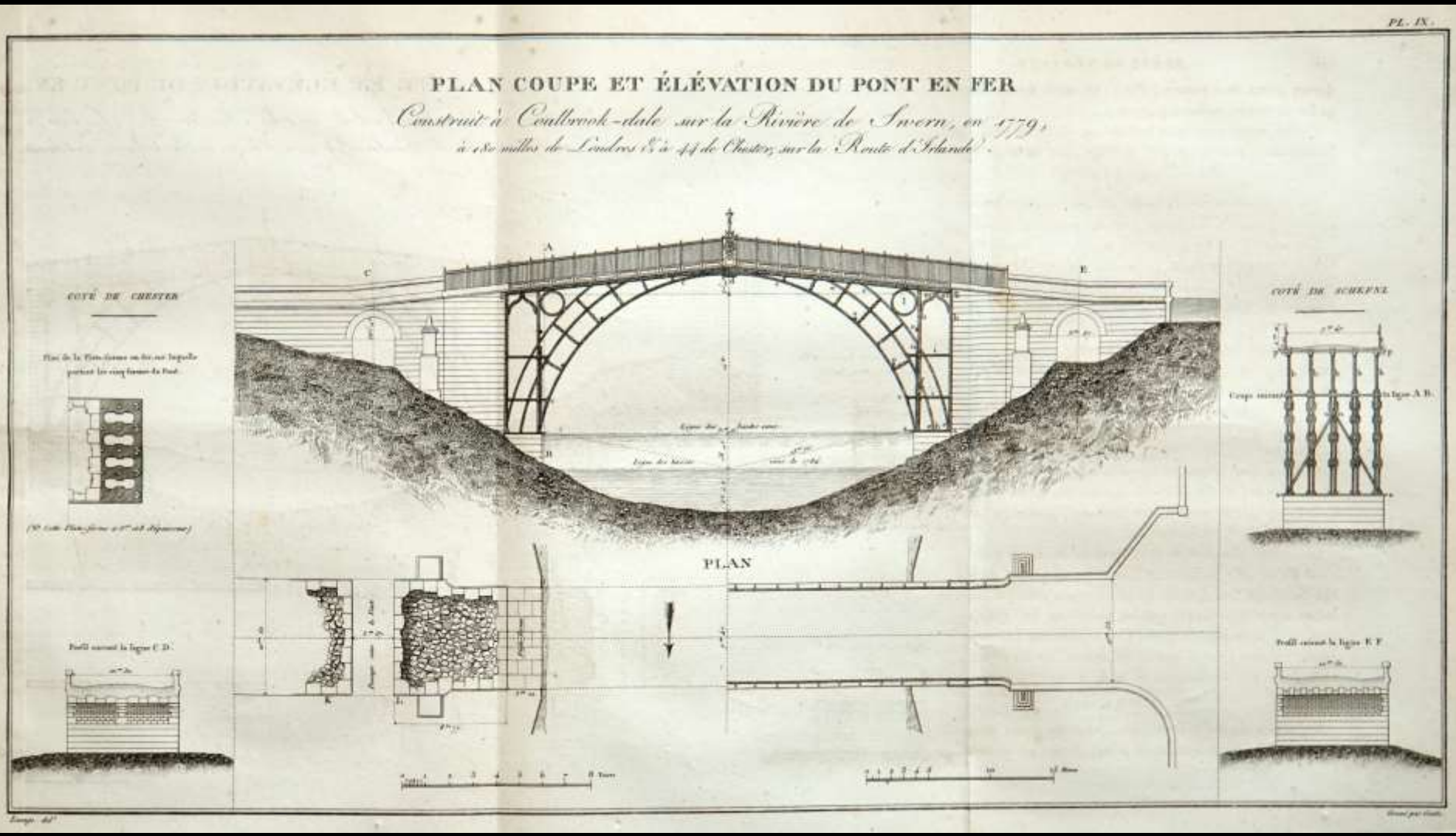
Coalbrookdale (Shropshire) um 1800, hier wird 1784 durch Henry Cort das „Puddeln“ erfunden
(Ph. J. Lutherbourg, *Coalbrookdale at Night*, 1801; London Science Museum, CC-BY-NC-SA 4.0)



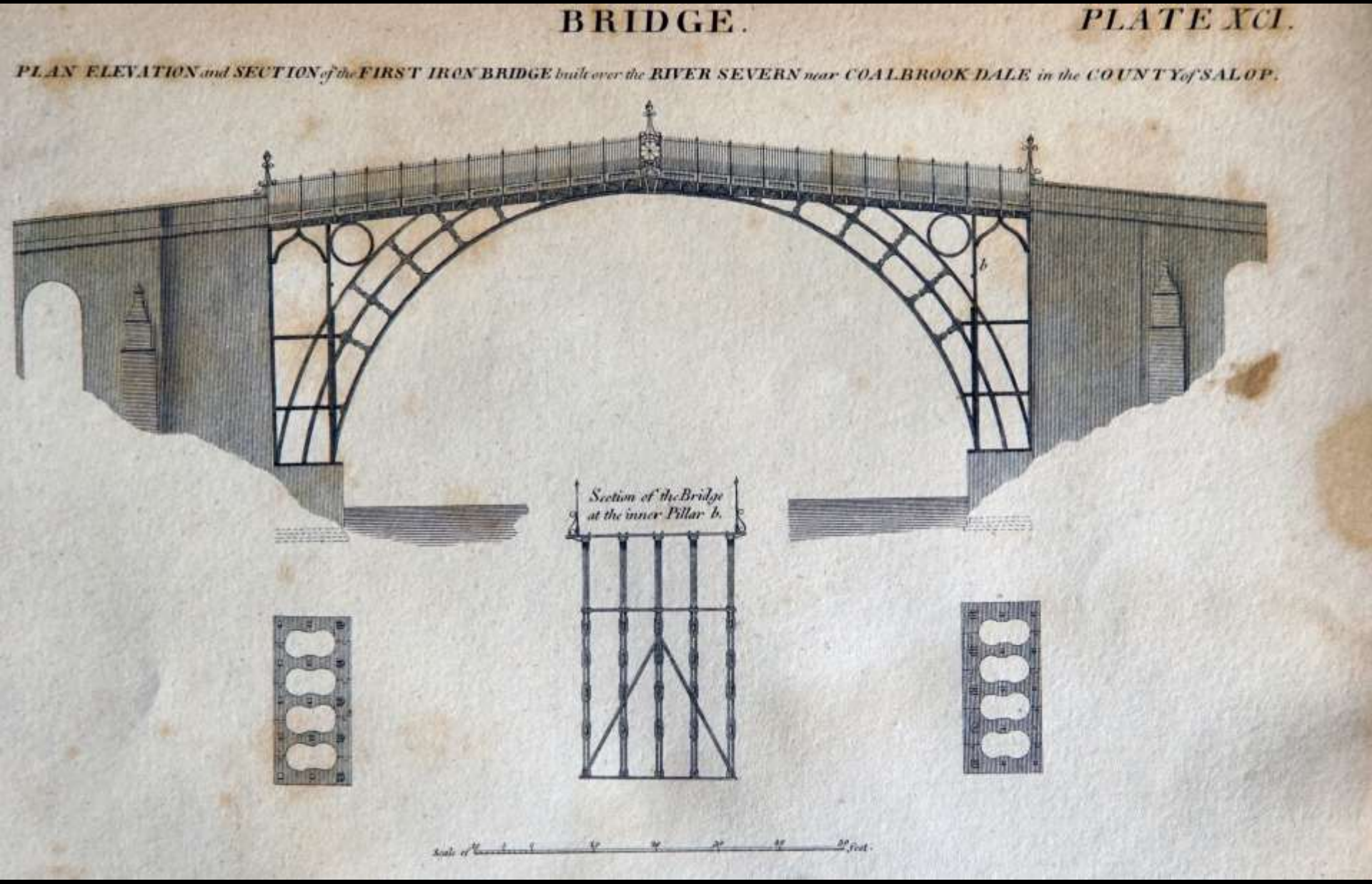
Puddlings-Flammofen: Frischen unter kontrollierten Bedingungen
(Karsten 1816)

England

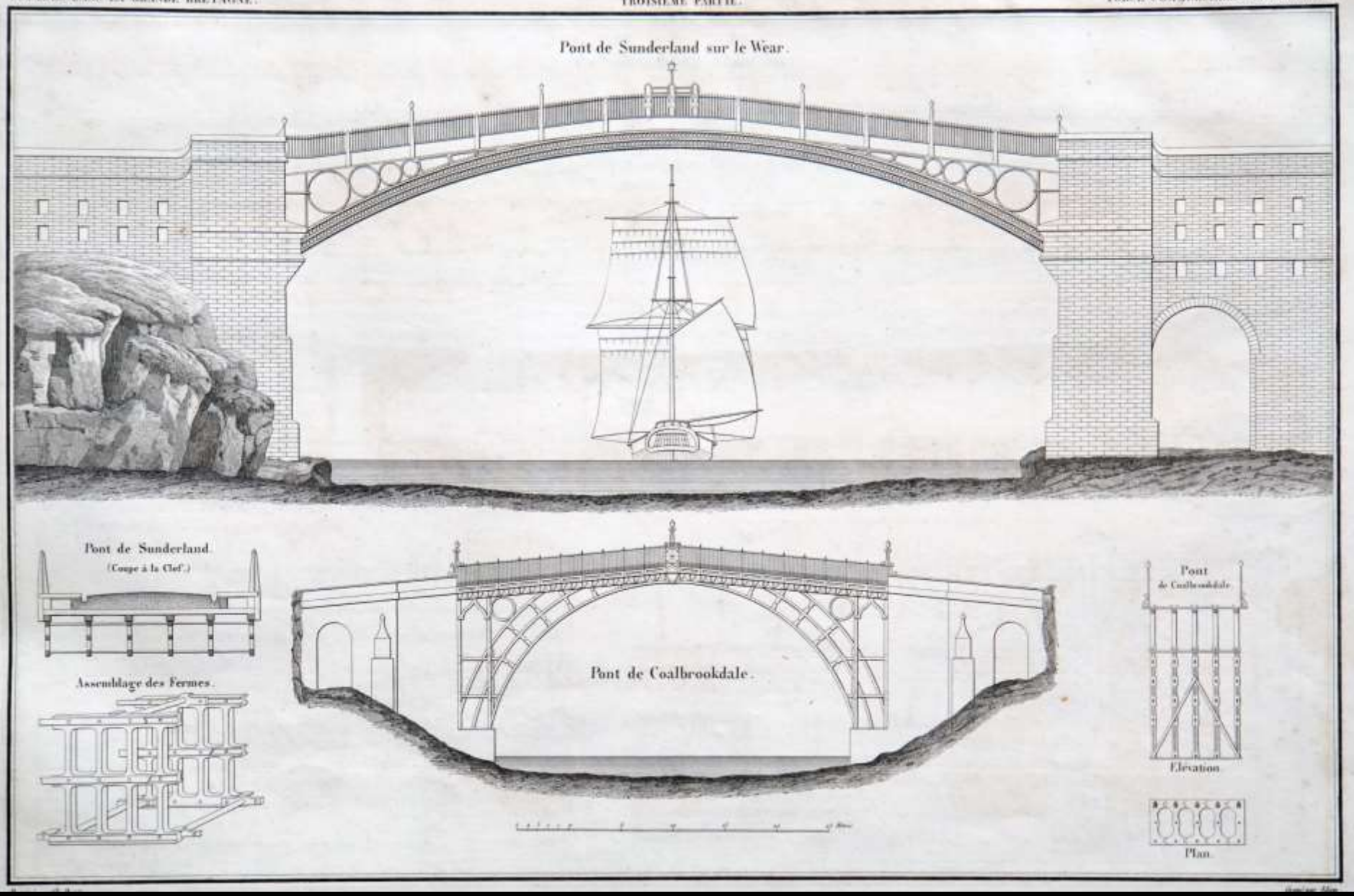
Bauen mit *Gusseisen*: von der Bogenbrücke zur Industriehalle



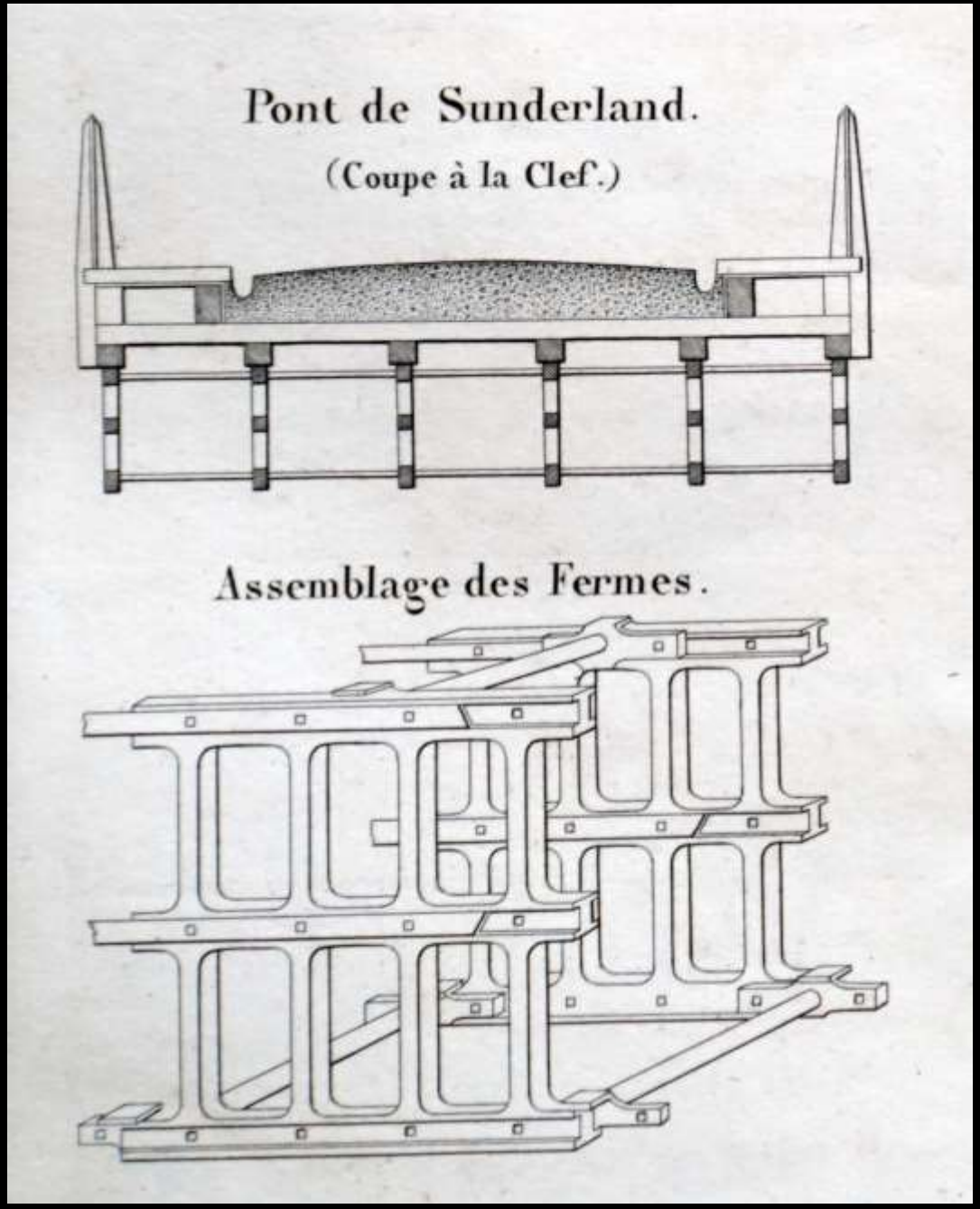
Abraham Darby III, Gusseisen-Brücke über den Severn in Coalbrookdale, 1779
(Lesage 1810)



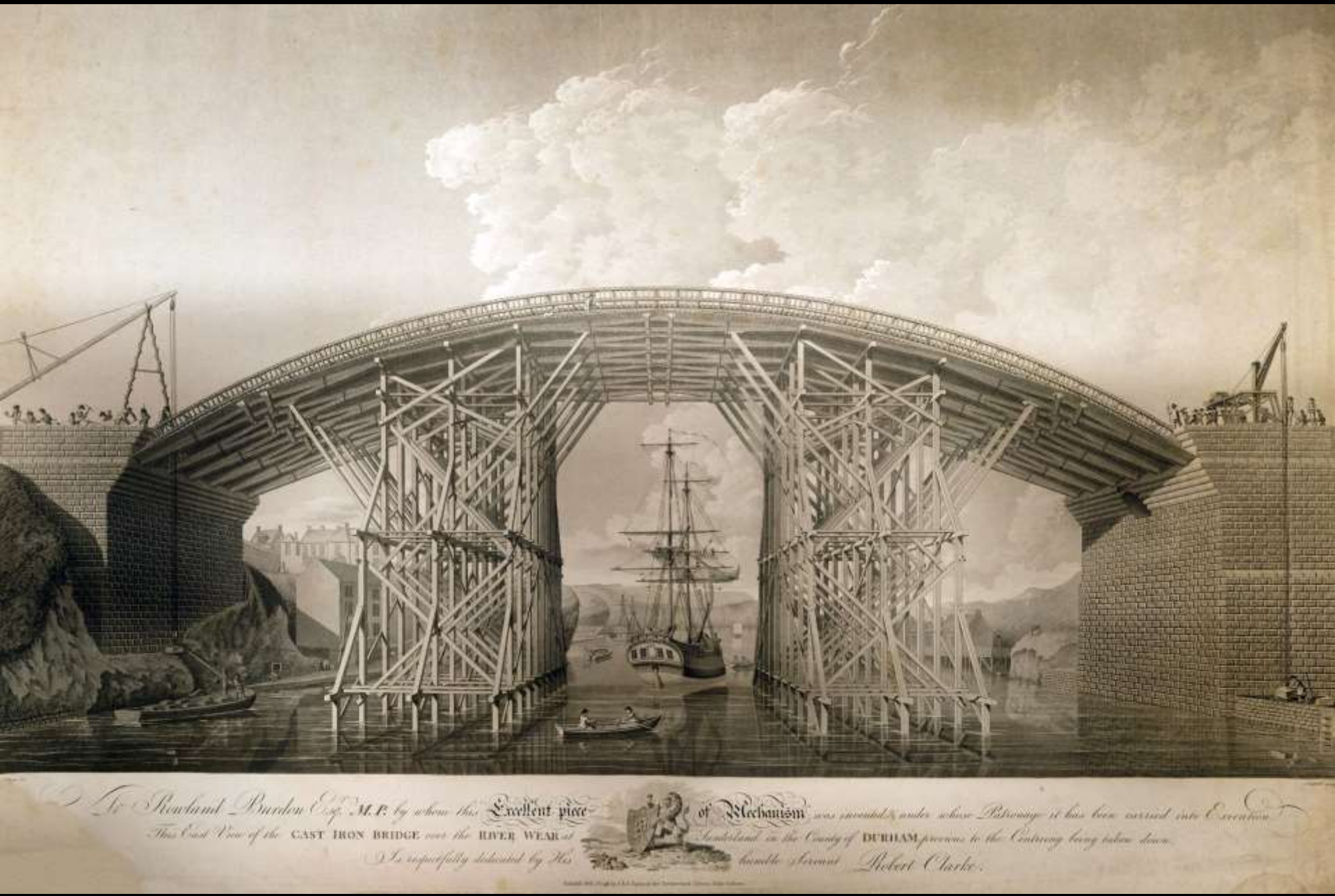
Abraham Darby III, Gusseisen-Brücke über den Severn in Coalbrookdale, 1779
(Telford, Edinburgh Encyclopedia, 1835)



Sunderland, Gusseisen-Brücke über den Wearmouth (Thomas Paine, 1796)
(Dupin 1824)



Sunderland, Brücke über den Wearmouth (1796), Detail der Gusseisen-“Keilsteine“
(Dupin 1824)



Sunderland, Gusseisen-Brücke über den Wearmouth (Thomas Paine, 1796)
Montage der Brücke auf einem Lehrgerüst (Stich von J. Raffield)

Bath, Gusseisen-Brücke in den Sydney House Gardens (1800)

Bath, Gusseisen-Brücke in den Sydney House Gardens (1800)

Bath, Gusseisen-Brücke in den Sydney House Gardens (1800)
Verbindung der Gussteile im Scheitel

Chepstow, Gusseisen-Brücke über den Wye (1816)

Chepstow, Gusseisen-Brücke über den Wye (1816)

Tewkesbury, Mythe Bridge über den Severn (Thomas Telford, 1826)

Tewkesbury, Mythe Bridge über den Severn (Thomas Telford, 1826)

Tewkesbury, Mythe Bridge über den Severn (Thomas Telford, 1826)

Giesshalle der Sayner Hütte bei Koblenz, Deutschland (1826-30)

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Giesshalle der Sayner Hütte bei Koblenz, Deutschland (1826-30)

A

PRACTICAL ESSAY

ON THE

STRENGTH OF CAST IRON,

INTENDED FOR THE ASSISTANCE OF

ENGINEERS, IRON MASTERS, ARCHITECTS, MILLWRIGHTS, FOUNDERS, SMITHS, AND OTHERS ENGAGED IN THE CONSTRUCTIONOF MACHINE S, BUILDINGS, &c.

CONTAINING

PRACTICAL RULES, TABLES, AND EXAMPLES;

ALSO AN ACCOUNT OF SOME

NEW EXPERIMENTS,

With an Extensive Table of the

PROPERTIES OF MATERIALS.

ILLUSTRATED BY FOUR ENGRAVINGS.

BY THOMAS TREDGOLD,

CIVIL ENGINEER;

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS; AUTHOR OF ELEMENTARY PRINCIPLES OF CARPENTRY; THE ARTICLE JOINERY IN THE SUPPLEMENT TO THE ENCYCLOPÆDIA BRITANNICA, &c.

——"The same Truth, which is a Principle in science, becomes a Rule in art." *Playfair.*

London:

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1822.

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1831.

THEORETICAL

AND

EXPERIMENTAL RESEARCHES

TO ASCERTAIN THE

STRENGTH AND BEST FORMS

OF

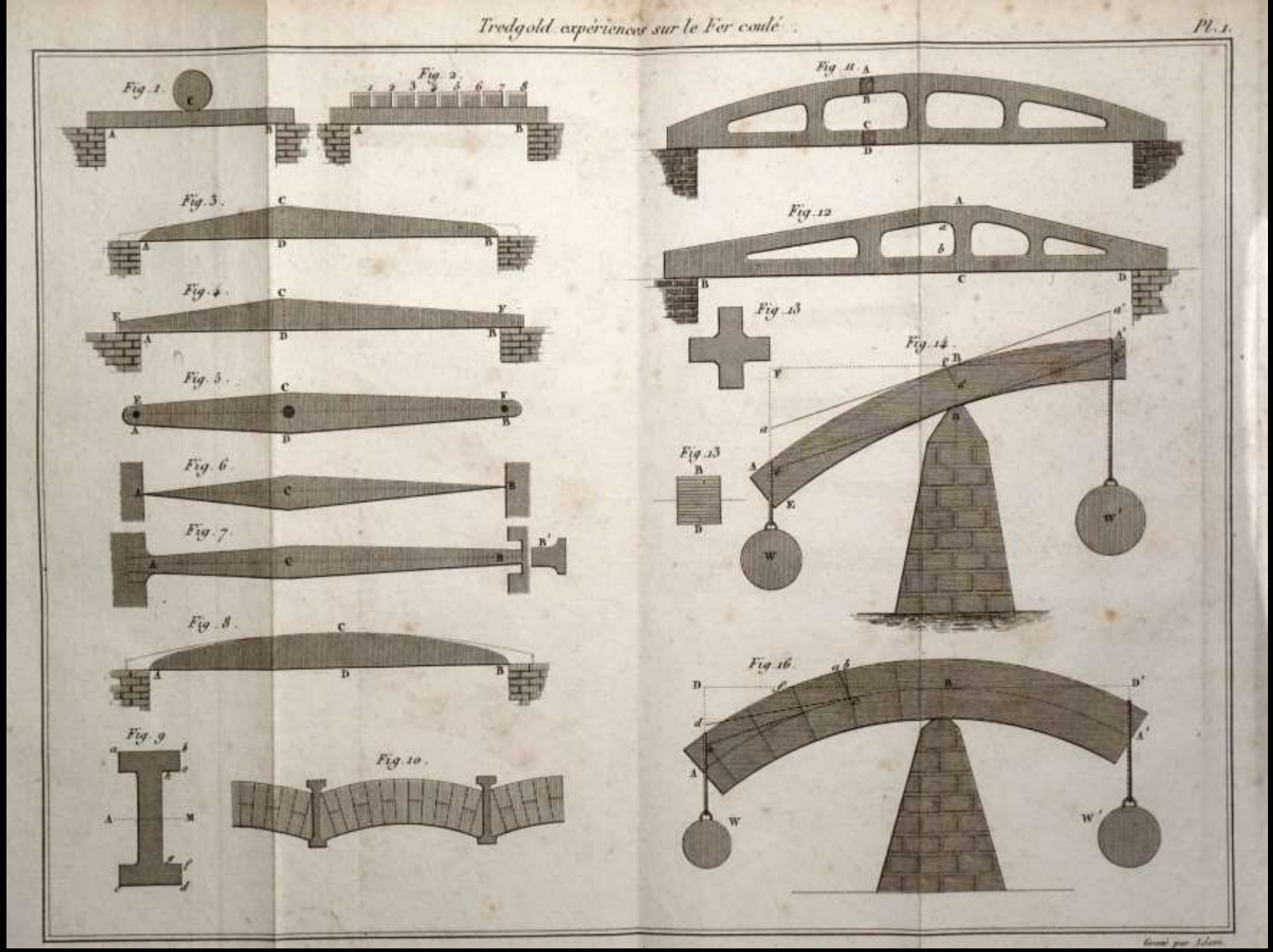
IRON BEAMS.

BY MR. EATON HODGKINSON.

(Read April 2nd, 1828.)

THE very frequent use of iron beams for supporting the floors of factories, and of other places crowded with people, renders it extremely desirable that the best information should be obtained with respect to the strength of this material, in order to insure, without a great superfluity of metal, the requisite stability. In a case so deeply involving the loss of life, and where a failure would be attended with such serious consequences, hardly too much research can be applied. The scientific character of the subject also imparts to it additional

Grenzen des Gusseisens und die Suche nach der besten Form
(Tredgold 1822 und Hodgkinson 1831)



Günstige Formen gusseiserner biegebeanspruchter Träger
(Tredgold 1822/26)

I. EXPERIMENT.

Beam with equal rib at top and bottom.

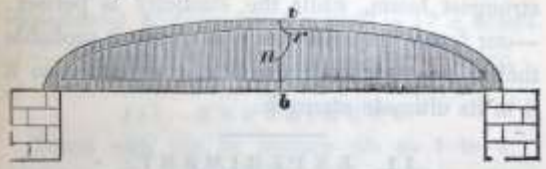
Dist. between supports, 4ft. 6ins. Depth of beam, 5⅛ ins.

Dimensions of cross section, at place of Fracture, in inches and parts.

Area of top rib = 1.75 × .42 = .735
Area of bottom rib = 1.77 × .39 = .690
Thickness of vertical part, between the ribs, = .29.

Area of above section = 2.82 inches.

Weight of Casting = 36¼ lbs.
Breaking weight 6678lbs. = 59 cwt. 70 lbs.



The form of fracture is represented by the line $b\,n\,r$, where $t\,r = .6$, and $b\,n = 2.5$, the figure being a side view of the beam.

To find the strength per inch of cross section, we have, dividing the breaking weight by the area, $\frac{6678}{2.82} = 2368$ lbs. per inch. This quantity in each

* All the sections in these experiments are laid down of ½ their real lineal dimensions in order to afford ocular comparison.

Breaking weight = 7368lbs. = 65 Cwt. 88lbs. It broke obliquely about 4 inches from the middle, the top inclining to it.

The form of fracture at the top of the beam was nearly the same as in Experiment 1; here $t\,r = .55$ inches: see second figure to that experiment.

To find the strength per inch of section, as in the last experiment, we have $\frac{7368}{2.87} = 2567$lbs. per inch.

Comparing this as above with the result of experiment 4, gives 2584 − 2567 = 17 = defect.
∴ Loss in strength = $\frac{17}{2584} = .0066$ or $\frac{1}{152}$.

III. EXPERIMENT.*

Beam with top to bottom rib as 1 to 4.

Dist. between supports, 4ft. 6ins. Depth of beam, 5⅛ ins.

Dimensions of cross section in inches.

Area of top rib = 1.07 × .30 = .32
Area of bottom rib = 2.1 × .57 = 1.2
Thickness of vertical part. = .32.
Area of cross section = 3.02.
Weight of casting = 40 lbs.

* At the preceding experiments and at several of the latter ones, Mr. John Kennedy was present, as well as Mr. Ewart who attended them generally.

The beam twisted a little before breaking: this however was not usually the case in the other beams from the same model.

Form of fracture as in figure, $t\,r = .75$.

Hence strength per inch of section = $\frac{8270}{3.2}$ = 2584lbs.

V. EXPERIMENT.

This casting had its top rib a parabolic arch and the top and bottom ribs nearly equal in section, with equidistant ordinates only between them.

Dist. between supports and depth of beam as before.

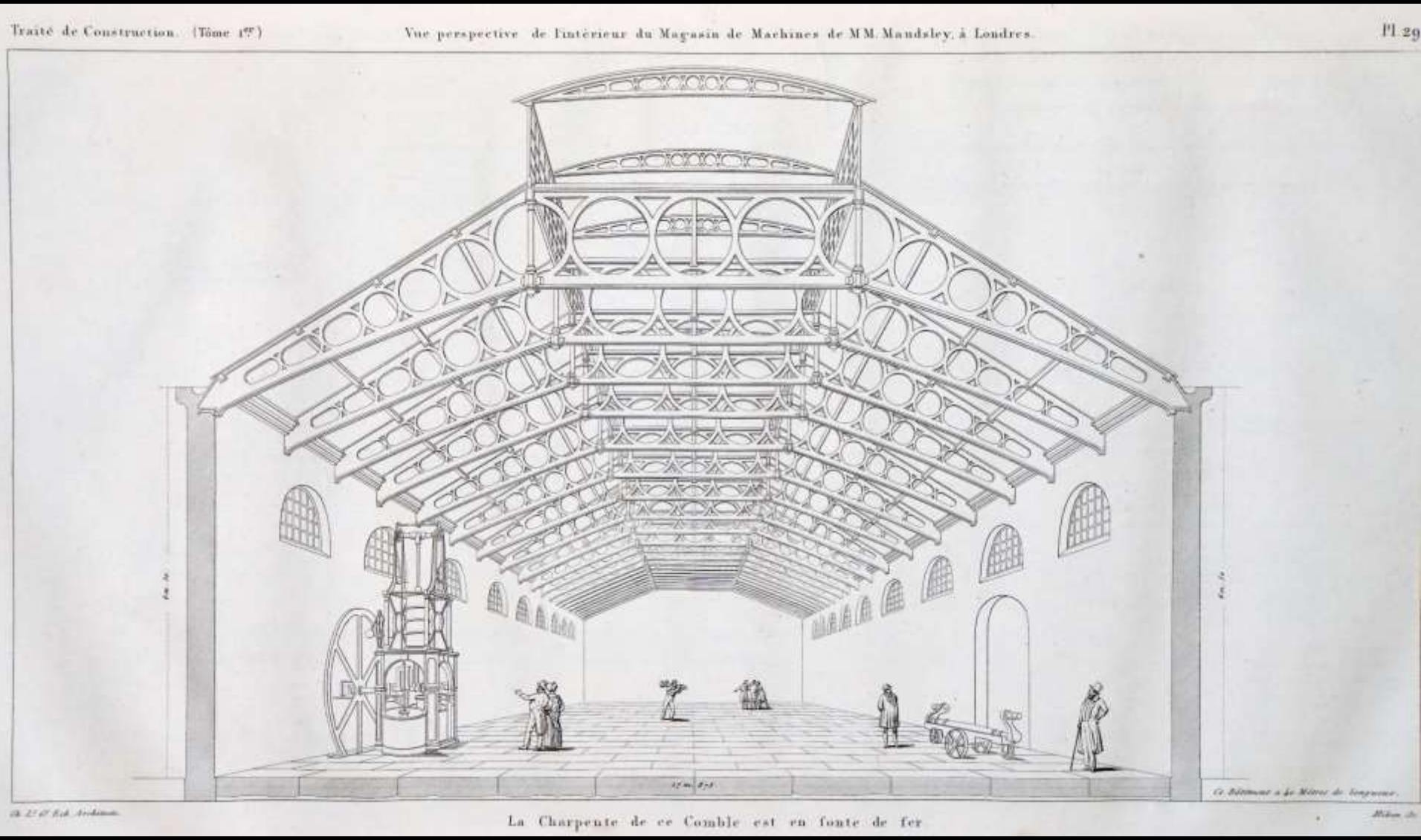
Dimensions of ribs in inches.

Area of top rib = 2.2 × .56 = 1.23.
Area of bottom rib = 2.2 × .53 = 1.17.

Weight of casting = 41¼ lbs.
Breaking weight = 5528lbs. or less: see next expt.
This weight however is but ⅔ of what was borne by the common beam in the last experiment.

It broke by separating, near the first ordinate,

Günstige Formen gusseiserner biegebeanspruchter Träger
(Hodgkinson 1831)



Fabrikhalle von Henry Maudsley mit Gusseisendach, um 1825
(Eck 1836)

Fazit Gusseisen

- Wegen der Materialeigenschaften Anlehnung an Steinkonstruktion (Bogentragwerke)
- Keine echte Revolution des Bauwesens

Kontinent

Bauen mit Schmiedeeisen hinter klassizistischer Fassade

Feuersicheres Bauen in Paris – Eisengerippe und Tontöpfe
1784–1827

Vielleicht der erste Versuchsbau der feuersicheren Bauweise mit Eisenskelett und Tontöpfen:
Paris, Théâtre du Palais Royal, um 1784

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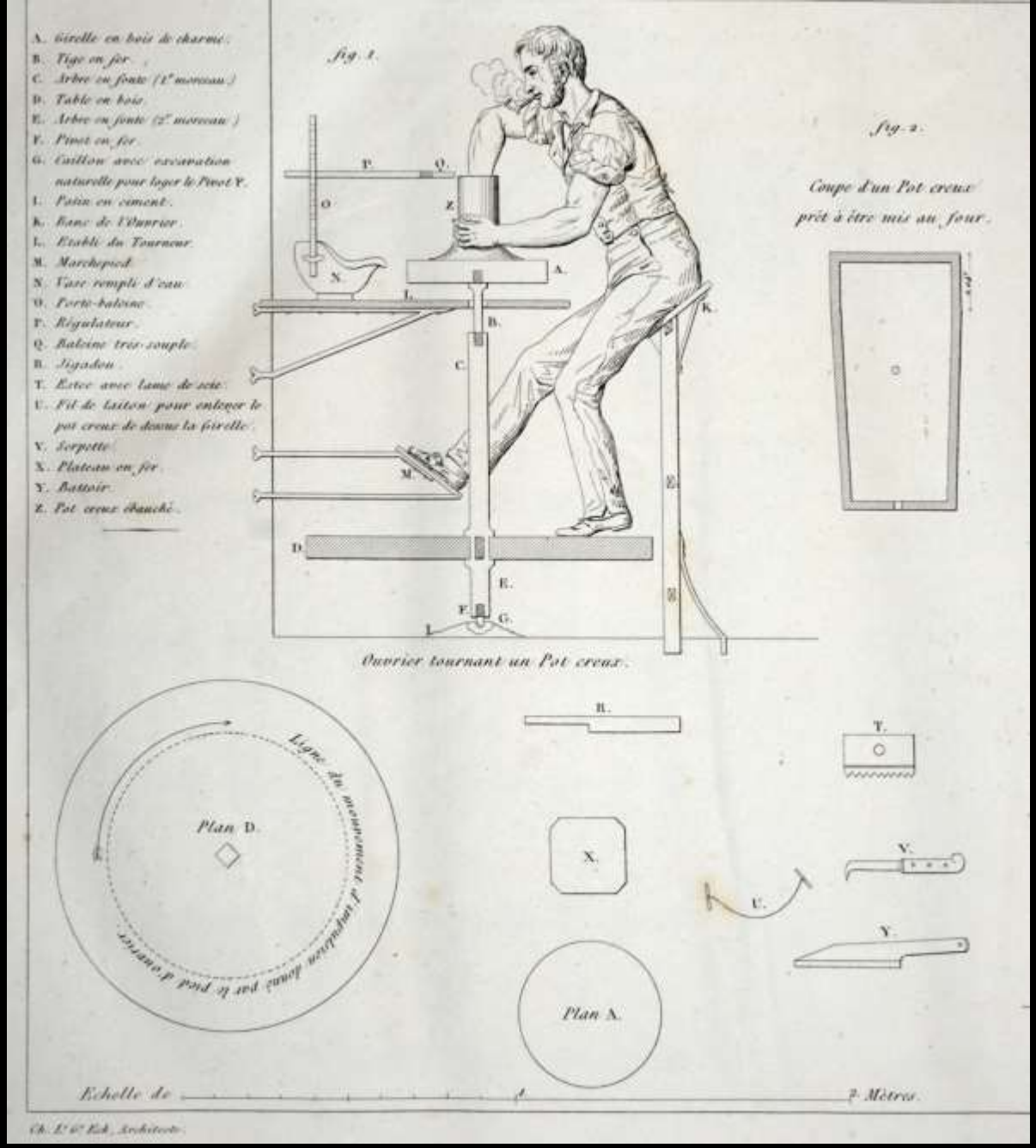
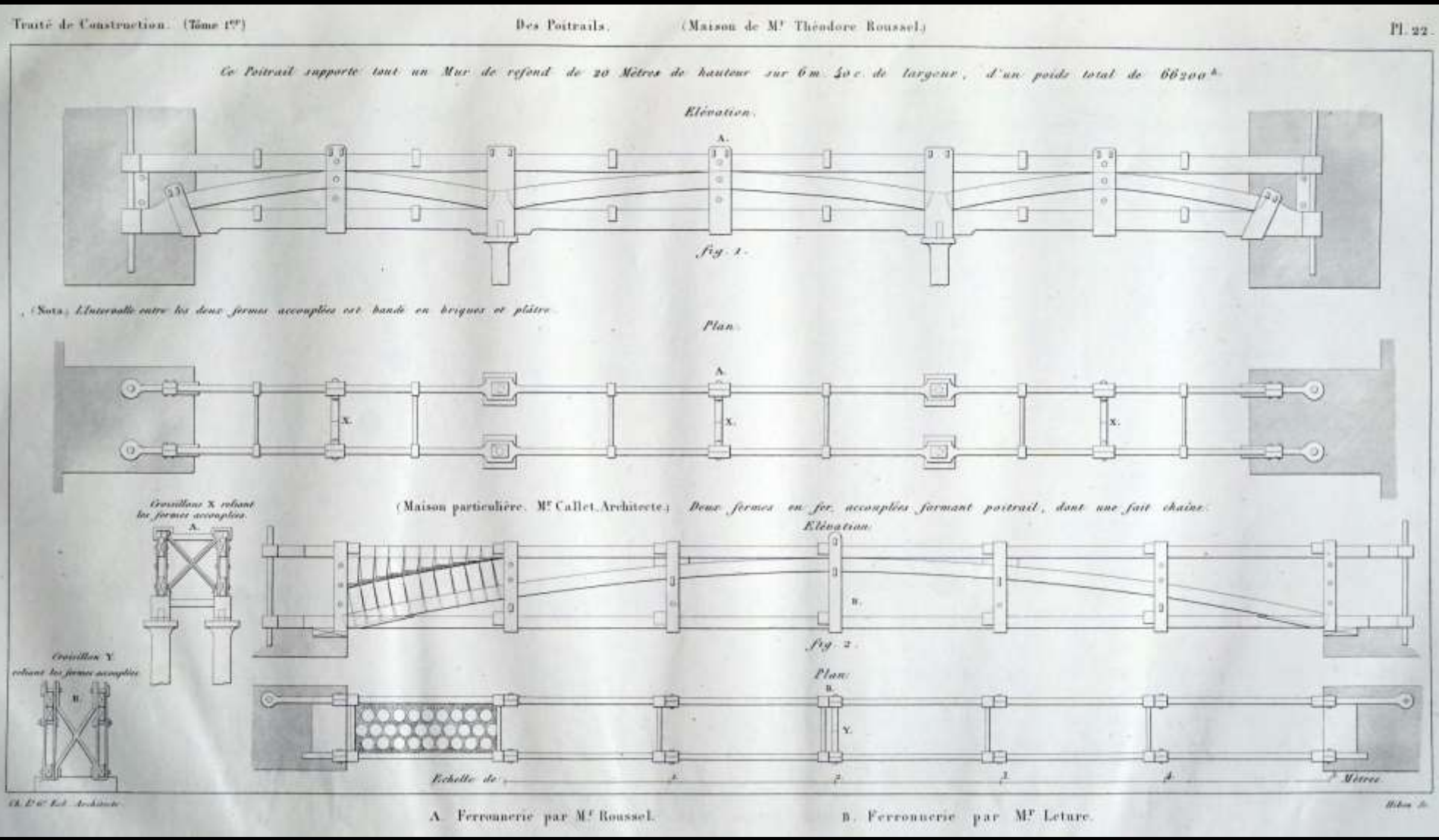
Paris, Théâtre du Palais Royal, um 1784

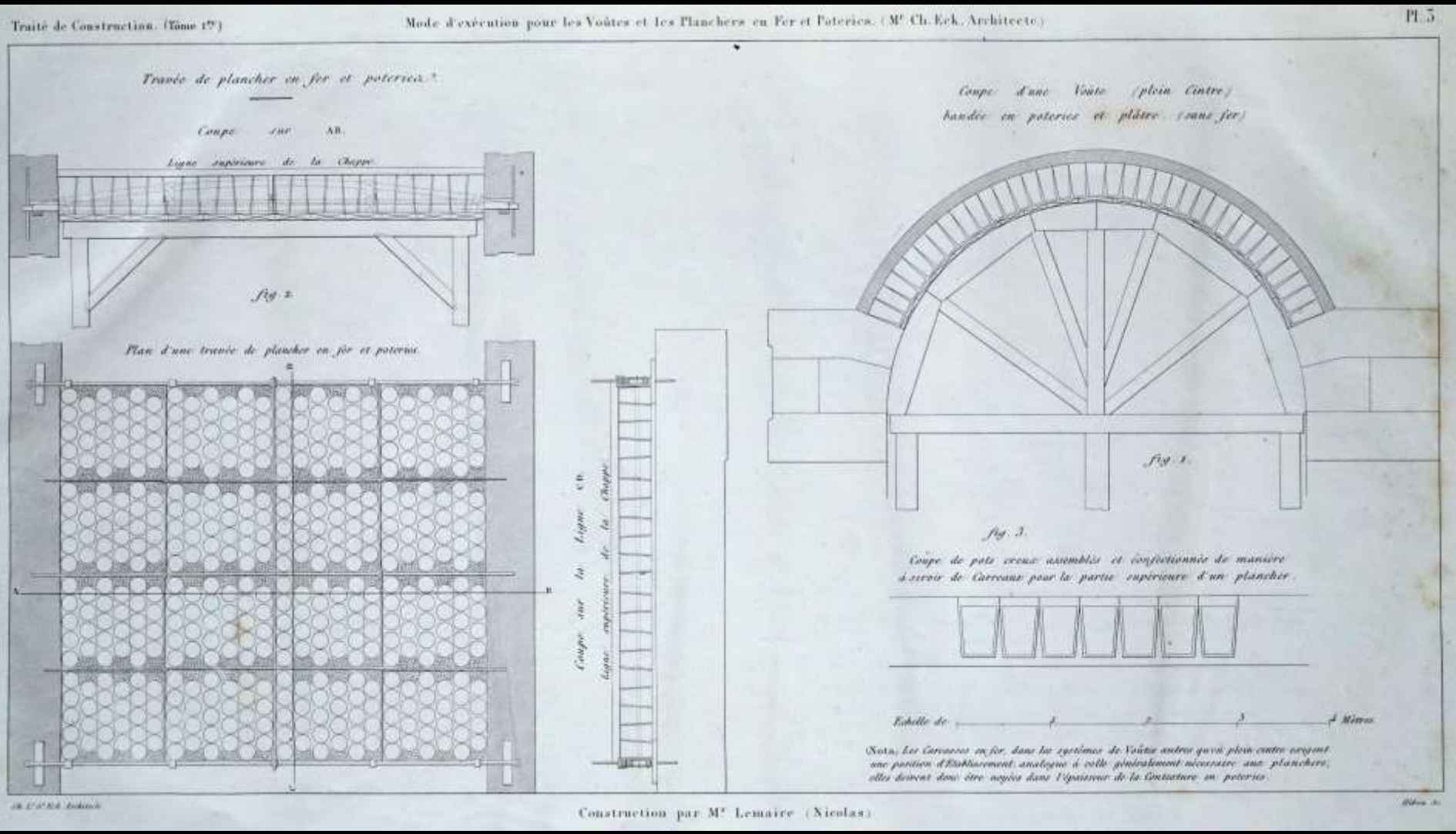
Vielleicht der erste Versuchsbau der feuersicheren Bauweise mit Eisenskelett und Tontöpfen:
Théâtre du Palais Royal, um 1784



Herstellung der Hohlkörper
(Eck 1836)

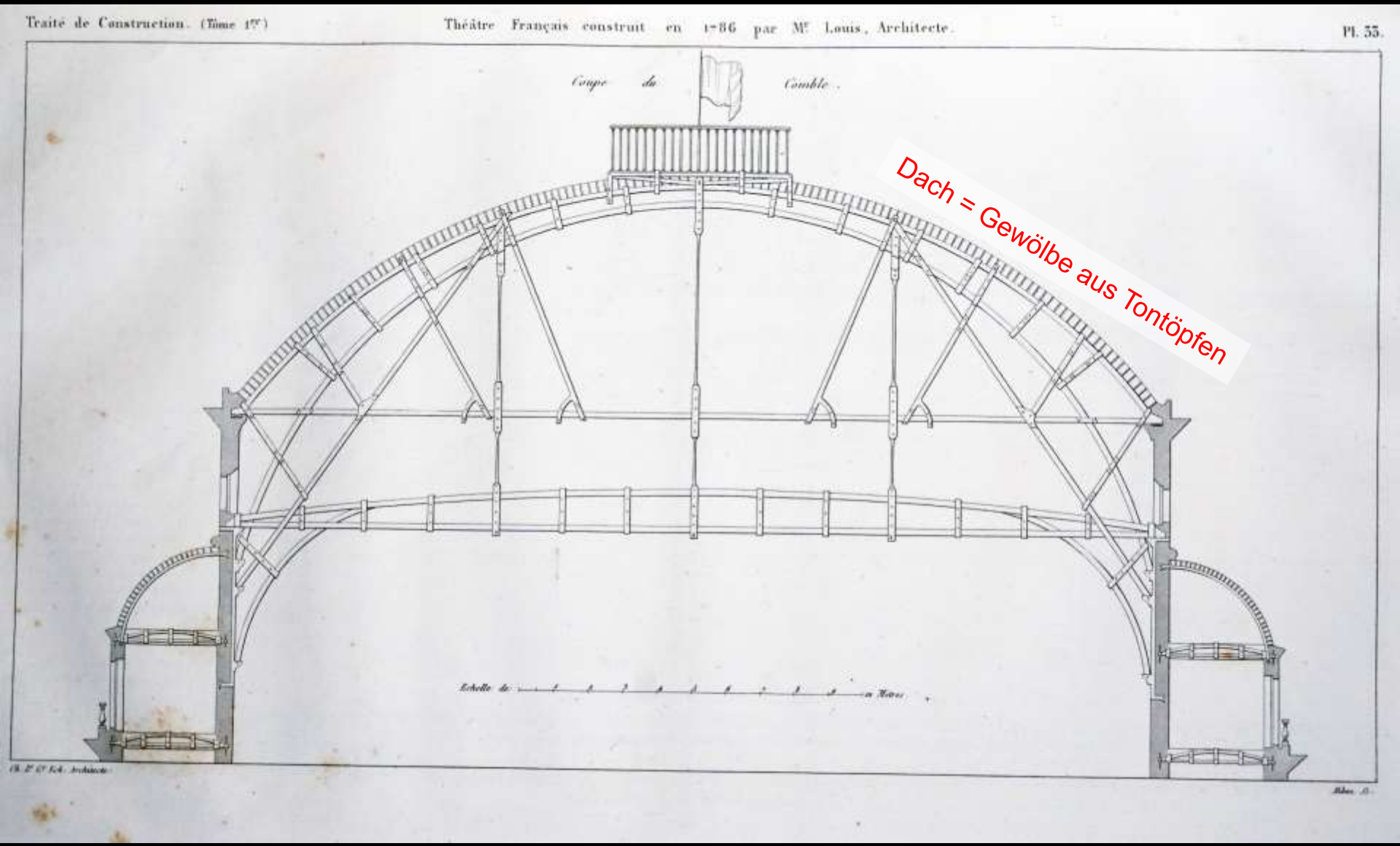


Feuersicheres Bauen mit Bandeisen und Eisenstäben
Das Kombinationssystem „Hohlkörper“ + “Eisengerippe“ = sogenannter „Pariser Rost“ nach Angot 1782 (Eck 1839)

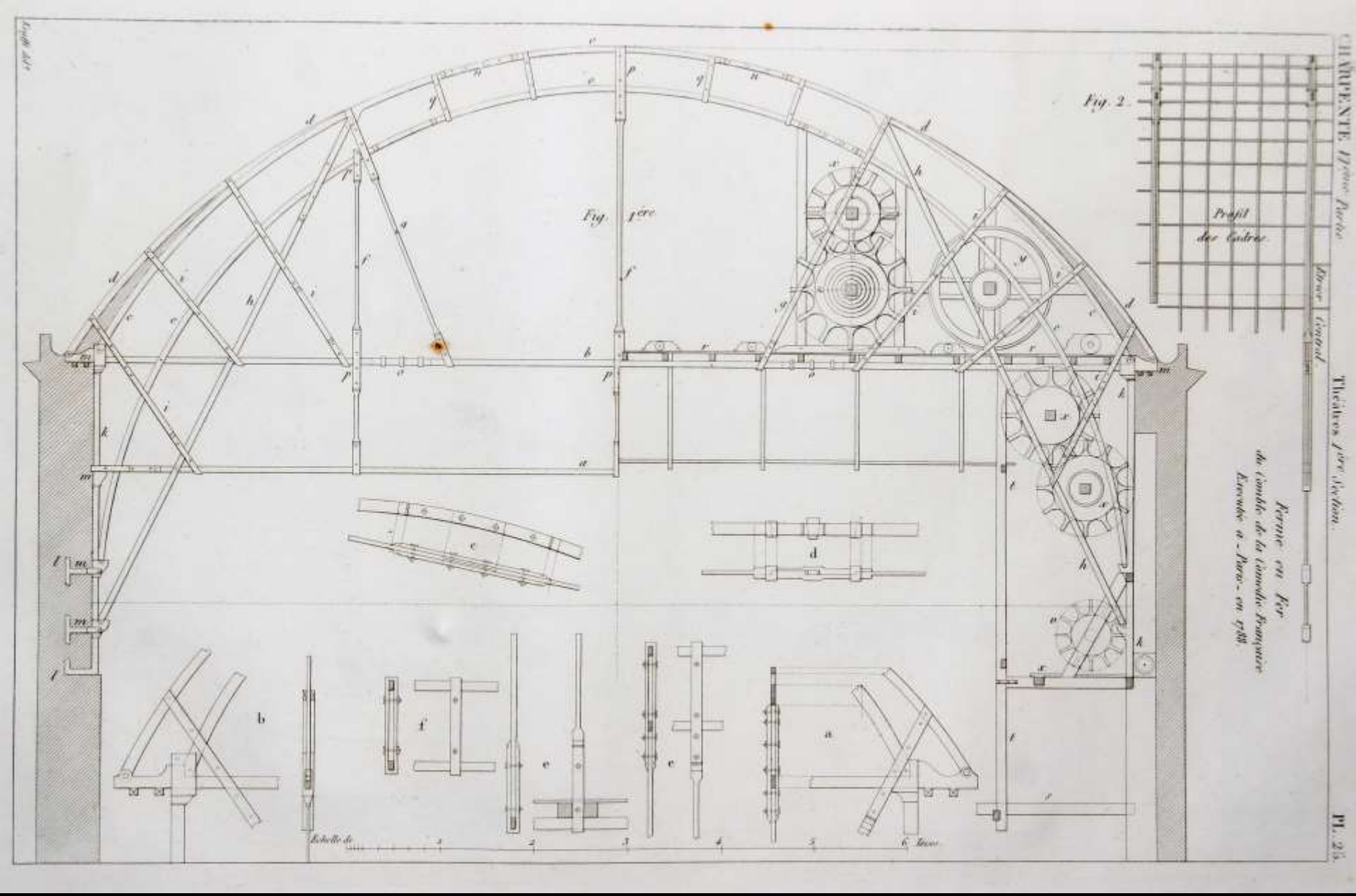


Feuersicheres Bauen mit Bandeisen und Eisenstäben
Das Kombinationssystem „Hohlkörper“ + “Eisengerippe“ = sogenannter „Pariser Rost“ nach Angot 1782 (Eck 1839)

Hubert Robert, Brand des Opernhauses im Palais Royal, 1781 (Paris, Musée Carnavalet)

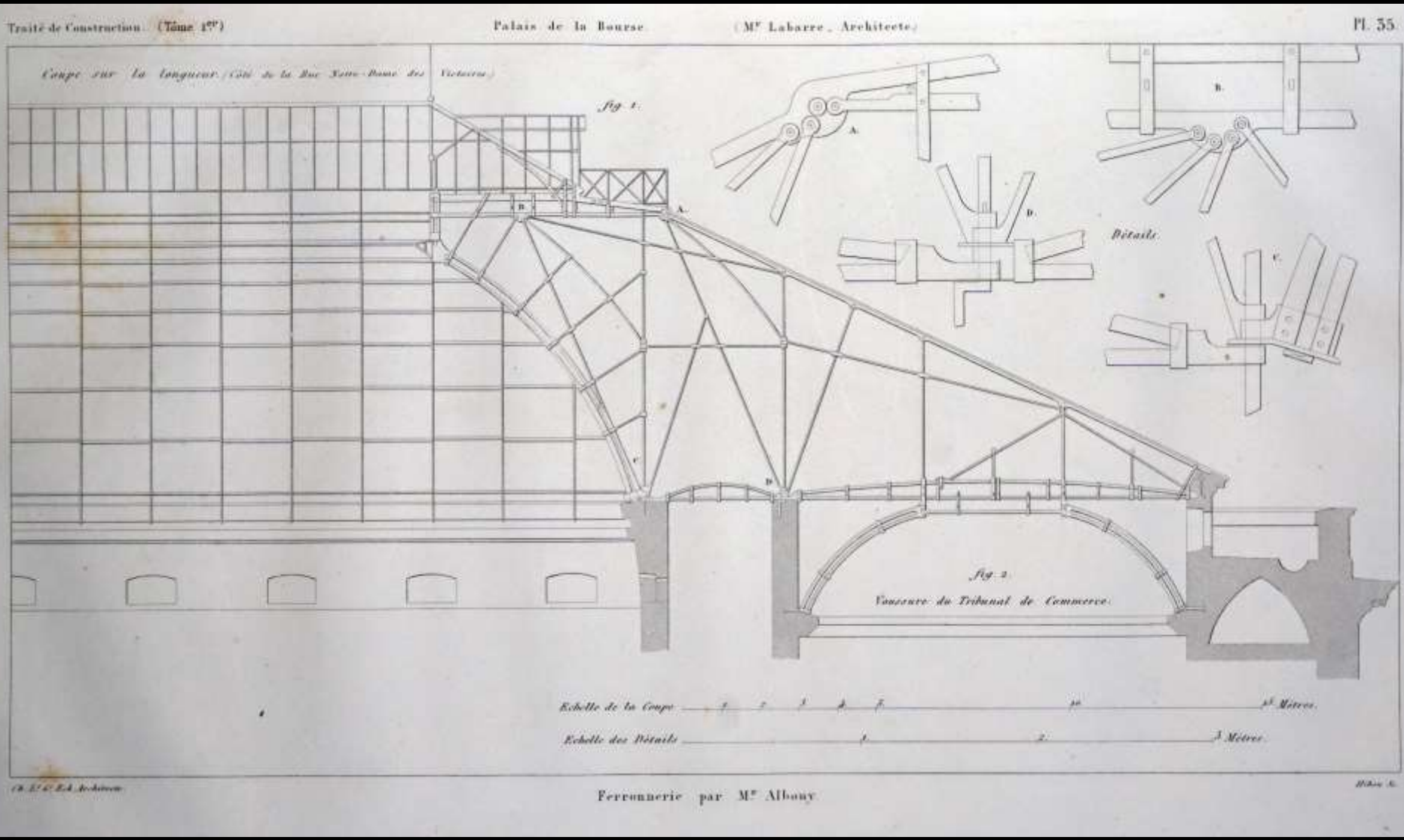


Paris, Wiederaufbau des Théâtre Français im Palais Royal (Victor Louis, 1786)
(Eck 1836)

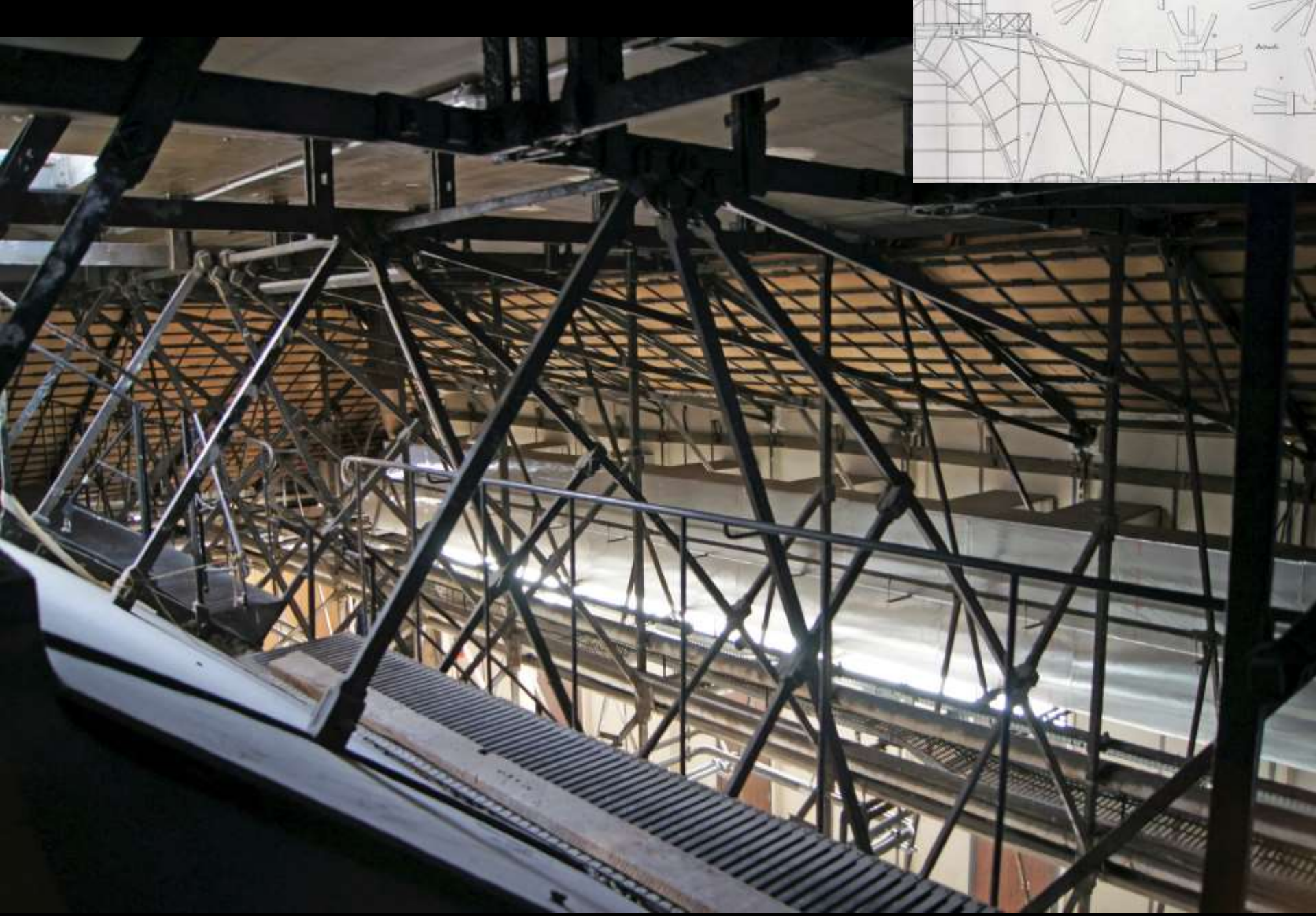


Wiederaufbau des Théâtre Français im Palais Royal durch Victor Louis 1786-90
Details der Eisenkonstruktion
(Krafft 1819-22)

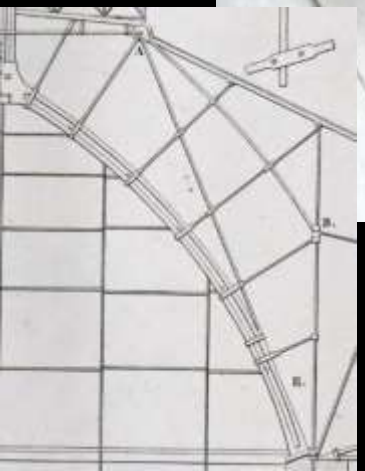
Paris, Börse (Brongniart und Labarre, 1821-27)



Paris, Dachkonstruktion der Börse (1821-27)
(Eck 1836)



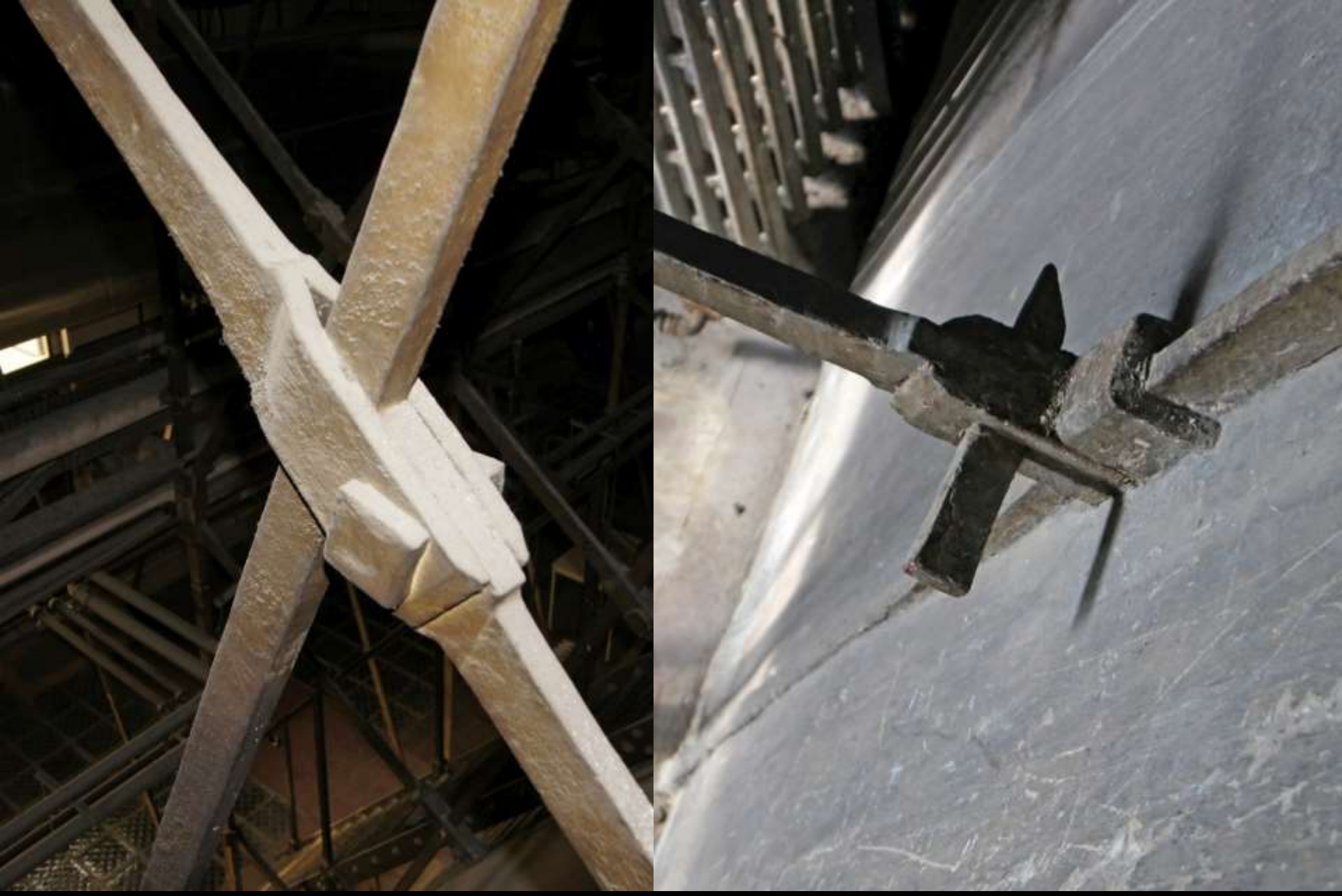
Paris, Dachkonstruktion der Börse (1821-27)
Dachkonstruktion



Paris, Dachkonstruktion der Börse (1821-27)
Detail der radialen Streben

Paris, Dachkonstruktion der Börse (1821-27)
Anschlussdetail mit Quadratmuttern und Montagemarkierungen

Paris, Dachkonstruktion der Börse (1821-27)
Anschlussdetail mit Quadratmuttern und Montagemarkierungen



Paris, Dachkonstruktion der Börse (1821-27)
Anschlussdetails der „Speichen“

Paris, Dachkonstruktion der Börse (1821-27)
Kuppelschale aus Tonhohlkörpern

Walhalla bei Regensburg
(Leo v. Klenze 1836-40)

Walhalla bei Regensburg: Innenraum der Cella
(Leo v. Klenze 1836-40)

Walhalla bei Regensburg: Dachwerk über dem „Adyton“: eisernes „Bogenhängewerk“
(Leo v. Klenze und „Mechanicus Manhard“ 1836-40)

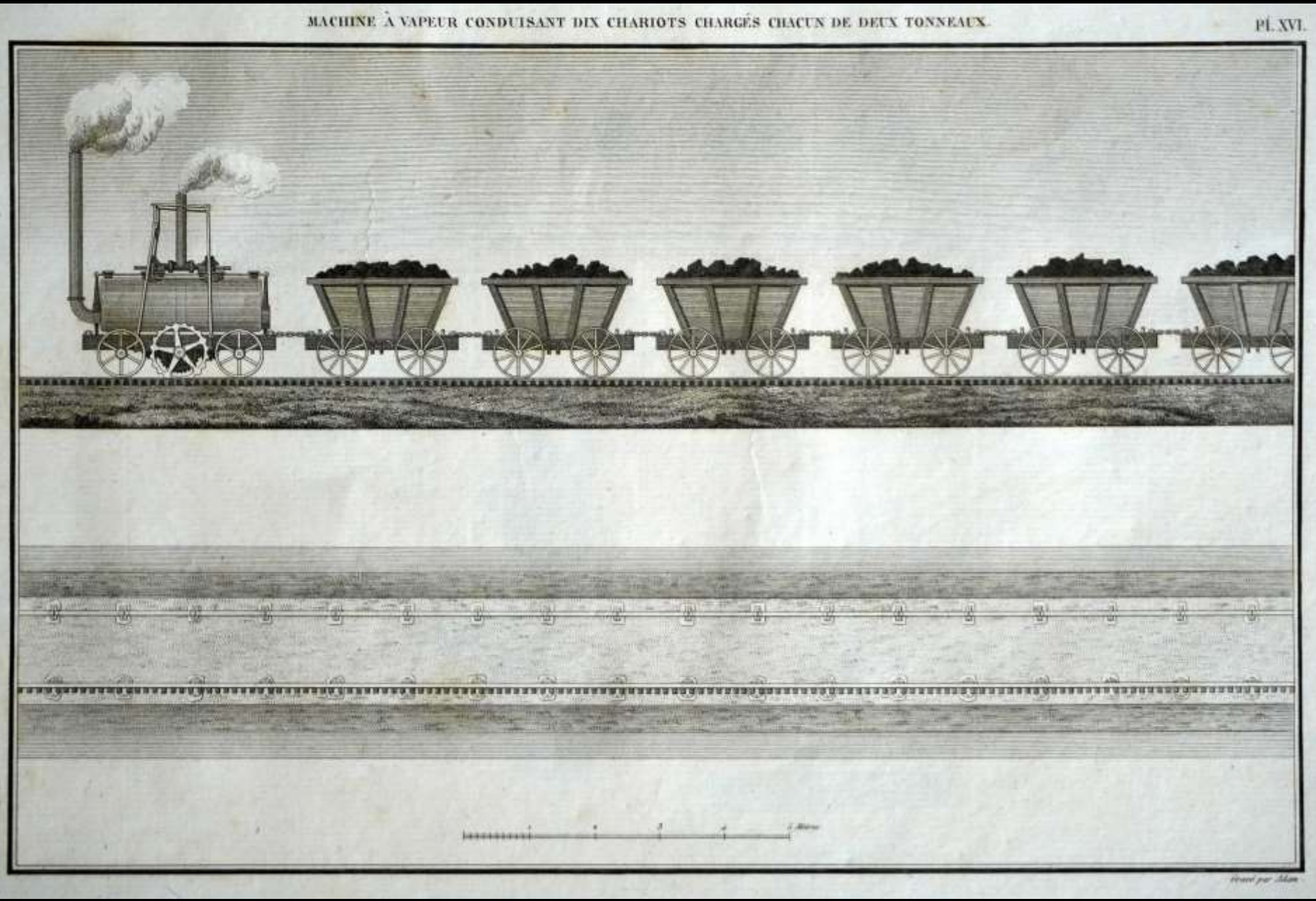
Walhalla bei Regensburg: Dachwerk über dem „Adyton“
(Leo v. Klenze und „Mechanicus Manhard“ 1836-40)

Walhalla bei Regensburg: Dachwerk über dem „Adyton“: Auflager des Bogentragwerks
(Leo v. Klenze und „Mechanicus Manhard“ 1836-40)

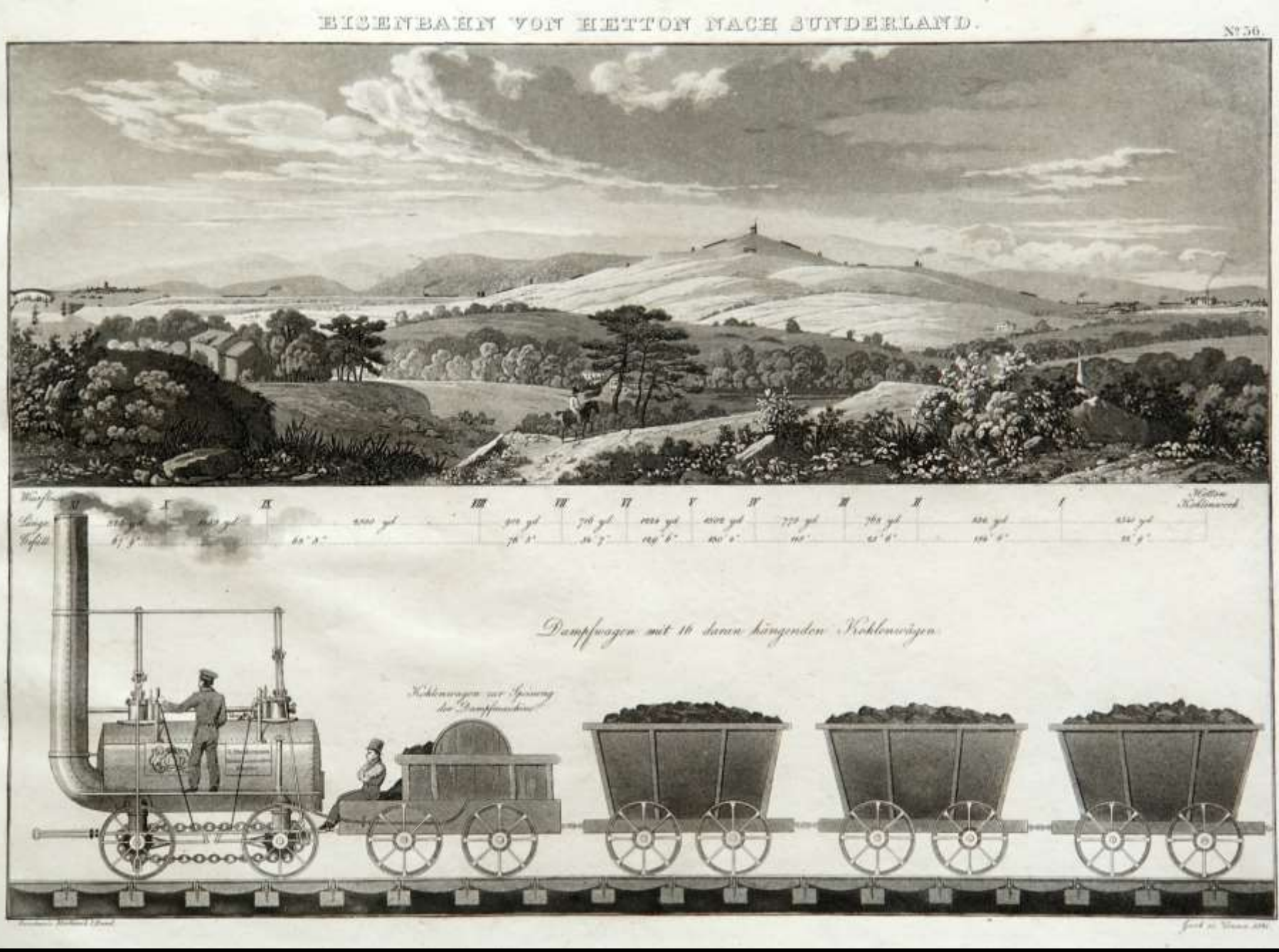
Walhalla bei Regensburg, „Adyton“: Anschlussdetail mit Keil und Gegenkeil, „Abbundmarken“
(Leo v. Klenze und „Mechanicus Manhard“ 1836-40)

Walhalla bei Regensburg, Dachwerk über dem „Adyton“: abgehängte Eisen-Draht-Putz-Decke
(Leo v. Klenze und „Mechanicus Manhard“ 1836-40)

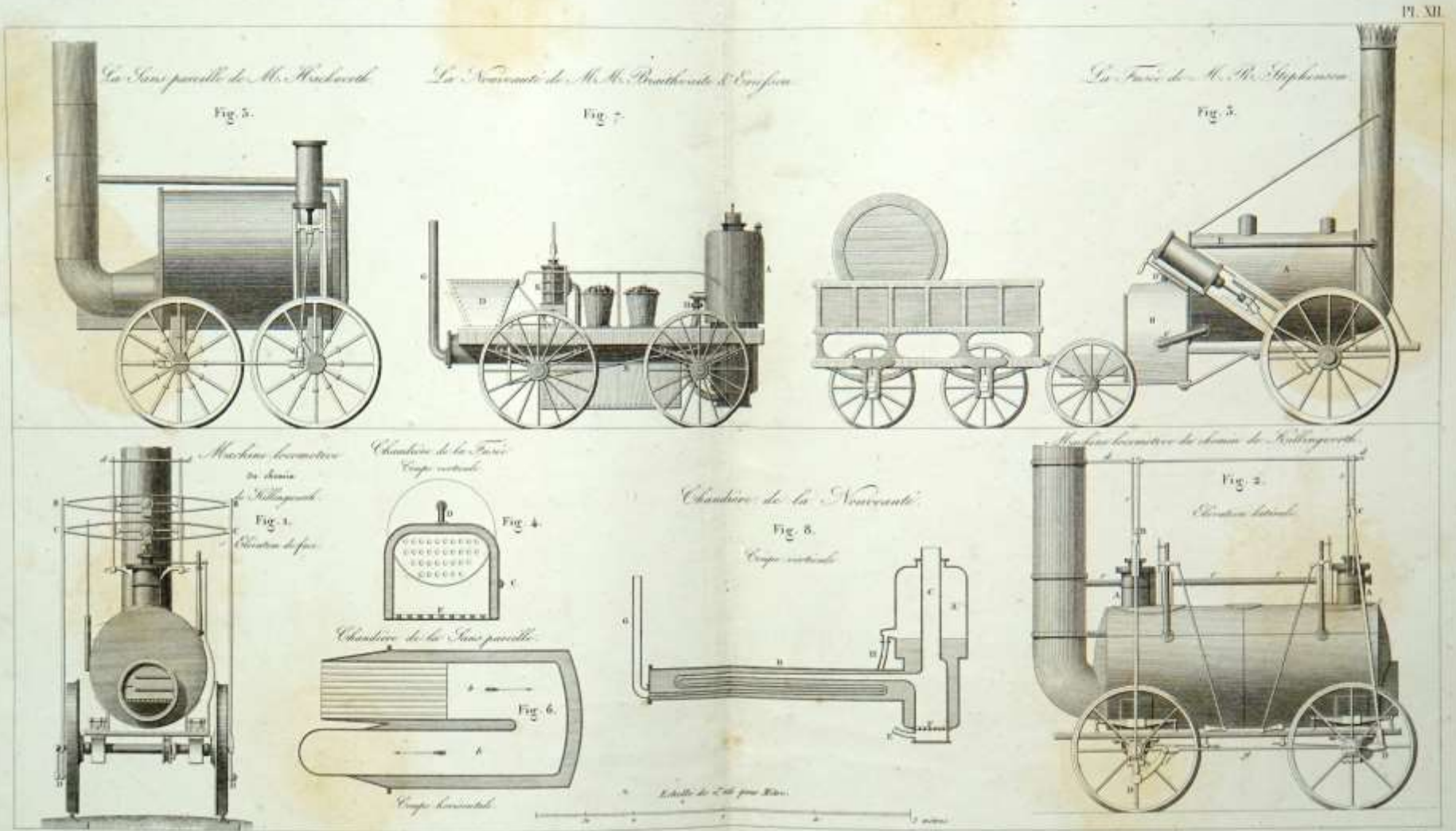
Die Eisenbahn und die Folgen



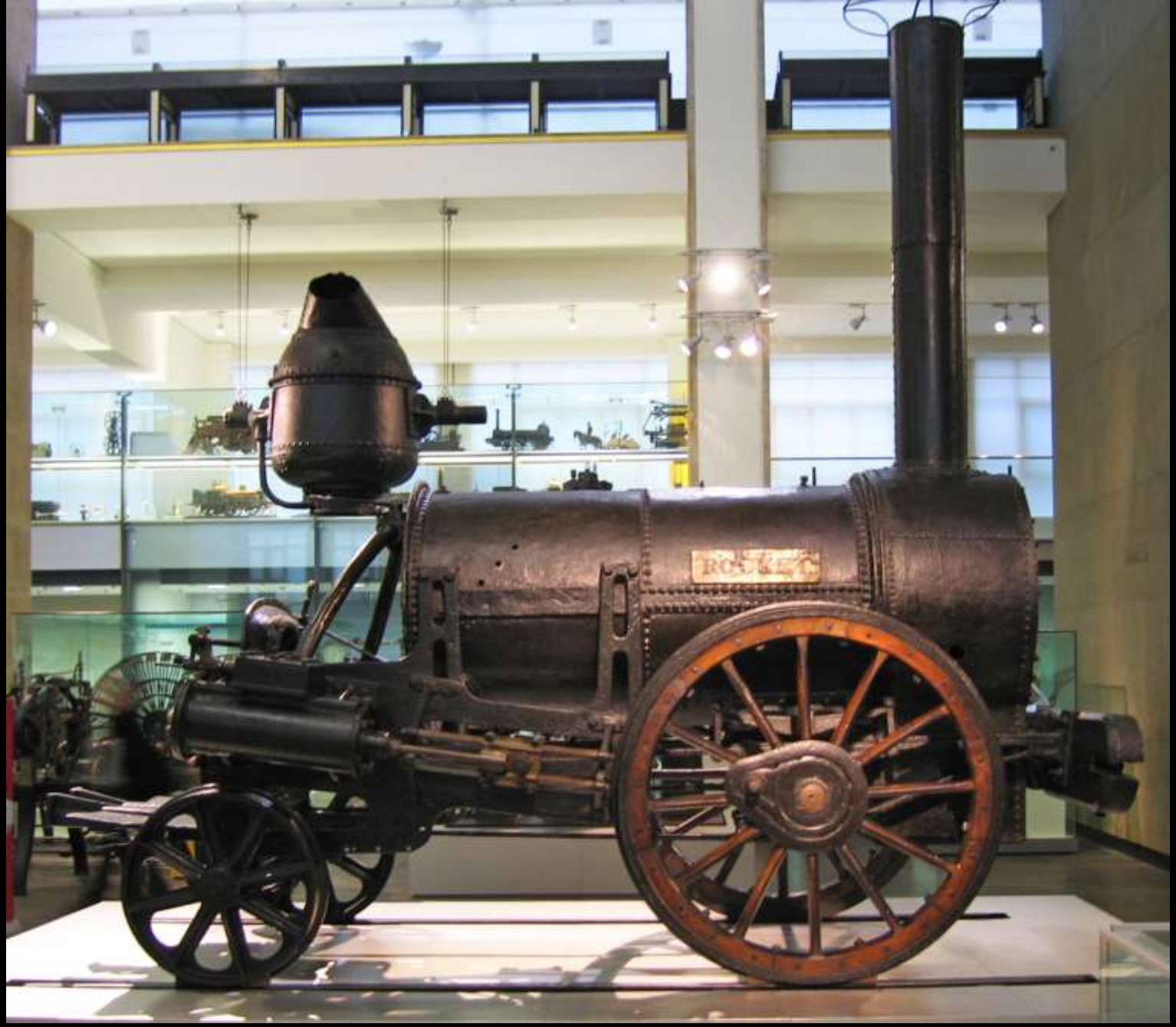
Die ersten Eisenbahnen mit Lokomotivbetrieb: Leeds, Middleton Railway, 1812: Lokomotive „Salamanca“
(John Blenkinsop und Matthew Murray; Abb.: J. Cordier 1823; man beachte den Zahnradantrieb!)



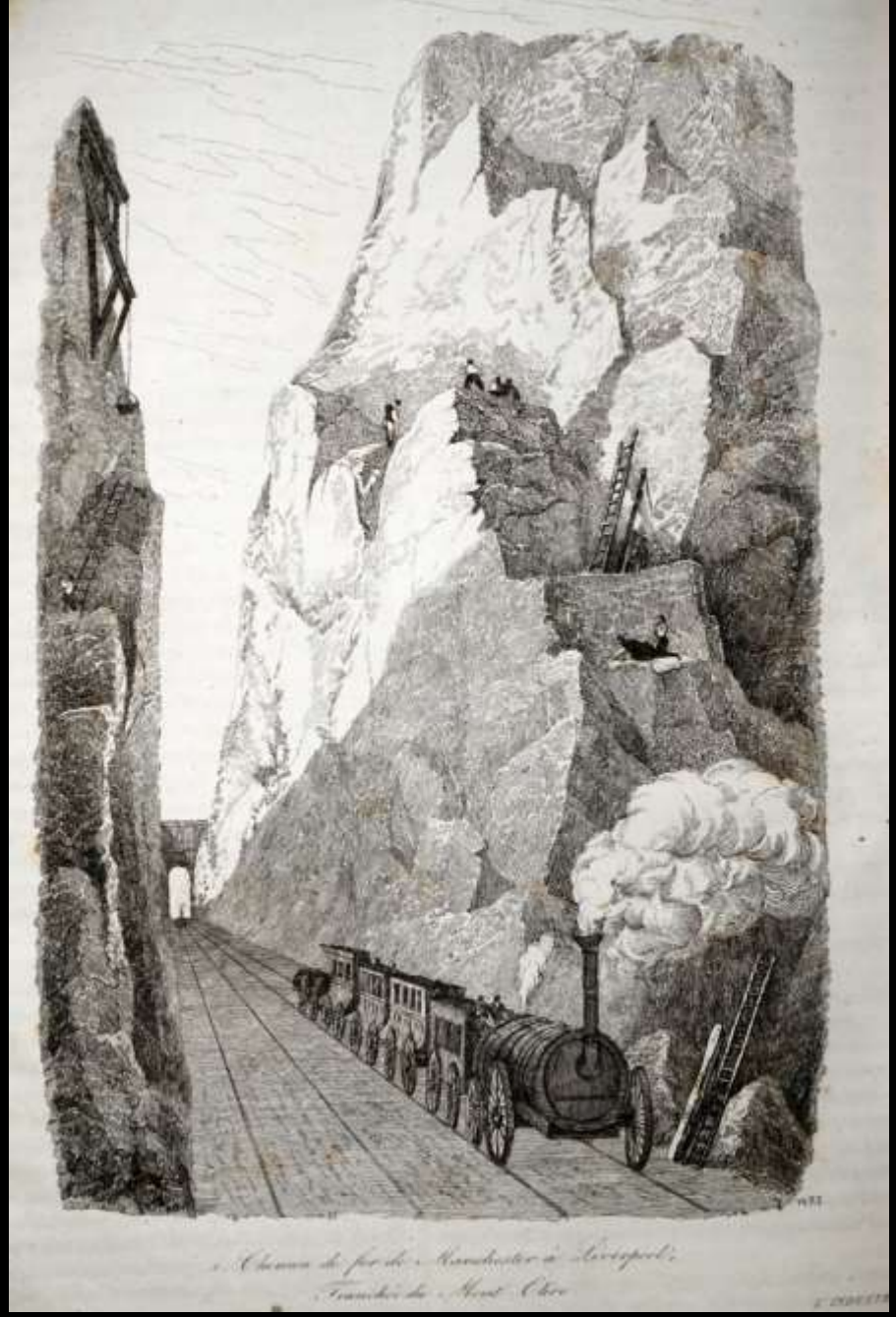
Die ersten Eisenbahnen mit Lokomotivbetrieb: George Stephenson‘s Hetton Colliery Railway, 1825
(Gerstner 1831; reine Reibungstraktion)



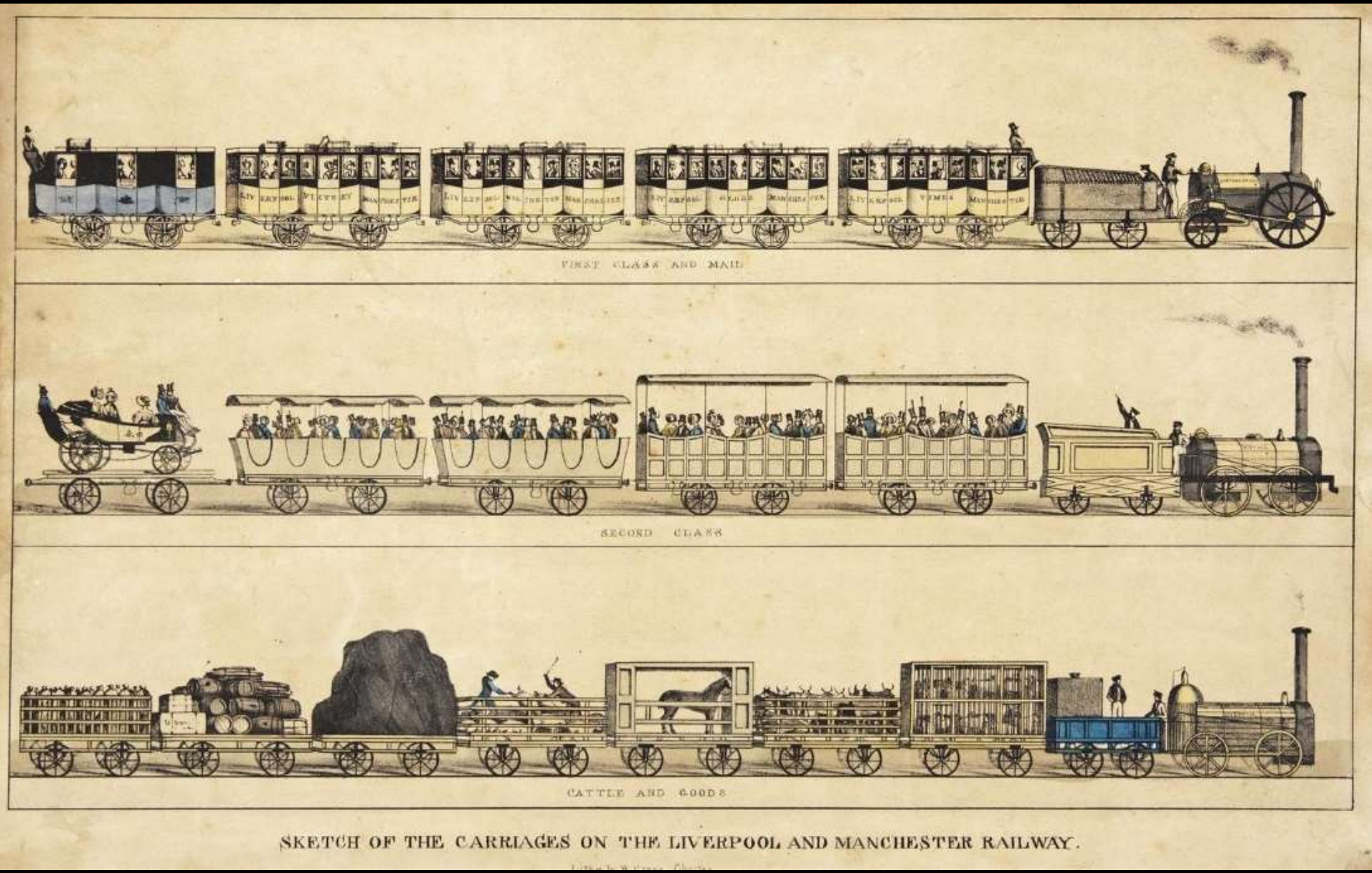
Dampflokomotiven der ersten Generationen. Rechts oben Stephenson‘s „Rocket“
(Wood 1831/1834)



George & Robert Stephenson‘s „Rocket“ (1829), Siegerin der Rain Hill Competition
(London, Science Museum)

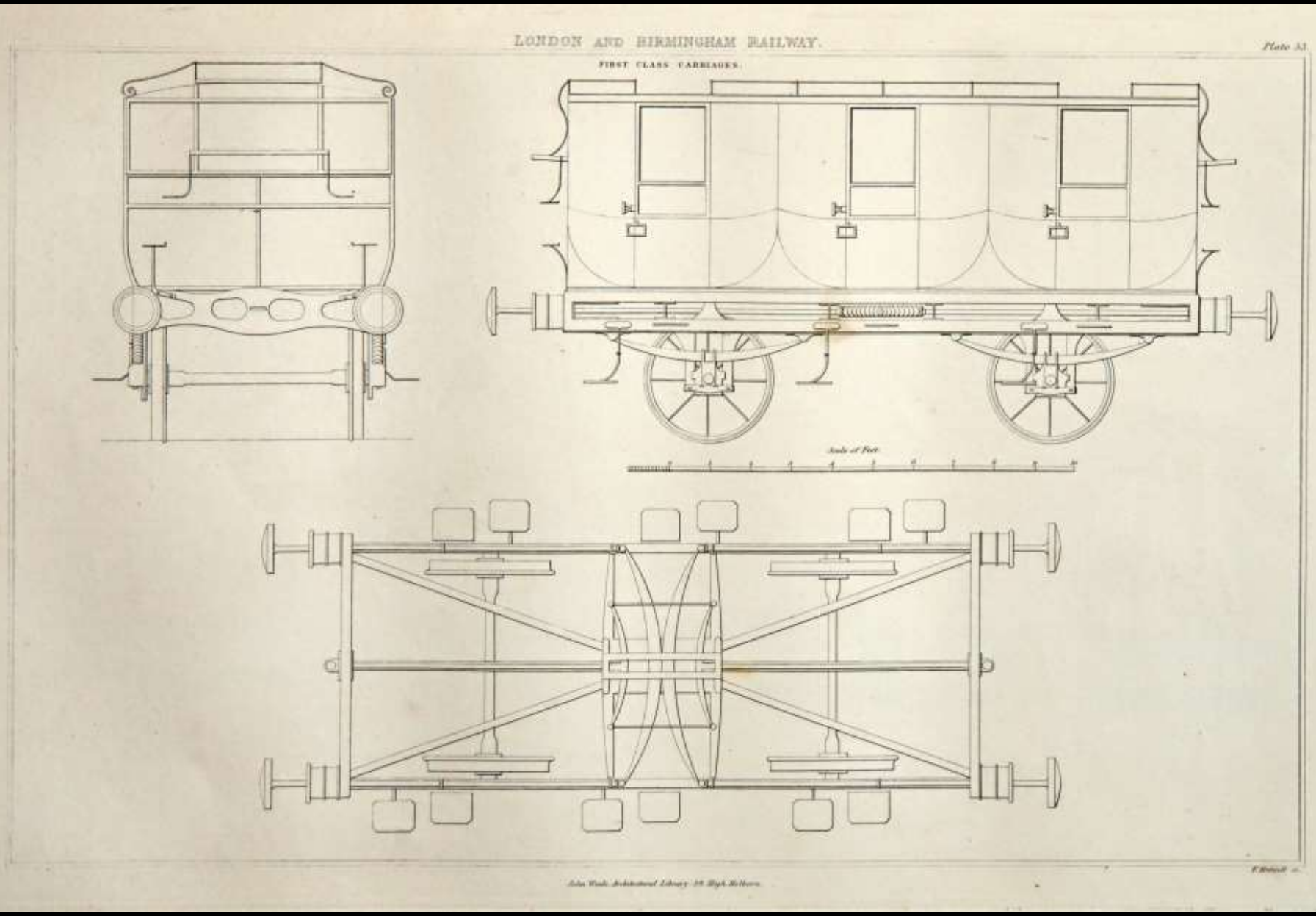


Die Eisenbahn Liverpool-Manchester (1830), erste grosse Personen- und Frachteisenbahn
(Mount Olive Cutting, S. Flachat 1835)



SKETCH OF THE CARRIAGES ON THE LIVERPOOL AND MANCHESTER RAILWAY.

Die Liverpool-Manchester-Eisenbahn (1830)
(Stich von W. Crane, Chester, um 1830; Scan: Science Museum London, CC-BY-NC-SA 4.0)



Die Personenwägen der Eisenbahn London-Birmingham (Gesamtstrecke eröffnet 1838)
(Simms 1838)

Eisenbahnen in England um 1855 (Perdonnet 1855)

Eisenbahnen in Frankreich um 1855 (Perdonnet 1855)

Eisenbahnen im deutschsprachigen Raum um 1855 (Perdonnet 1855)

Zweckbau – von der Markthalle zur Eisenbahnhalle
Die „eigentliche“ Architektur des 19. Jh.?

(1815–1846)

Bourg-sur-Gironde, Waschhaus (1828)

Bourg-sur-Gironde, Waschhaus (1828) mit Pfettendachbinder

Paris, Marché Saint-Germain (1817; heute Rekonstruktion)

Projets de Marchés.

Louis Bruyère, Projekte für Markthallen (1823)

Augsburg, ehem. Bahnhofshalle (1840)

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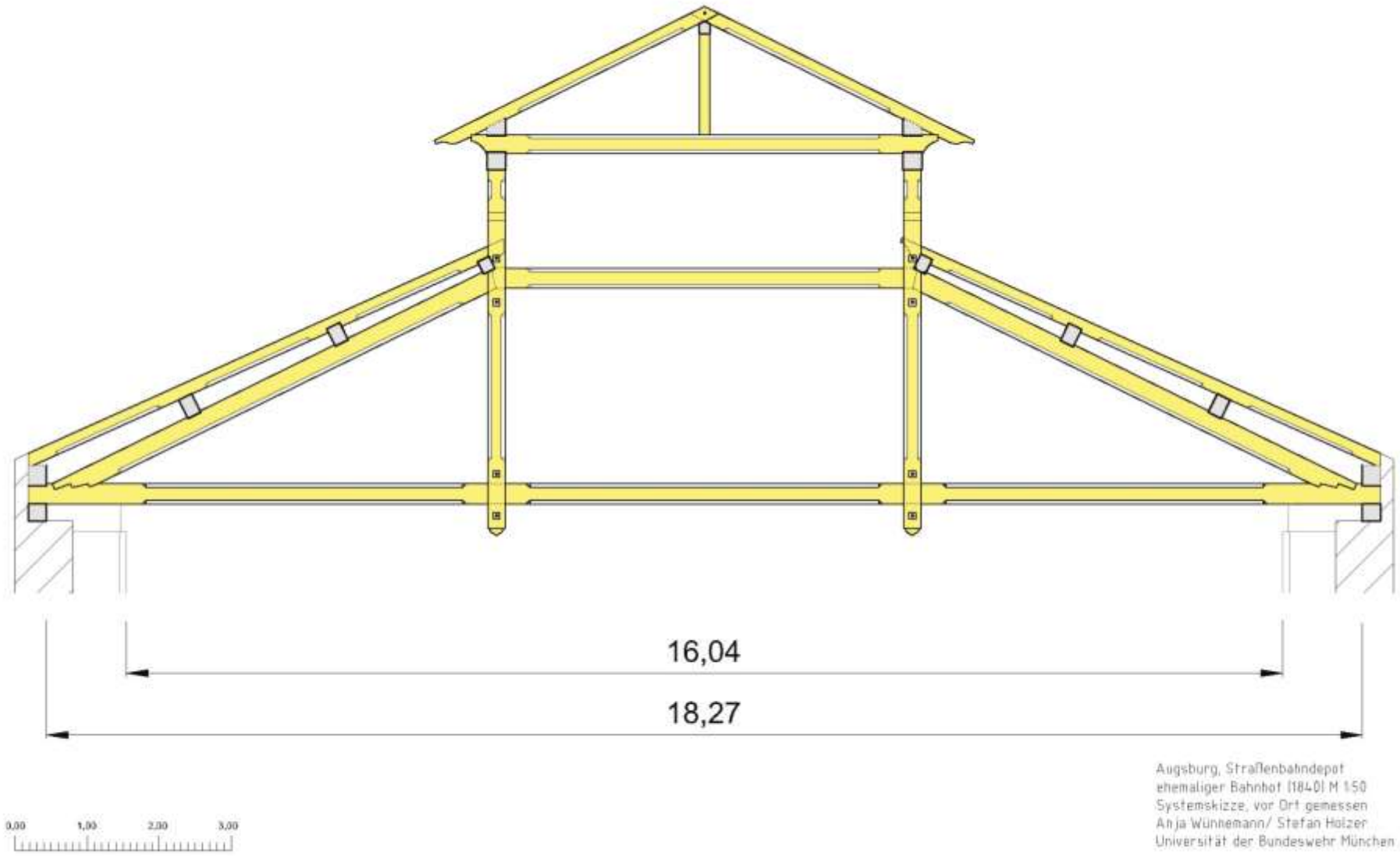
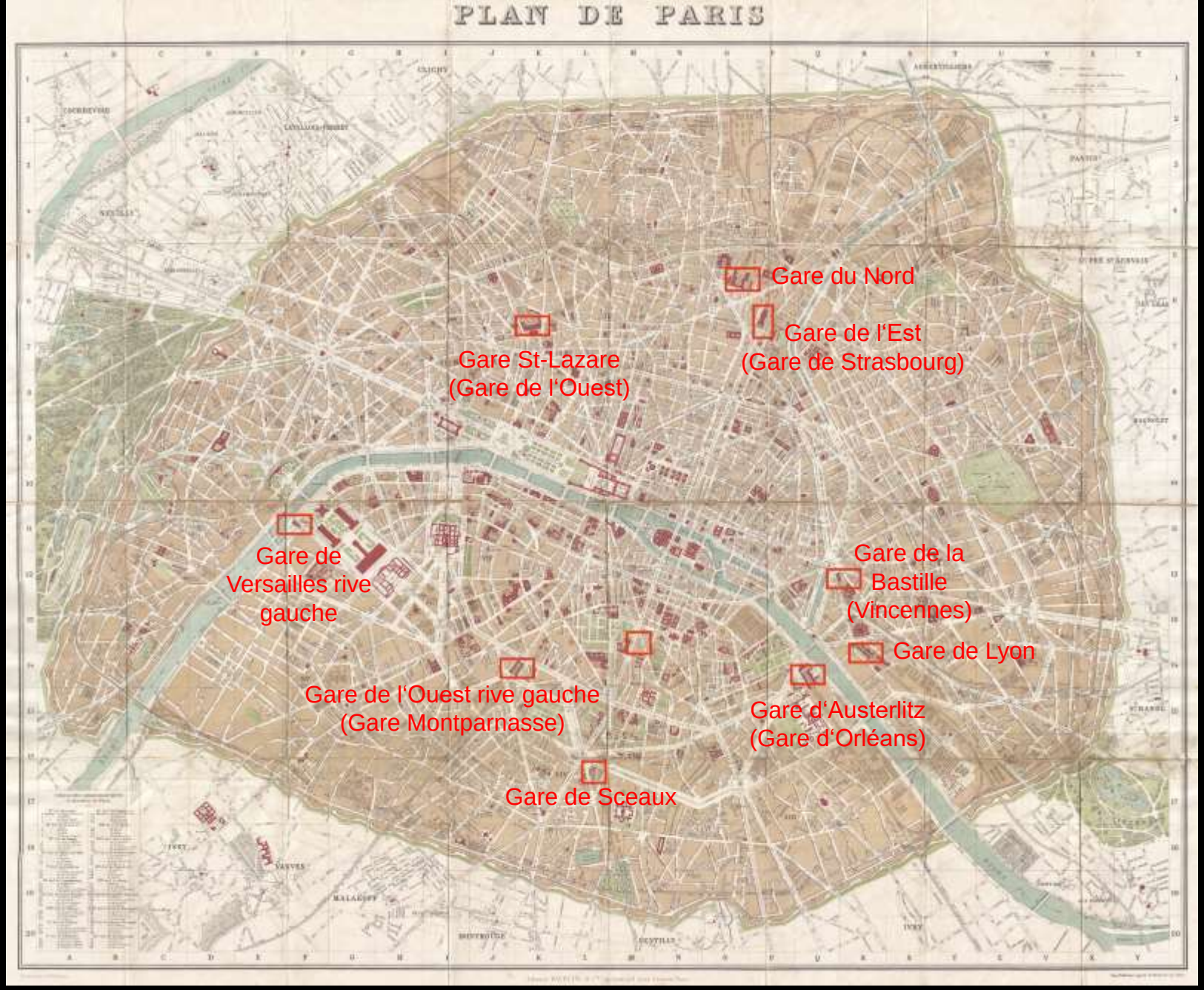
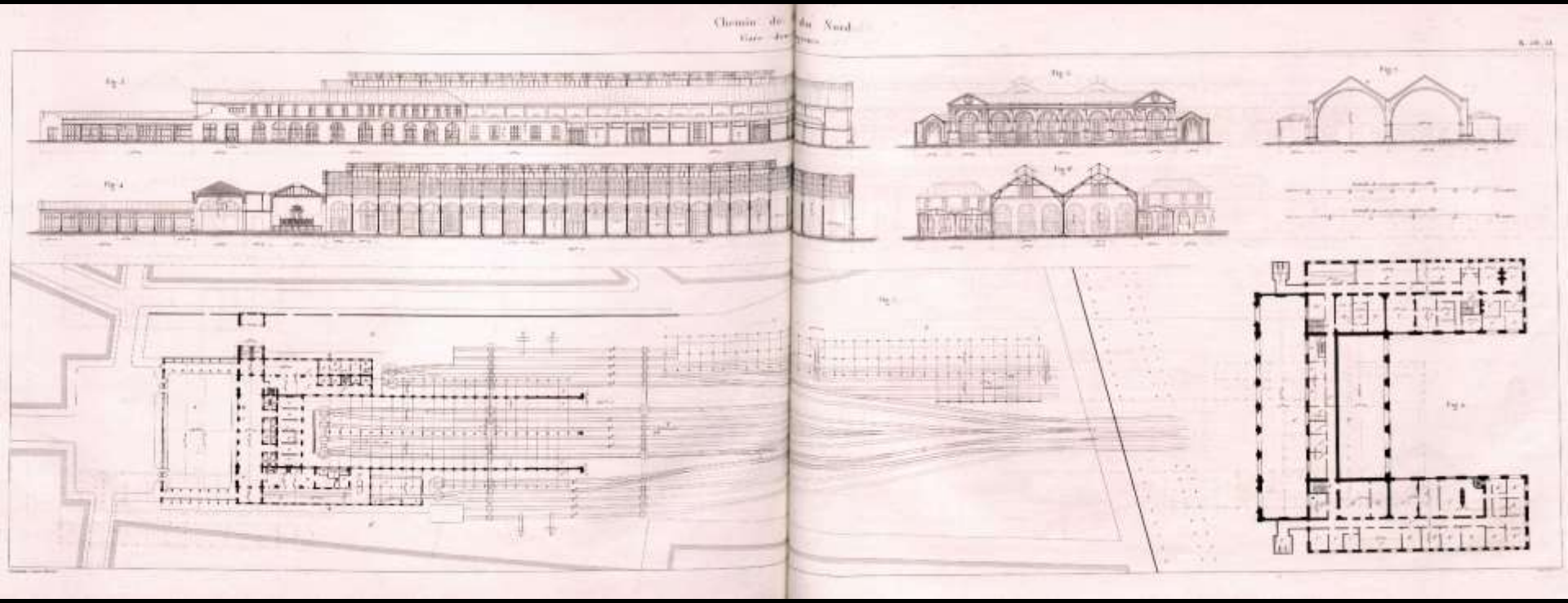


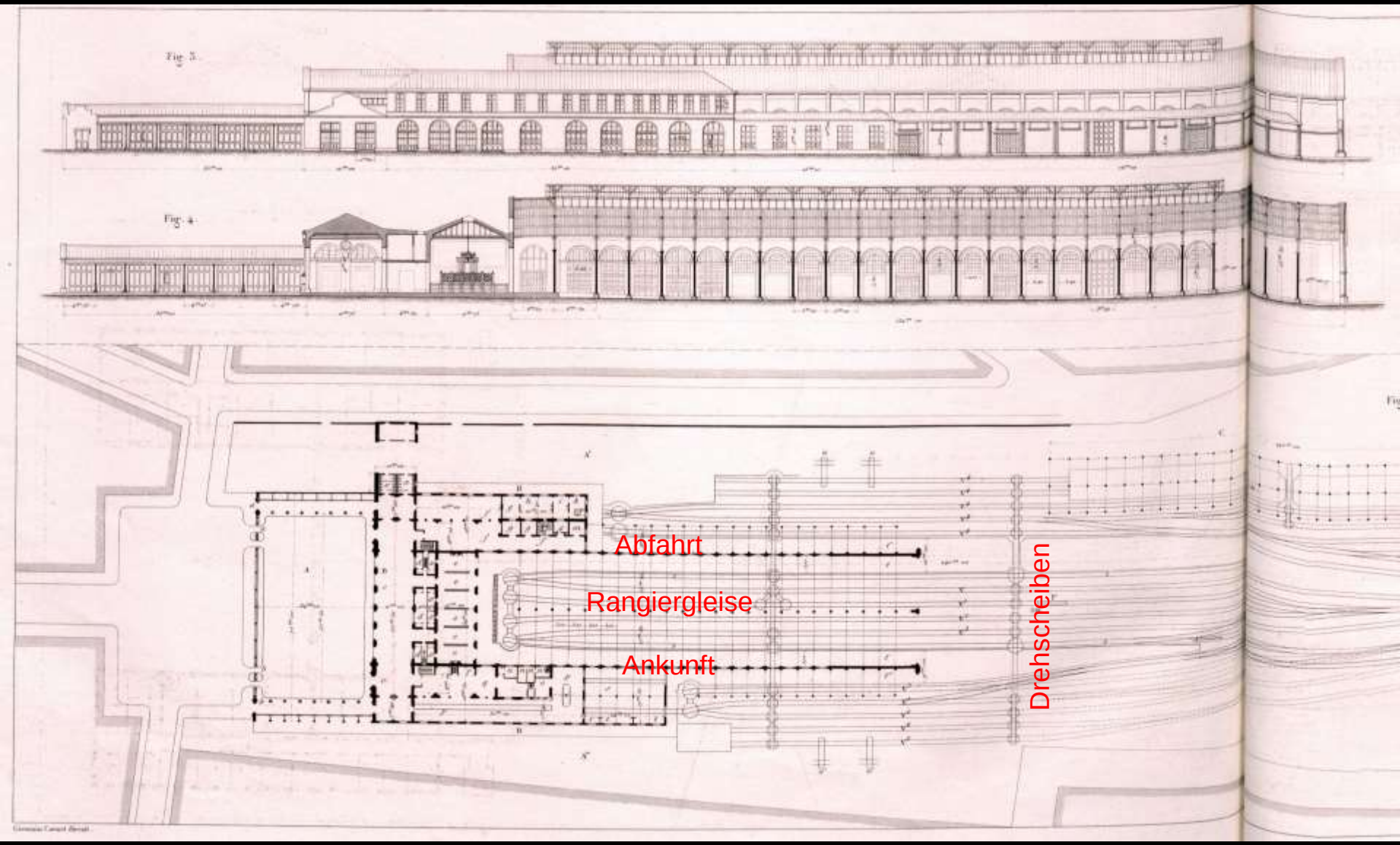
Augsburg, ehem. Bahnhofshalle (1840)



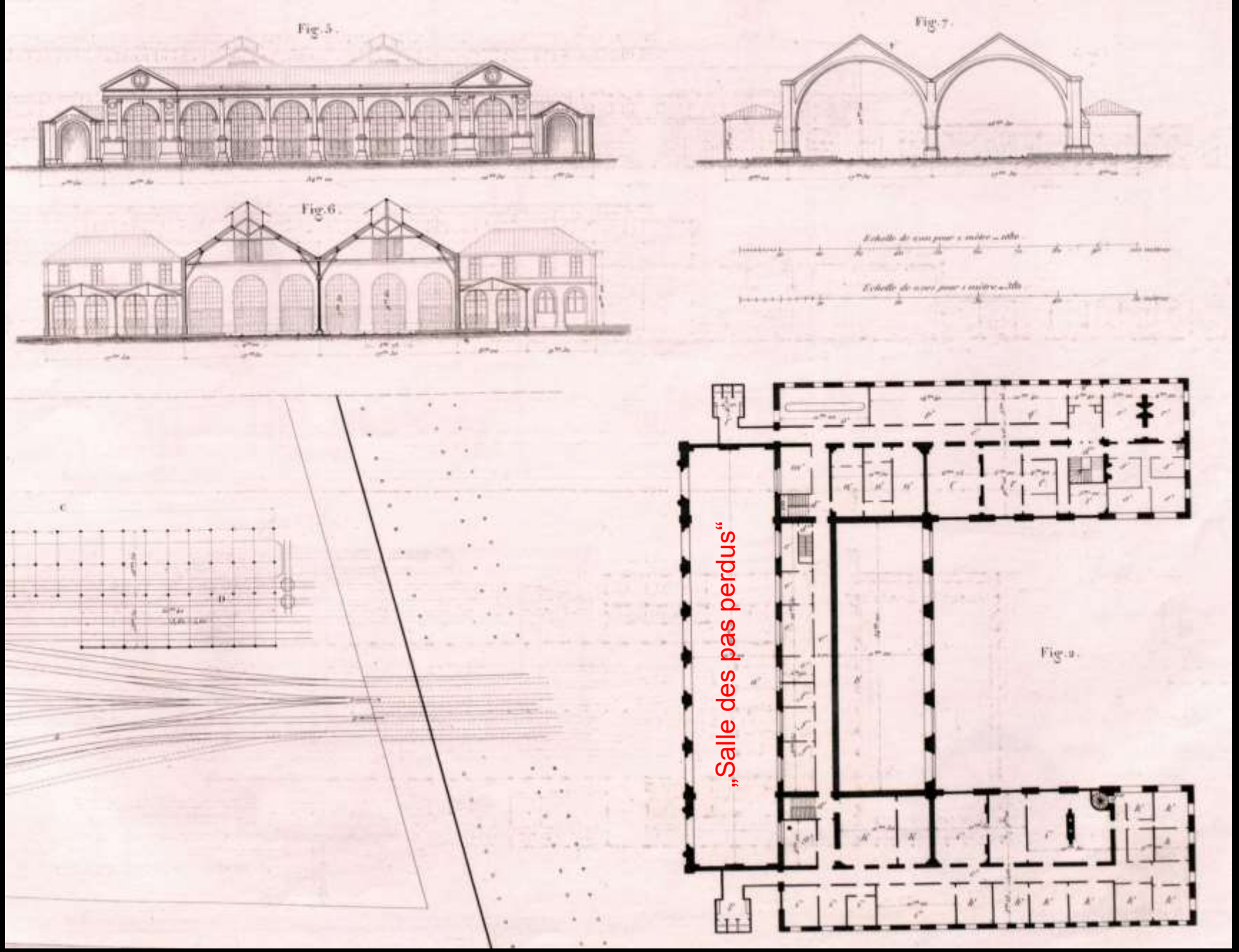
Paris, die Bahnhöfe
(Plan v. Vuillemin 1894)



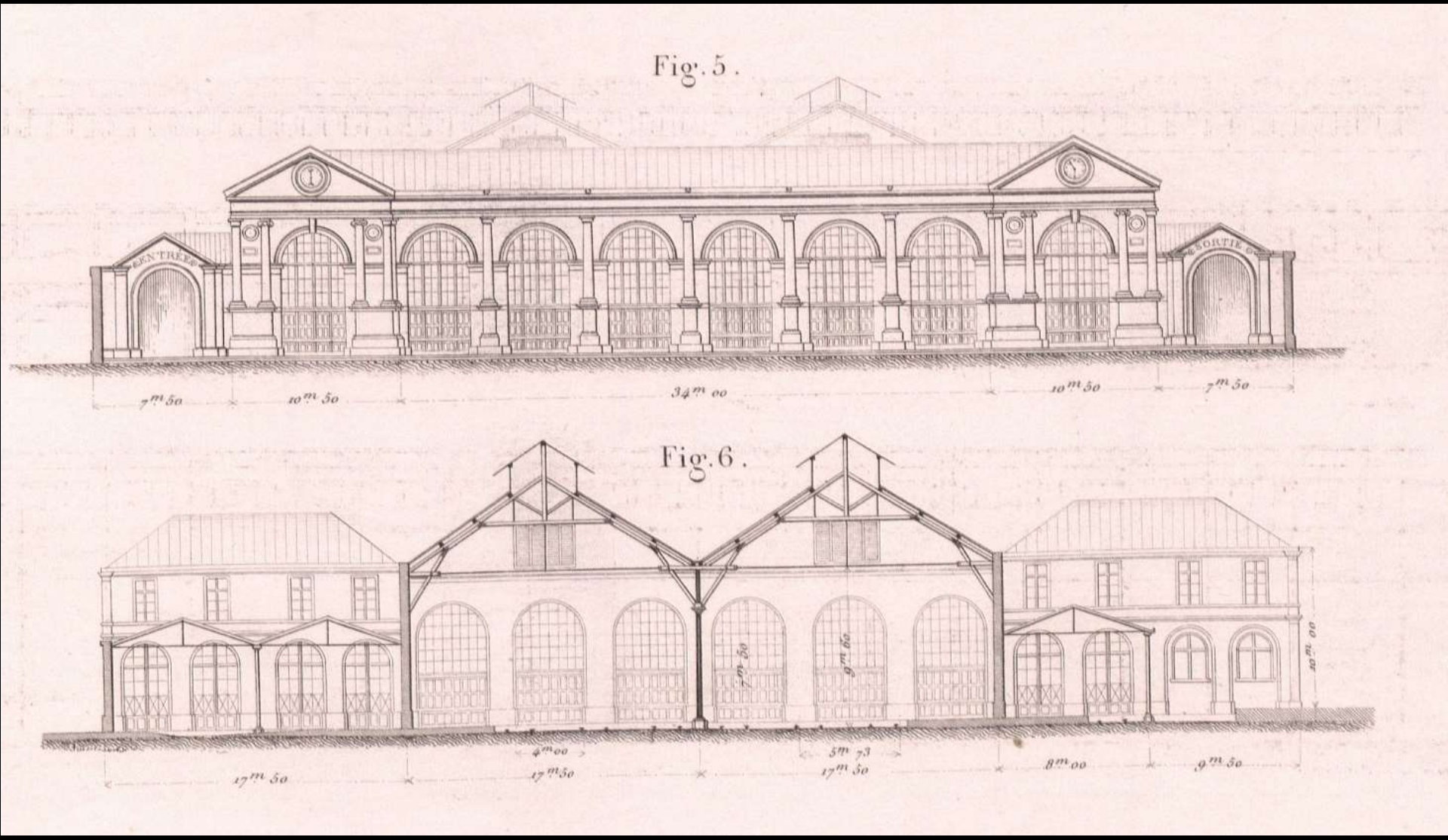
Paris, Gare du Nord (1846)
Gesamtdisposition (Perdonnet/Polonceau 1846)



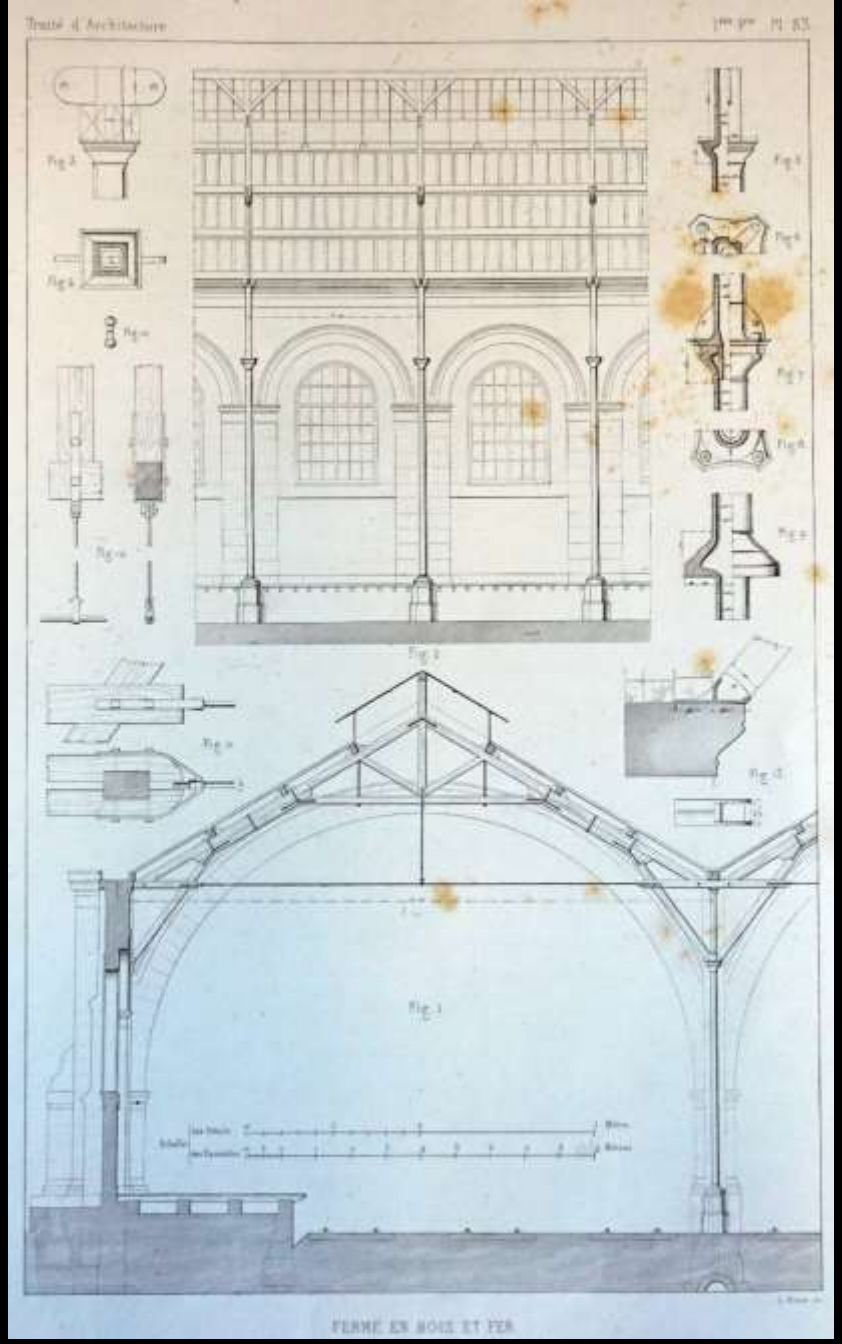
Paris, Gare du Nord (1846)
Gesamtdisposition (Perdonnet/Polonceau 1846)



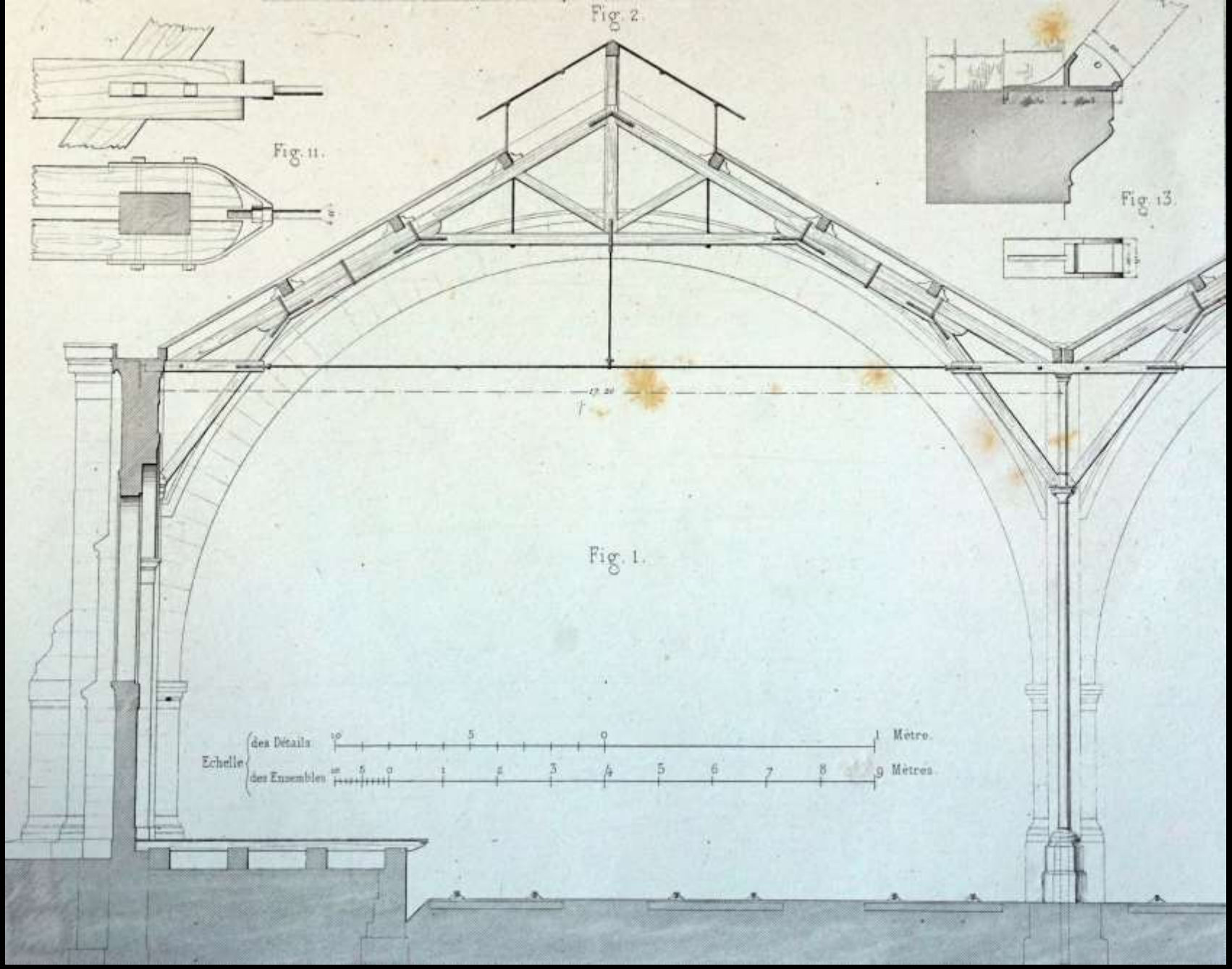
Paris, Gare du Nord (1846)
Gesamtdisposition (Perdonnet/Polonceau 1846)



Paris, Gare du Nord (1846)
Fassade und Schnitt durch die Einsteighalle (Perdonnet/Polonceau 1846)

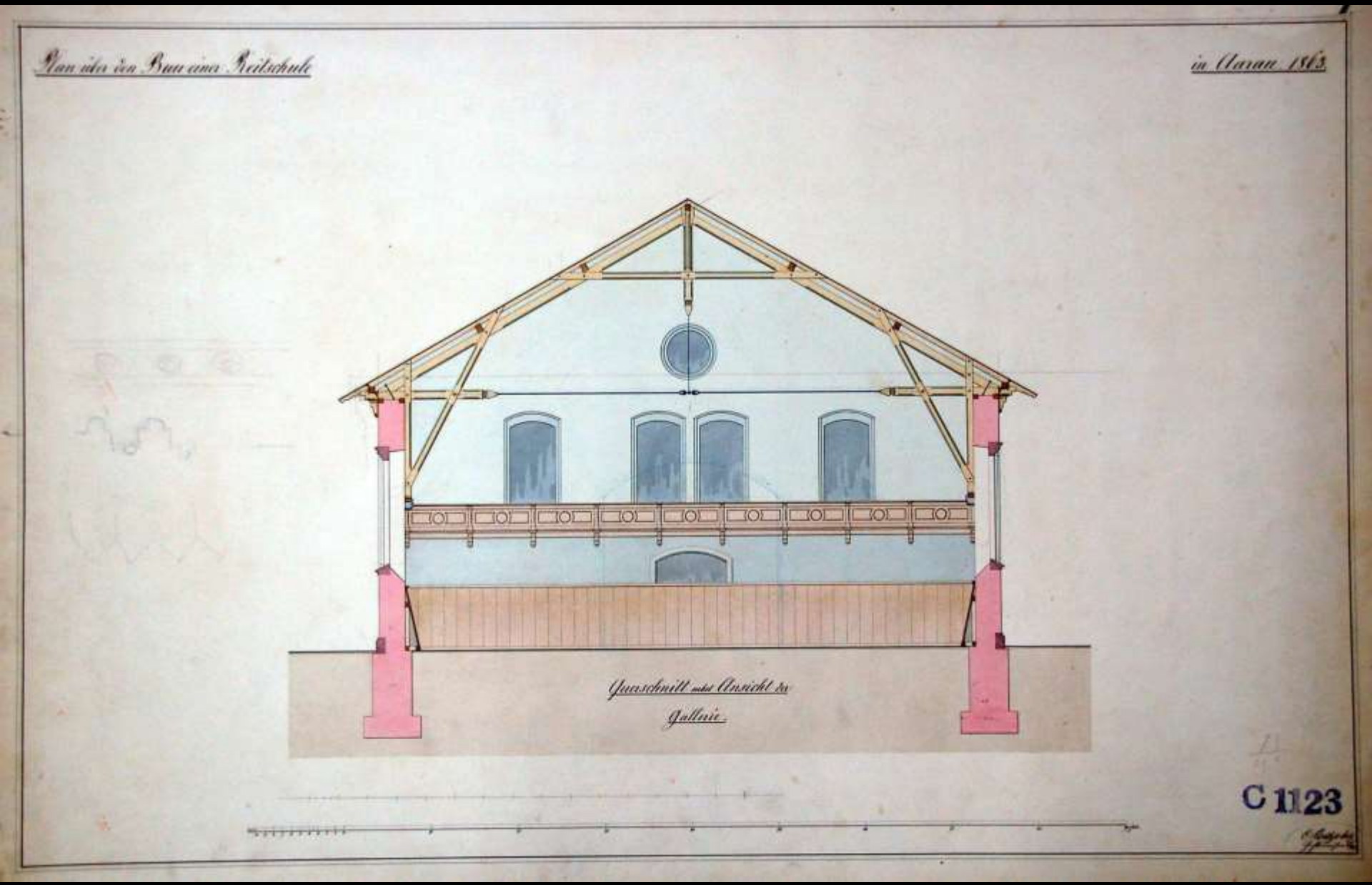


Paris, Gare du Nord (1846), Einsteighalle von Leonce Reynaud (Reynaud 1860)

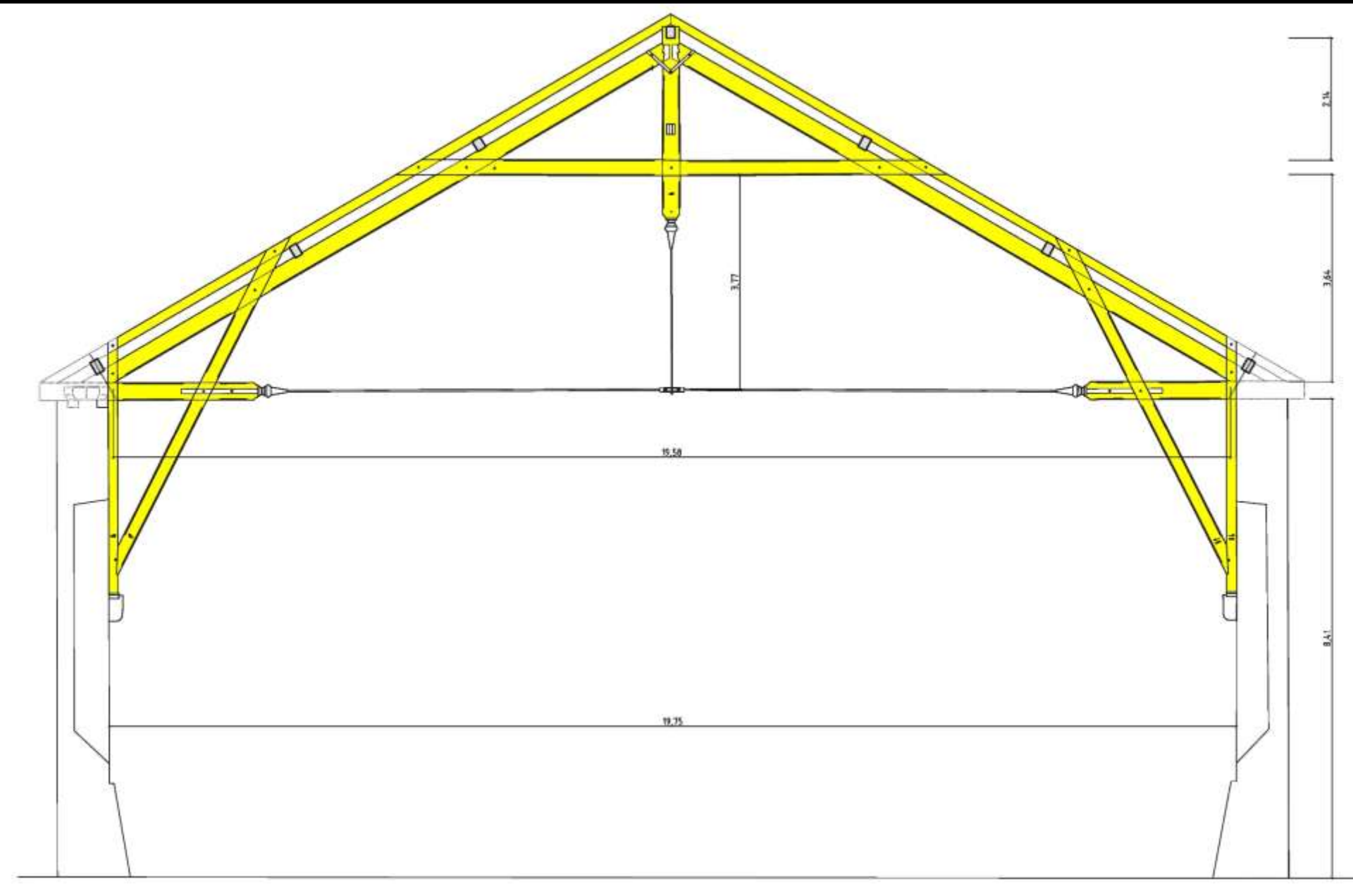


Paris, Gare du Nord (1846), Einsteighalle von Leonce Reynaud
(Reynaud 1860)

Paris, Gare du Nord (Leonce Reynaud, 1846-50; zeitgenöss. Modell im Cons. Arts & Métiers, Paris)



Aarau, Reithalle (1864; KA Aargau)



Aarau, Reithalle (1864)

Aarau, Reithalle (1864)

Aarau, Reithalle (1864)