

Tile Vaults in Post-War Germany

Santiago Huerta

Tile vaults, made with burnt bricks set flat and gypsum, are the most economical way to cover a space with masonry. They originated in the Mediterranean area, probably around the 10th century (the first known example, in Murcia, Spain, dates from the 12th century). They are found throughout most of the Iberian Peninsula, in the south of France, in Italy, and in the north of Africa. Tile vaults have also been found in Iran. These vaults are difficult to distinguish from other types of brick vaults as their intrados was usually plastered with gypsum; further research would probably notably expand our knowledge of their diffusion. In any case the widespread diffusion, geographically and chronologically, of a single building technique is noteworthy. The technique easily migrated from one culture to another, and was integrated in different building traditions. This chapter considers a single episode of this diffusion: the transfer of tile vaulting to post-war Germany, between 1940 and 1960. To put the work in context, similar episodes in other European countries will first be briefly considered.

EUROPEAN POST-WAR TILE VAULTING

Tile vaulting had a “renaissance” in the context of the second war and post-war Europe, say between 1940 and 1960. In several countries, it was realised that the economy and speed of construction of these vaults could be very useful in reconstruction work in the context of iron, wood and cement shortages. In some countries, the building tradition was revived; in others, a technique that was completely unknown or had been forgotten was imported. In what follows, I will briefly review this history in Spain and France, with some mention of Italy and Russia, before finally studying post-war German tile vault construction in some detail.

Spain

In Spain, the construction of tile vaults was widespread from the beginning of the 17th century. Fray Lorenzo de San Nicolás (1639) offered a full description of this way of building, putting tile vaulting at the same level as stone and regular brick vaulting, (plate I, A). Tile vaulting was employed mainly in modest buildings, such as parish churches and convents of the mendicant orders. Fray Lorenzo's description is the only published contribution before the end of the 18th century when Bails copied parts of Lorenzo's description, quoting him as an authority in his *Arquitectura civil*, together with passages copied without acknowledgement from Blondel-Patte (1771). When a tradition is fully alive handbooks are not needed to explain the technique. This may explain the scarcity of references to tile vaulting in Spanish architectural and construction treatises. Only one monograph, by Fornés y Gurrea (1841), was published in the 19th century, (plate I, B–C). The architect Ger y Lóbez included a substantial chapter in his treatise of 1889. Ironically, most of the references in Spanish treatises come from French sources, mainly Blondel-Patte and Rondelet. This led to some “schizophrenic thinking” (to assume at the same time one hypothesis and its contrary) as the French information contradicted in some cases the Spanish, particularly acute in the case of the “no thrust” hypothesis enunciated first by Espié (1754) and perpetuated in French manuals, despite the evidence of cracking of vaults and leaning in buttresses (Huerta 2003). In the second half of the 19th century the tile-vaulting technique was applied to some new industrial buildings (Redondo 2013).

A crucial episode of technology transfer occurred when the Spanish architect Rafael Guastavino emigrated to the United States in 1881 and, with enormous ingenuity, intelligence and hard work, spread this type of construction throughout the country. In 1889 he founded the Guastavino Fireproof Construction Company, and Guastavino's vaults populated the most important buildings constructed in the US around 1900. After his death in 1908, his son, Rafael Guastavino Jr., continued with the company until 1943 when he sold it. The company remained active until 1962. The story of the Guastavino, father and son, was rediscovered in the 1960s by the historian George R. Collins who, in extremis, managed to save a large part of the company's archive after its dissolution in 1962 (Collins 1968). Since the beginning of the 21st century, there have been several monographs on the Guastavinos' work (Huerta 2001, Ochsendorf 2010). The present book contains also a chapter on Guastavino (Ochsendorf 2021).

At the beginning of the 20th century, tile vaults were still being built in Spain, although they were losing ground in favour of reinforced concrete and steel construction. After the

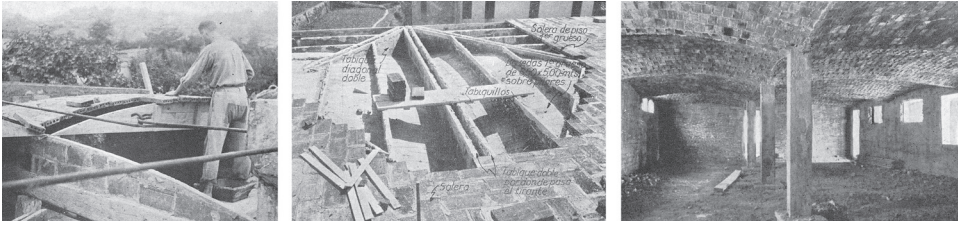


Figure 1. Tile vaults for horizontal floors on a reinforced concrete frame. Left: The vault is a translation surface using a wooden guide supported on arched walls on top of the beams; centre: Small walls form a net to reinforce the one-brick shell and place the brick floor; right: View of the completed vault from below (Bosch 1949).

Spanish Civil War (1936–39), the technique was used on a large scale, both in reconstruction work and in new construction (plate II). The war first, and dictator Franco’s autarchy post-war, led to a great shortage of cement and iron. Thus a large part of the reconstruction of the devastated regions was carried out using vaults. Some episodes have been studied in detail, such as the reconstruction of the village of Villanueva de la Cañada in Madrid (Churtichaga 2001), or the construction of cheap houses in Girona (Cabrera et al. 2005) following the so-called “four-point vault” (fig. 1) devised by the architect Ignacio Bosch (Bosch 1949). Although there is a lack of general studies on the diffusion of vaults in Spain or the use of the tile vault in the post-war period, it is enough to take a look at the issues of the journal *Reconstrucción*, published between 1940 and 1953, to see how widely the technique was used.

The interest in tile vaults in Spain led to some important articles and books. Professor Buenaventura Bassegoda delivered a lecture on the topic in 1946 (Bassegoda 1947). Another, expanded, article was published in 1952. Perhaps the most important contributions were made by the architect Luis Moya, which is the subject of another chapter in this book (Gil Crespo 2021). Moya also published an excellent monograph in 1947, *Bóvedas tabicadas* (tile vaults), which as we shall see had an international impact. The book was written with the upmost clarity and excellent drawings, which promoted an understanding of tile vaulting among non-experts (fig. 2).

Moya revived the Arab-Spanish tradition of building crossed-arch domes, which originated in the Mosque of Córdoba. First, the cross arches were built with centering; then all the work proceeded without any centering or form, until the final completion of the roof, which was supported on the tile webs between the arches. It is hard to imagine anything more ingenious and economical, a modern application of “Gothic logic” (fig. 3).

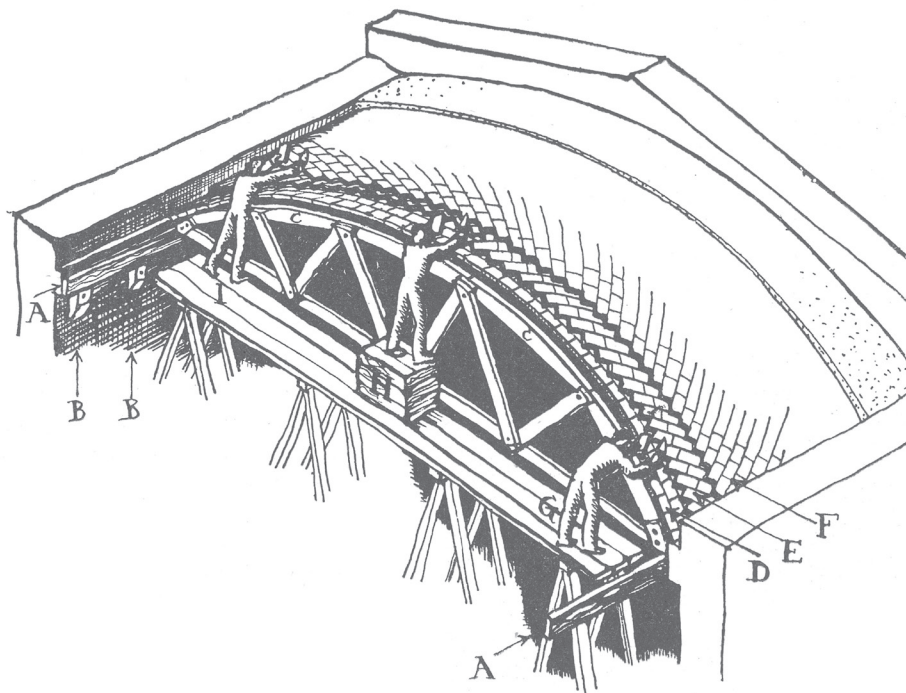


Figure 2. Construction of a barrel tile vault. The masons use a “form” (not a centering) to guide their work. The first layer of flat bricks is set with gypsum, which sets in seconds and serves as “centering” for the second layer with lime or cement mortar, which requires much more time to set (Moya 1947, 10).

In the 1950s the Catalan architect Àngel Truñó wrote the manuscript for a book in which he described tile construction in great detail, with an extraordinary photographic documentation of the technique, based on his own work employing tile vaults in Barcelona. The typescript was preserved in the Library of the Catalan Architects Association and was eventually published in 2004 (Truñó 2004) (plate II, E–G).

Vaults continued to be used in the 1960s and 1970s, although they were already in clear decline. However, it is interesting to note that the staircases of apartment buildings continued frequently to be built with tile vaults until the 1980s, a reflection of the speed and economy with which vaults could be built. Fernando Cassinello’s booklet on brick vaults of 1961 (reprinted in 1968) includes a chapter on “*Escaleras tabicadas*” (tile-vault stairs) describing the technique.

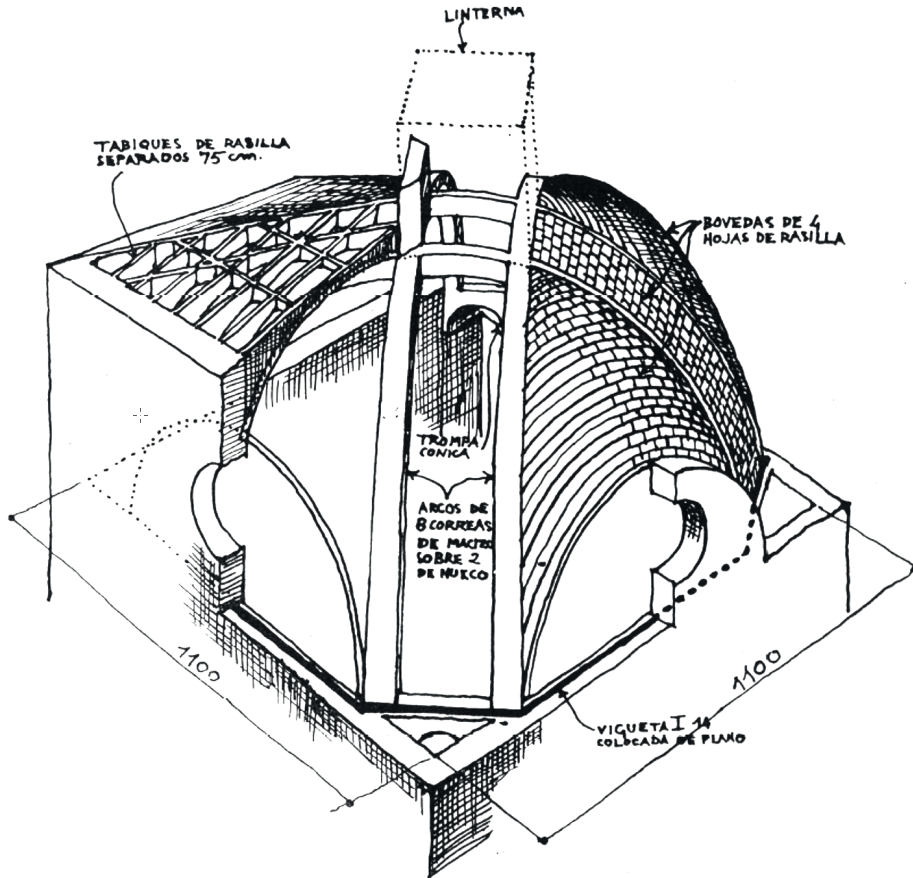


Figure 3. Church of Manzanares. Crossed-arch dome of 13.30 m span, supporting a lantern. The drawing describes the constructive process (Moya 1947, 26).

In the past two decades, the rise of construction history as a new independent discipline has produced a renewal of the interest in tile vaulting. Contributions on tile vaulting have been made in every Spanish Congress of Construction History since the first congress held in Madrid in 1996. After the sixth congress of 2009 in Valencia, the time seemed ripe to organise an International Symposium on Tile Vaulting, which was eventually held in 2012 (Zaragoza et al. 2012). A second International Symposium was held also in Valencia in 2018.

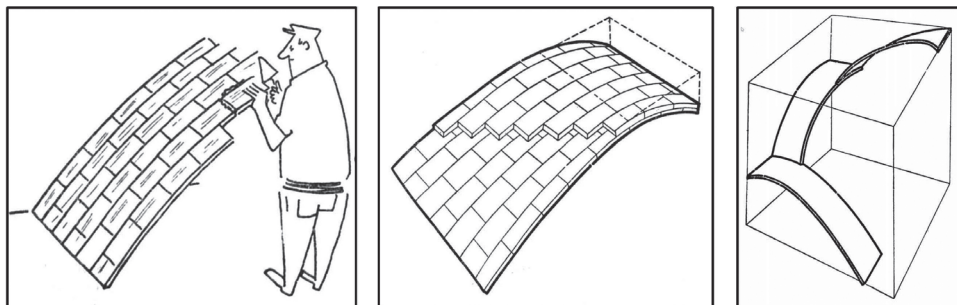


Figure 4. Building a tile-vault stair. Left: The first shell is built on the air, the first bricks “stuck” to the lateral wall; centre: A second layer is built breaking joints; right: Next flights are supported on those already built (Cassinello 1961).

France

Tile vaults were traditional in the Roussillon in the south of France. This region belonged to the Spanish kingdom until 1659, after which the tile-vaulting technique was transmitted to the Languedoc. In the first half of the 18th century tile vaulting aroused the interest of French architects, and the peculiarities and advantages of the technique were discussed in several sessions of the *Académie Royale d’Architecture* between 1747 and 1755. However, though the Académie valued the new technique, it eventually recommended the placement of bricks not flat but *sur le champ*, following the so-called pitched brick technique, and using cement mortar mixed with gypsum, which required centering. However, in 1754 the Count of Espié published a book with the title *Manière de rendre toutes sortes d’édifices incombustibles* (How to render all types of buildings incombustible) (plate III, A), which had an immediate impact in Europe: it was published in 1756 in England, in Germany in two editions of 1760 and 1774, and in Spain in 1776 by Sotomayor. What mainly attracted attention was Espié’s proposal to make a roof entirely of brick and therefore incombustible. Espié also developed a “theory” about the structural functioning of vaults that was essentially erroneous, since it held that vaults do not produce thrust (Huerta 2003).

Espié’s ideas were collected in general treatises on architecture and construction, including his false assumption about the lack of thrust – in fact, this false theory has survived, against all evidence, up until our day. Patte in his additions to Blondel’s *Cours d’architecture* (1771–77) dedicated a whole chapter (chapter 2 in vol. 6), fifty-seven pages and seven plates, to tile vaults (fig. 5 and plate III, B–C). He described in detail this type of vault,

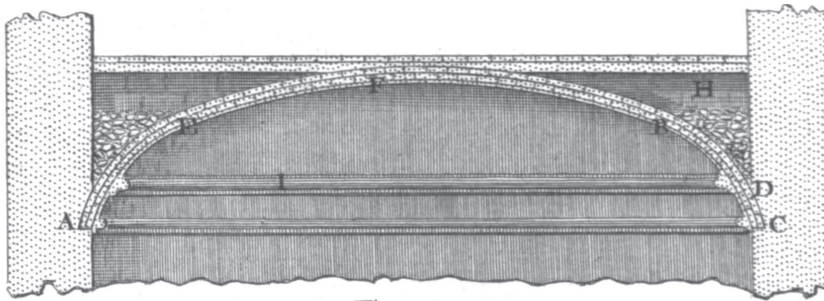


Fig. X.

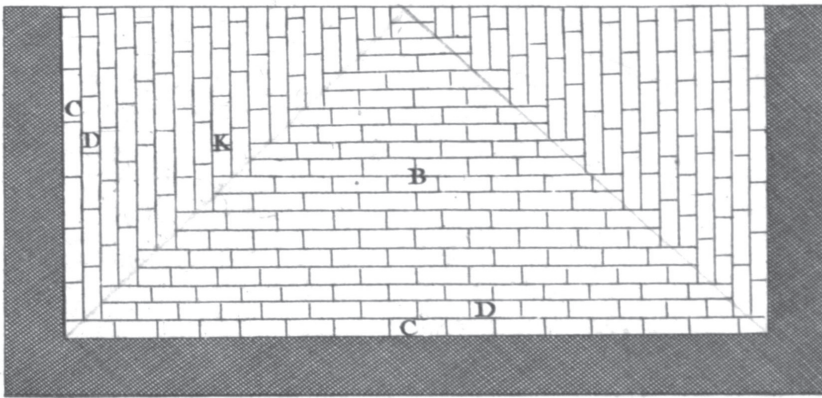


Figure 5. Construction of a cloister tile vault (Blondel-Patte 1771, VI, Pl. 85).

giving examples of their application in important buildings. Perhaps for the first time tile vaults were employed in a multi-storey building subject to great loads. In Versailles, the architect Berthier constructed the *Hôtel des Affaires Étrangères et de la Marine* in 1761–62. He employed surbased tile vaults to protect the archives kept in the building from fire. The *Imprimerie Royale* occupied the ground floor, the *Affaires Étrangères* the first floor, the Marine office took the next three stories, and the attic held the ordnance models (Bannister 1968) (plate III, E).

Rondelet in his *L'art de bâtir* summarised Patte's information. Rondelet's treatise, with numerous French editions and translations into German and Italian, was the main channel for the diffusion of tile vaults in central Europe, where this tradition had apparently never been active. The best source to study this episode of tile vaulting in 19th-century France is Bannister (1968), a paper written about 1950 and published posthumously with revisions

by George R. Collins. The contents of the massive notes, which doubled the size of the text, can be “mined” today with surprising results.

It appears that in the 19th century tile vaults were no longer employed in representative buildings, but were used for rural constructions (Lasteyrie 1820, Saint-Félix 1820) (plate III, D), or parish churches. However, evidence about the actual use of tile vaults is scarce. In 1837 the civil engineer D’Olivier published a paper on construction with tile vaults and made tests to ascertain their thrust. He demonstrated that tile vaults do thrust, but made no mention of the erroneous theory of Espié. Almost twenty years later another engineer, Fontaine (1865), made extensive tests on tile vaults supported on big iron beams. In each test the load was increased to collapse. One of the tests described was undertaken on three tile vaults with a span of 4 m (and a rise of 0.4 m), spanning between wrought iron I-beams (of 47 cm depth) with a span of 6.25 m, covering a total area of 72 m². The test was carried out until failure occurred under a load of 1,250 kg/m². In another test on a tile vault spanning 3.75 m (again with rise:span ratio of 1:10), the vault carried a load of 2,700 kg/m² without failing. Tests of such magnitude were not made in an isolated manner. Indeed, Fontaine mentions that: “The 72,000 square metres of floor that we have to build are made up of a succession of flat vaults of 4 metres span resting on flexible beams”¹ (Fontaine 1865, 152). The tests were probably made during the construction of such an enormous work; however, Fontaine gives no data about it. From the proportions and dimensions of the tests, it could have been a textile factory (Huerta 2003). Tests on tile vaults in the 19th century have been studied in detail by Redondo (2013) and in a chapter of this book (Redondo 2021).

There is documentary evidence, though fragmentary, of the construction of tile vaults for churches in the second half of the 19th century, either new or in works of restoration. Although this history requires more research, I can offer some data here, selected almost at random. In the *Catalogue de brevets d’invention* for the year 1844 appears a *Procédé de fabrication de briques propres à construire, avec solidité et économie, des voûtes planes, cloisons et toits, sans employer de charpente*, (Process for the manufacture of bricks suitable for the construction, with solidity and economy, of tile vaults, partitions and roofs, without using a wooden framework) registered by Luri et Nicolai in Bastia (Corsica). A certain E. Heurteau from Orleans appears in several documents as a builder of tile vaults for churches in the 1860s and 1870s. For example, a notice in the *Bulletins de la Société Archéologique de l’Orléanais* of 1862 states that he had to rebuild some vaults in the church of Saint-Donatien, Orléans:

This sad necessity has enabled Mr. Heurteau, plasterer-contractor, to give a new proof of the intelligence and taste he displays in his profession. His ribbed vaults and colonettes, made of ad hoc bricks, leave nothing to be desired in terms of solidity of construction and perfection of work.² (Buzonnière 1862, 207)

Haurteau also rebuilt some vaults of the Église Paroissiale Saint-Germain (plate IV, A). Hurteau was succeeded by Pothin, another constructor of Orléans, who in 1877 patented a *Système de briques creuses destinées à remplacer la pierre dans la construction des nervures des voûtes d'église* (Hollow brick system to replace stone in the construction of church vault ribs), published in the *Bulletin des lois de la République française* (Vol. 1, 126). Eventually the Ancienne Maison Pothin was succeeded by Bocquereau & Cie as advertised in the *Annuaire du bâtiment et des travaux publics*, 63^e année, 1893 (plate IV, B). Several details included in the advertisement are remarkable. First, it is claimed that the system was employed in the construction of more than 500 churches in France, and also in some important buildings such as the Palais du Trocadéro built for the Exposition Universelle in Paris in 1878. Besides stressing the advantages of tile vaulting, such as economy, lightness, robustness and absence of centering, relevant technical data are offered: the vaults are supposed to resist a load of 2,300 kg/m². Finally, another advantage is the absence of thrust, “*pas de poussée possible*.” The false assumption of Espié continued to be exhibited as an argument to choose tile vaults. The detail in the advertisement shows a disposition that was repeated in later adverts by other companies like Fabre and Pradier. It is remarkable that, in contrast with the tile vaults of the 18th century (plate III), there is only one shell of bricks, with a thickness of about 4 cm.

There were several *maisons* that built tile vaults for churches, but it was Auguste Fabre who appears to have been the most active and who eventually dominated the field. He established a company in 1896, which then flourished for decades. The company became famous for Fabre's work at the Exposition Universelle de Paris of 1900, where the Fabre system was used in the great dome and vaults of the Petit Palais, a feat remarked by the engineer Arthur da Cunha who edited the book on the works of the Exposition (Cunha

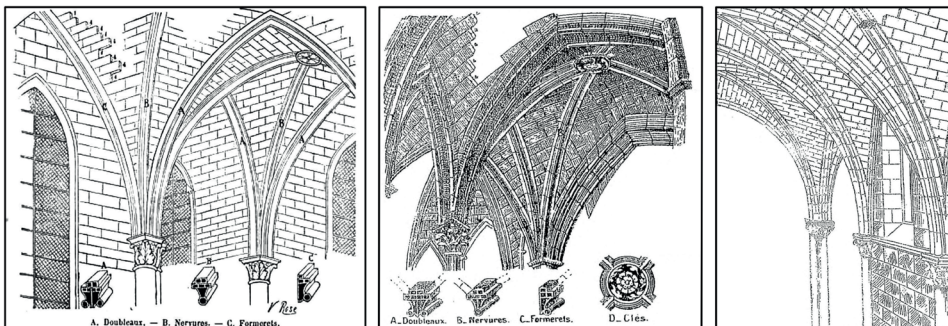


Figure 6. Drawings extracted from advertisements of several tile vault building companies. Left: Bocquereau 1893; centre: Pradier 1903; right: Fabre 1903.



Figure 7. Palais de la Céramique in the Exposition Internationale of 1937 (Ragot 1987).

1900). Paula Fuentes has made a thorough study of the origins and activity of the maison Fabre in France and of the derived patents in Belgium (Fuentes and Wouters 2019; Fuentes 2021a, 2021b, 2021c). In what follows we will summarize the pertinent information for this chapter; the interested reader should consult Fuente's contributions.

Fabre patented several solutions between 1900 and 1945, and his advertisements appeared in the most important French architectural journals. Up until the 1930s the company's main activity was the construction of vaults for churches, and Fabre claimed to have built 1,500 churches by then (Fuentes 2021b). Then, in 1935 he patented a roof, *Système de voûtes porteuses de toitures* (System of load-bearing roof vaults), combining tile vaults and reinforced arches embedded in hollow bricks (plate V, A–B). However, Auguste Fabre proved himself to be ingenious and able to adapt to the requirements of the project and the desires of the architect. Together with the architects Robert Camelot and Jacques and Paul Herbé, he adapted his patent for the great dome of the Palais de la Céramique, with a circumference of 17 m, at the Exposition Internationale of 1937 in Paris, (Ragot 1987) (plate V, C–G). The roof rests on double radial tile walls, which are supported by the single layer tile dome. Inside the walls, which serve as formwork, reinforced concrete arches are joined together in an upper ring. At the base, a reinforced concrete tie beam absorbs the thrusts of the dome (plate V, G). In the barrel vaults the reinforced glazed arches provided lighting, wind bracing and stiffening for the tile vaulting (plate V, D).

The last advertisements for the Établissements A. Fabre found in French journals are from 1945. The emphasis had by then changed from church vaults to roof vaults (plate V, A–B). What happened to the company? A review of Fabre's known work shows a great mastery of tile-vault building, and he collaborated with great architects in important buildings over four decades. Was Fabre a "French Guastavino," able to collaborate and improve the architectural projects in which he was involved? Here is another episode of the history of tile vaulting that needs detailed research.

The tile-vaulting technique was well known, then, in pre-war France. It would have seemed logical to use this technique in the tasks of reconstruction, first during the Vichy Régime and then after the defeat of Germany in 1945. However, it appears that only a single person, the architect Pol Abraham, seriously considered this possibility. Only one monograph (Miraygou 2008) has been published on Abraham (1891–1966) although he was well known in France in the 1930s for his projects in the style of the so-called “modern architecture” and he developed an early interest in masonry vaults. He also had a strong technical background, having worked as a structural engineer (reinforced concrete) before initiating his career as an architect (Collura 2008). In 1924 he completed his studies and submitted the title of his thesis on Viollet-le-Duc, which he completed in 1933 and published as a book in 1934 (Abraham 1934). Abraham’s ideas, including his frontal attack on Viollet-le-Duc’s theories, provoked an “earthquake” in the interpretation of Gothic, the waves of which continue to affect today’s publications (Cisternino 2005; Huerta 2009). Most pertinent today is his deep knowledge of the structural behaviour of masonry vaults. Although Abraham’s analysis are sometimes biased by his over-critical attitude to Viollet-le-Duc, it is evident that he has a profound understanding of the equilibrium of vaults, which is the central issue in masonry architecture (Heyman 1995).

In the 1930s Abraham was able to combine frantic activity as a “modern architect,” editor and contributor to important French architectural journals, with inspection works in medieval churches and a continued reflection on the possibilities of traditional masonry in modern construction. (Abraham considered reinforced concrete, *béton armé*, as a modern kind of masonry, *maçonnerie*. Traditional, historic masonry, *maçonnerie*, was unreinforced). In fact, just after completing his dissertation he became Departmental Inspector of Technical Education in the reinforced concrete section. In 1938 he became an architect for the *Enseignement* (training) department and was responsible for the construction of the School for Masonry Trades (*L’école des métiers de la maçonnerie*) in the rue Saint-Lambert in Paris.

When war broke out in 1939, Abraham was commissioned with the never-completed avant-project of building a new factory in the provinces to replace one in the Paris region (Abraham 1942). All the roofs of the new factory would have been built with tile vaults, covering a surface of around 35,000 m². The vaults were supported on a reinforced concrete skeleton of piers and bow-string arches (plate VI) and consisted of a double shell of single tile vaults connected with single brick ribs (plate VI, D). The bricks were hollow (*briques creuses*), measuring 7.5 × 15 × 30 cm. To improve isolation, the space between the shells is filled with coke slag. The construction results using this method are much more economical than with shells of reinforced concrete, due mainly to the absence of formwork. The factory

was never built, but the avant-project was a strong declaration of intent on the possibilities of tile vaulting in modern buildings.

In 1941 Abraham published a paper on the use of surbased tile vaults for floors in multi-storey buildings. He took as a precedent the already mentioned *Hôtel des Affaires Étrangères* in Versailles (plate III, E). The five floors of this building are vaulted with spans of 6.75 m and a height 1/10 of the span, about 60 cm. Abraham points out that these vaults had supported the enormous weight of the archives for 180 years and that this was an incontrovertible proof of their strength and safety. As already stated, he was then involved in the construction of the *Musée de la Maçonnerie* in Paris, for which the floors would be tile vaults (plates VII–VIII). The idea is the same as in the factory: a reinforced concrete framed skeleton, which supports the vaulted floors. He considered the cloistered vault surbased to 1/10 as the more adequate (fig. 8, top). He then made a comparison in terms of price, erection time and carbon consumption between a tile vault and a reinforced concrete floor (fig. 8, bottom). The overall cost reduction in favour of tile vaults is about 30%, but Abraham stressed that carbon consumption is drastically reduced to almost one third. This last fact was crucial in war times as France, as Abraham pointed out, was a coal-importing country. (Today the same comparison may be quite relevant for the decarbonization of buildings!). Abraham's project for the museum had some repercussions in the construction world and, for example in Spain, was cited on several occasions by Bassegoda (1947, 1952) and Moya (1947).

At the same time that he was finishing the construction of the musée, Abraham completed a project for a big school for apprentices in Andressy (Hermant 1942) (plate IX), again using exclusively tile vaults for the floors. The project was not eventually built. It is, however, an indubitable sign of the interest in employing tile vaults.

Along with his work on the musée, Abraham maintained a constant reflection about the means to integrate masonry walls and vaults in modern architecture. Within this general context, he also felt the urgency of constructing with limited means after the war devastation. A year later, in 1943, Abraham published another article with the title “*Défense et illustration de la maçonnerie*” (Defence and illustration of masonry). At the very beginning of the article he expresses his conviction that masonry construction would play a crucial role in the future: “the aim of this study is to show that the art of masonry is not in decline, but on the threshold of a gigantic revival”³ (Abraham 1943, 229). He discusses its advantages; for example the weight, which for a modern mind is synonym of cost, to Abraham is what gives calm to housing – “*le poids est le facteur essentiel du calme dans l’habitation*” (Abraham 1943, 233) – as it reduces the noises and tremors and, crucially, gives thermal inertia to the buildings.

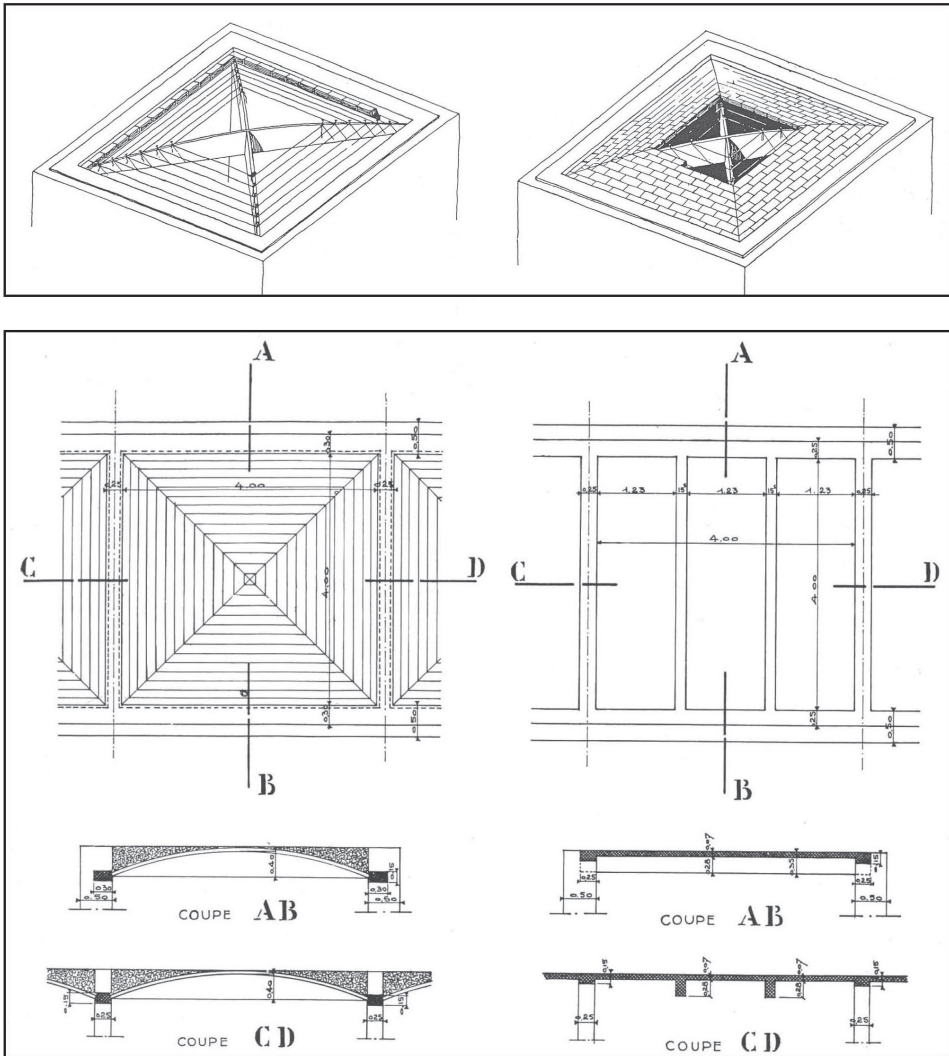


Figure 8. Top: Construction of tile vaults without centering; bottom: Comparison of prices, time spent and tonnage of coal for the two floors. Left: tile vault (bricks $7.5 \times 15 \times 30$ cm), mass concrete backfill and perimetral ties; right: Reinforced concrete ribbed slab (Abraham 1941).

In the article Abraham also discusses the origin of prejudices against masonry in different sections: the illegitimate comparisons, the abusive analogies, the usual critics, the pre-war building shortcomings. But he also speaks of emerging hopes and the possibility of integrating traditional masonry, in an improved form, in the architecture of the future.

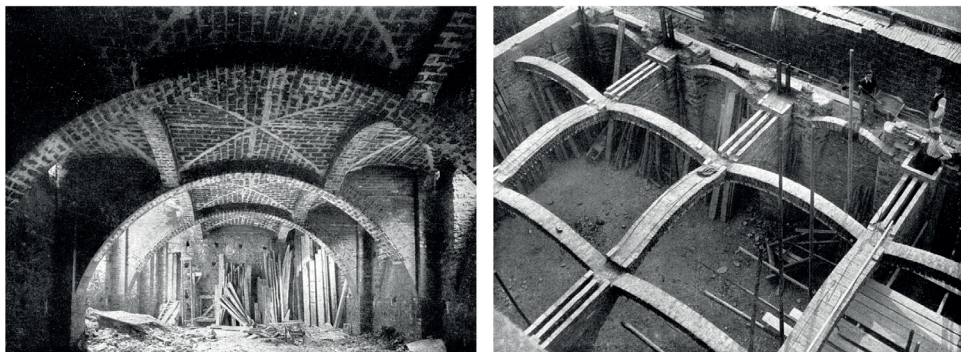


Figure 9. Construction of the vaults and frame of the Masonry Museum (Abraham 1941, 44).

Abraham complains that the success of reinforced concrete has produced a basic distrust towards traditional, unreinforced, masonry. He complains that it appears that brick or stone are under suspicion:

It seems that stone and brick masonry has become minor, or crippled; it is no longer conceived without a medical corset. We must react. Structure is not only about lintels and posts; it is also about arches and walls.⁴ (Abraham 1943, 236)

For Abraham masonry, improved by local reinforcements and ties, will play a major role in the future. He affirms that vault action, combined with tension ties, is an eminently economical artifice. The whole article has a “prophetic,” revolutionary, tone, like many writings by Le Corbusier. But this time the revolution consists in accepting the essential characteristics of masonry. This revalorisation of masonry should go hand in hand with the industrialisation of building, and Abraham dedicated a whole section to high-performance wall construction methods.

A year later, in 1944, Abraham delivered a conference paper on “*L’évolution des procédés traditionnels de construction dans la maçonnerie de bâtiment*” (Abraham 1945). Here the discussion focuses on the standardisation of the construction of unreinforced masonry walls, with all the associated problems. It appears that Abraham finally recognised that vaults could not actually compete with reinforced concrete floors. It is only at the end of the paper that he mentions the employment of tile vaults for roofs (fig. 10). The image shows an improvement of Fabre’s patent of 1935 (plate V, A): the reinforced concrete arches have disappeared and the reinforced concrete slab acts as a tie to equilibrate the vault. It is again a new version of Espié’s *comble briqueté* (plate III, A).

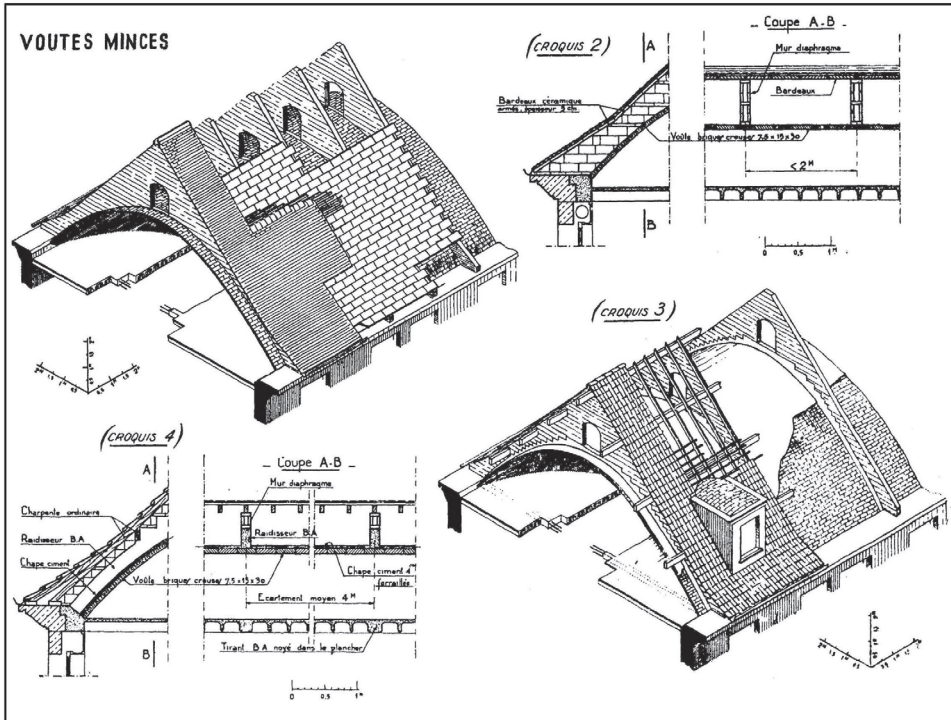


Figure 10. Construction of tile vault roofs (Abraham 1945, 11).

Another type of masonry vault had great success in post-war France: the barrel vault of ceramic tubes, *fusées céramiques*. According to Delemontey (2020, 150), by 1959 more than 150,000 m² had been built in France and more than 500,000 m² in other countries. These hollow tube vaults were barrel vaults, parabolic or catenary in shape, and were built with the help of a continuous formwork.

Italy

In Italy the tradition of building tile vaults is very old. In the south of Italy there are examples dated to the 15th century (Bares and Nobile 2012); however, mentions in architectural and construction treatises only appear centuries later. The first occurs (Fatta et al. 2016, 131) in the treatise of Amico (1726, 1750). In the 19th century tile vaults are mentioned in almost every architectural or construction treatise, though without much detail. As stated above, when a tradition is alive there is no need to give many explanations. The wide diffusion

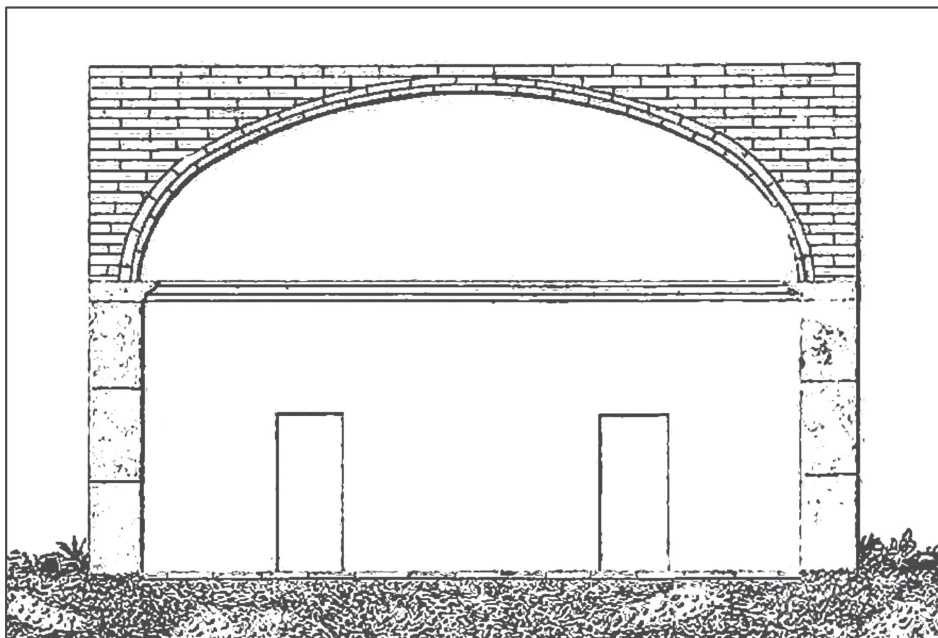


Figure 11. Tile vault, *volte alla volterrana*, in the architectural manual of Cavalieri San-Bertolo (1827, Pl. 12).

of tile vaults in Italy may explain the numerous names: *volte in foglio*, *in piano*, *leggeri*, *volterrane* or *di quarto*. The great impact of Espié's book in Europe and the Italian translation of Rondelet in the 1830s (with two editions), which summarised the descriptions of Blondel-Patte, may have encouraged Italian authors to mention this technique. One of the first to include a brief description is Cavalieri San-Bertolo (1826–27) (fig. 11), who however does not mention Espié's book.

Italian tile vaults aroused the interest of some foreigners during the 19th century. For example, the German building inspector Wild (1856) wrote, after travels through Italy in the 1850s, a brief description of the construction of tile vaults in the Tuscany, *volte Volterrane* (fig. 12). These vaults, according to Wild, were only of one shell of bricks set flat and therefore had a thickness of around 5 cm. The vault was reinforced by doubled arches of bricks about two feet apart (Fig. 2 in fig. 12). Vaults could have many different profiles, but the span-to-height ratio could not be greater than four. Centering and formwork were not needed, only some “forms” to guide the masons. Wild describes in great detail the building process, stressing the importance of good plaster and bricks. He also mentions the depth of

the buttress needed for different spans. The span/depth ratio is always greater than 10: to be stable the vaults would need great weight on top of the buttresses or iron ties. If the vault supports a floor then a wall should be built on the arches to reach the level of the keystone, and small vaults constructed between these walls. On top of these last vaults a filling of light masonry made of lime mortar and Puzzolana would form the floor.

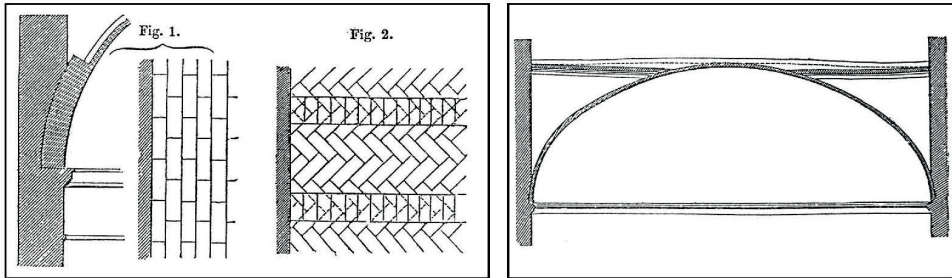


Figure 12. Description of the construction of tile vaults in Tuscany. Left: Barrel vault with filling until different bondings and reinforced arches; right: Barrel vault with extradosed transverse arches which support small vaults (Wild 1856).

At the end of the century, Choisy cited these vaults in his famous *Histoire de l'architecture* while describing the use of bricks set flat to form the Roman vaults, commenting on their robustness: “These curved tiles form a vault and are extraordinarily strong. In Italy, and especially in Rome, curved ceilings are nowadays built using bricks laid flat in this way”⁷⁵ (Choisy 1899, I, 524).

It seems that in the first half of the 20th century tile vaulting was already in decline. In the context of pre-war and war times it would have been sensible to revive tile vaulting due to the scarcity of iron and cement. However, I am not aware of any such initiatives. The only description I have found for the building of tile vaults in Italy in the first half of the 20th century comes from a German architect born in Italy, Carl Sattler, who was commissioned by the Nazi Government to study the possibility of importing the technique from Italy to Germany. In 1940 Sattler travelled for five weeks through Italy, visiting buildings and paying a master mason to erect a series of tile vaults (plate X). In Florence he visited the Institute of Agriculture for Italian Africa, where some stairs with tile vaults were being built. He documented their construction (plate XI, A–C) and was fortunate enough to witness some loading tests on the stairs (plate XI, E–F). He recorded the results: the thin vaults supported a load of 650–800 kg/m², and showed a sinking of only 1.7–2.85 mm during

loading and of 0.1–0.3 mm after unloading. On his return to Germany he wrote a report, with explanatory drawings (plate XII), which was published in the *Bauwerk* journal (Sattler 1941). Sattler's article had some impact. In France, some of the drawings were published in the special issue on masonry in the journal *Techniques et architecture* (1943, n. 9–10). Eventually, Sattler's report was included in a book on vaults published in 1948 by Friedrich Hess, professor at the ETH in Zürich (Sattler 1948).

What is most surprising is that some of the illustrations and photos of Sattler (1941) were included in a Russian book on the construction of tile vaults published a few years later (Šerencis 1945). As much as can be judged by the illustrations and mathematical formulae – I cannot read Russian – the book describes in detail the construction of tile vaults and presents the construction of several buildings. However, the vaults were built with a kind of mobile centering apparently invented by a certain Tupolev (1944) (fig. 13 and plate XIII). The matter of course needs much more research. It is also remarkable that today a Russian architect, Anton Bulatetsky, inspired by Šerencis's book, is building wonderful tile vaults (www.nepole.ru).

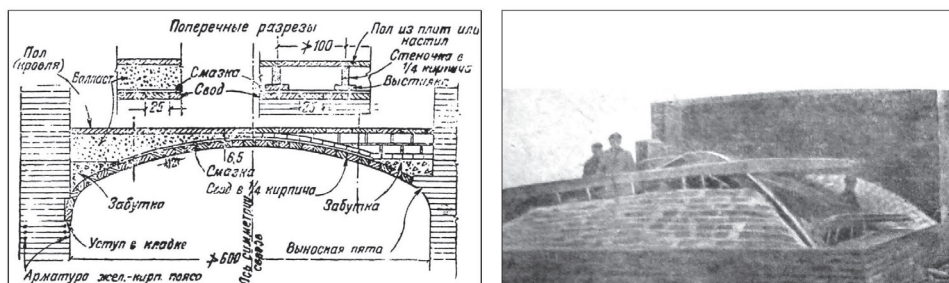


Figure 13. Tile vaults in Russia. Left: Construction of a barrel vault; cf. with plate XII, A by Sattler (1941); right: Vault under construction using movable centering (Šerencis 1945).

I consider it very probable that the Italians used tile vaults in reconstruction or new constructions after the war. However, I have found no written notice about this practice. As a curiosity, I would mention one episode of the employment of thin brick vaults, the so-called pitched brick vaults. The English architect R. E. Enthoven discussed the use of vaulting without centering in a lecture delivered in 1946, recounting his experiences as a Monuments and Fine Arts Officer in Italy (Enthoven 1946). In particular, he described the reconstruction of the vaults of the church of Santa Teresa in Turin, bombed in 1942–43. The photographs show the spectacular use of this construction technique without shoring by self-supporting arches, with the simple guidance of light forms (fig. 14).

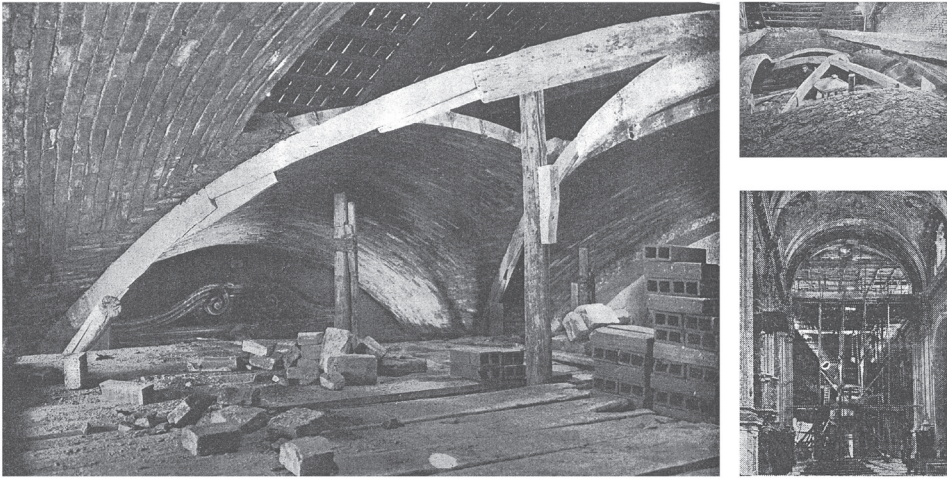


Figure 14. Reconstruction of the vaults of the church of St. Therese in Turin (Enthoven 1946).

TILE VAULTS IN GERMANY

Tile vaults were unknown in Germany until the publication of Espié's book. The construction of light fire-proof vaulted roofs caused a great deal of interest (Bode 2002, 302). A first German translation of Espié's book was published in 1760, followed by a second edition in 1774. From the end of the 18th century, when Gilly (1798) included this type of vault in his very popular handbook, the "*espiesche Gewölbe*" (Espié's vaults) are quoted, though without much detail, in many architectural and construction handbooks, for example in Breymann (1849), which ran to many editions up until the beginning of the 20th century. It appears that the most detailed study of their application was made by Steiner, who in 1803 published a book on the "Design of a new quite fire-resistant construction type with vaulted ceilings and roofs for the safety and welfare of human dwellings and other buildings" (plate XIV). The book became quite popular and some authors referred to tile vaults as "Steiner's vaults," "*Steiner'sche Gewölbe*." As the technique was completely alien to German builders there existed some distrust towards it. However, after Bode (2002, 340), Steiner succeeded in building a tile vault covering a room of 5.6 m by 4.7 m, with a rise of 0.4 m and a thickness of 6.5 cm, in the Weimar Palace around 1800. Perhaps tile vaults were not so popular in Germany because they had another method of building vaults without centering, the so-called pitched-brick vaults. The method, publicized by Lassaulx (1829), was traditional in the north of Germany, probably since the late Middle Ages. In the 19th century the

technique was described in detail in most of the German handbooks on architecture and construction. The use of these vaults in Germany has been studied in depth by David Wendland (2008).

The employment of tile vaults in Germany is an episode in the transmission of construction knowledge which, although it did not have the impact that Guastavino had in America, is of enormous interest for the history of construction and is also yet another proof of the versatility and ease of transmission of the vaulting technique. The episode is linked to two personalities: an architect and a builder, both of Bavarian origin. The architect is Carl Sattler who, although coming from a German family, was born in Florence where he spent his childhood and adolescence. The builder is Max Rank, a member of a family of Munich builders, but who had strong ties with Spain, as we shall see.

Carl Sattler (1877–1966)

Eberhard Carl (“Carlo”) Sattler was born in Florence to a wealthy family from Schonungen in northern Bavaria. His father was the painter Ernst Sattler, who after his marriage settled in Florence, where he met the famous sculptor Adolf von Hildebrand, and where his first children were born (most of this information about Sattler has been taken from Scherer [2007]). Later Ernst Sattler moved to Würzburg, Frankfurt am Main and finally Dresden, where he bought a house and set up his studio. A restless spirit, he travelled around Germany, and visited Paris and England. Ernst distrusted the bookish education of the time. The young Carlo attended the Gymnasium in Dresden between 1890 and 1894, but at the end of the last year his father took him out of the Gymnasium to put him to work in the summer months as a bricklayer on a building site, work which the young Carlo enjoyed, as recorded in his diary. In the autumn of 1894 he entered the Technische Hochschule in Dresden to study architecture. On completing his studies Carlo returned to Florence to work in the workshop of the famous sculptor Adolf von Hildebrand (he eventually married one of his daughters), with whom he continued to collaborate even after founding his own studio. We could therefore say that his youth was that of a well-to-do, cultured architect, in close contact, through his father and his master Hildebrand, with various artistic circles. He was interested not only in architecture but also in music, literature and all manifestations of the culture of his time.

From 1906 onwards Sattler lived in Munich, but continued to make trips to Italy and used vaults in some of his Italian projects, such as the Villa Apuana in Forte dei Marmi, Florence. He worked there intermittently until 1913. In this region of Italy, the construction of vaulted ceilings was still a popular tradition. Sattler was a curious man with a passion for

the art of vaulting. In the course of one of his projects in Forte dei Marmi he met a master mason, Francesco Tognocchi, who gave him a demonstration that had a great impact on him, as he records in his diaries (Scherer 2007, 59):

His [Francesco Tognocchi] light vaults, which I got to know in more detail later, were elegant and held excellently and made with only a string as the only tool. When he was to vault a hall of 6.50×13.0 m with lunettes and cloister vaulting according to my exact drawings and I asked for reinforcing arches and tie rods, he said: “None of that is necessary; let me prove it and don’t come until 5 o’clock this afternoon.” This did not seem quite understandable to me, but there was a great surprise: he had vaulted half the room and had loaded the fresh vault in the most unfavourable place with all kinds of sacks full of sand and cement and was standing on it with his whole staff to greet me by a kind of African dance! A German structural engineer or building official’s hair would have stood on end!

In 1926 Sattler was appointed director of the Kunstgewerbeschule (School of Applied Arts), though he was forced to resign in 1933 because of his wife’s non-Aryan origin, and in 1939 he was compulsorily retired. Although he did not belong to the Nazi party, he was able to continue to work occasionally and to use some of the school’s facilities. Around 1935 he wrote a short essay on the advantages of vaults (transcribed in Scherer 2007, 360–370). In it, he begins by lamenting the virtual disappearance of vaults in architecture, for, he says, “the art of vault construction is the culmination of masonry construction.” He also considers that the shortage of steel will serve to revive vault construction. He mentions explicitly tile vaulting as practised in Tuscany, praising its great slenderness, strength and economy. He stresses also the speed of execution, given that vaults are built without false-work, using simple guides. He also points out that all types of vaults can be built: barrel vaults, cloister corner vaults, domes, staircases. Crucially, he was already thinking of importing the technique to Germany and about the problems involved in this transfer, including the need to educate German masons and to adapt building regulations. Finally, he explains what the construction process of a multi-storey house with this type of vaulting would be like.

As we have seen, some notice of Sattler’s interest and knowledge about tile vaulting must have somehow reached the Nazi authorities, who sent him to Italy in 1940 to study the technique. After the trip, Sattler attempted without success to convince the authorities to apply the tile-vaulting technique for economical reasons. Eventually, in 1947 he received the commission for reconstructing the Landeszentralbank in Munich, destroyed during the war. The building company chosen for the task was Brüder Rank, whose director was also familiar with tile vaulting.

Max Rank (1900–75)

The Rank company was originally founded in 1862 as a carpentry workshop by Josef Rank (1832–1909), and was re-founded by his sons, Josef, Franz and Ludwig, as a building company under the name of Brüder Rank, Rank Brothers in 1899. In the early years, the company was engaged in the construction of houses for the upper middle class as well as apartment buildings. At the beginning of the 20th century, they specialised in the new building material: reinforced concrete. The first concrete buildings established the recognition and success of the company. Also at the beginning of the century, a relationship with Spain was established. In 1911 they received an order to build a gas and electricity plant in Seville, on which they worked from 1911 to 1915. When they began to work in Spain, the Germans admired the Spanish masons for their ability to build vaults without falsework, very light vaults built very quickly and economically. One of the Rank brothers, Ludwig, then decided to found a subsidiary company in Spain. The company ceased operations during the First World War. After the war Ludwig Rank settled in Spain. His nephew Max, Josef's son, came to help him and worked in Seville from 1926 to 1929. After another brief stay in 1932 due to the death of his uncle, Max returned to Germany as manager of the company. After the war, Germany was in a process of reconstruction marked by a shortage of iron and wood. It was then, it seems, that Max Rank considered the possibility of using vaulted ceilings. In the Basiner Archive, belonging to the former manager of the company, there are several books that show this interest: those by Moya (1947) and Bassegoda (1947), as well as the book published in 1961 by Cassinello (1961) on brick vaults, which has a couple of chapters dedicated to vaults.

The Landeszentralbank

Max Rank had the opportunity to apply his knowledge of Spanish tile vaults when his company was contracted for the rebuilding of the Landeszentralbank in Munich, after the project designed by Carl Sattler (plates XV–XVIII). Both men cooperated fruitfully during the four years of the work, between 1948 and 1951. This collaboration is the key work for understanding the spread of tile vaults in Germany. Rank knew the Spanish technique, whereas Sattler was familiar with the Italian one. Thus, a mixture of Italian and Spanish techniques was produced. Italian vaults, as we have seen, are normally of a single shell, with some spaced reinforcements by doubling with flat bricks at intervals, while Spanish tile vaults always have at least two layers of flat bricks. The rule that apparently was followed in the Central Bank was to make the vaults of a single layer when they were only self-supporting; that is to say, they formed a space but the main structure of ploughed concrete was independent. On the roofs,

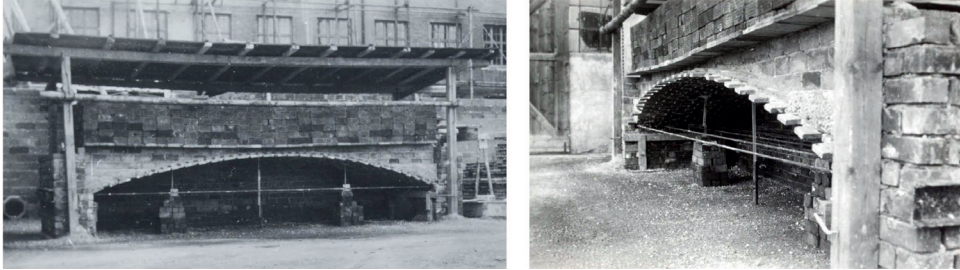


Figure 15. Load test on a tile vault made by the Rank Company (Archive Basiner).

however, the vaults had two layers. Probably the city of Munich asked for some guarantees about the robustness of this foreign technique. Then in July 1948 the Rank Company undertook a structural test on a vault of 4 m span and 0.40 m rise. The vault withstood a maximum load of 960 kg per square metre with minimal settlements (fig. 15).

The Landeszentralbank was used by Sattler and Rank as a testing ground for various kinds of vaults, including groin vaults, barrel vaults with lunettes in the casino, and continuous barrel vaults with skylights in the roof. It should be mentioned that a practice that Sattler had rarely seen in Italy was also followed, which was to leave the brickwork exposed in the soffit. This practice was made a trademark by the Spanish architect Guastavino in his vaults built in America, but Guastavino's work does not seem to have had the slightest influence on the work of Sattler and Rank.

Tile Vaults in Munich

After the enormous success of the Landeszentralbank, which was described in Bassegoda's 1952 book, Sattler did very little work and finally retired. Max Rank, however, continued to use vaults in reconstruction work with notable success. For example, the traditional Mathäuser brewery was rebuilt and the groin vaults with oculi were constructed in 1956 (plate XIX). The vault of the Reiche Kapelle in the Residenz was also rebuilt in 1957 using the same system (plate XX). The church of St. Anna, formerly the Kloster-und Damenstiftskirche St. Anna, was destroyed by a bombing in 1944; between 1957 and 1958 its dome was rebuilt with great economy using a simple rotating form (plate XXI).

The great dome of the former Augustinian church, Agustinerkirche, now the Jagdmuseum, with a span of 9 m and a length of 55 m, was completely destroyed. Figure 16 shows the reconstruction of the vault and the current state where the plaster and decoration hide the brickwork (see also plate XXII).



Figure 16. Old church of S. Agustin, now the German Hunting and Fishing Museum, in Munich. Left: Main vault reconstructed with tile vaults just after completion (Rank 1962), see also plate XXII; right: The vault in its finished state (Basiner et al. 2012, 366).

The company also received commissions for the use of brick vaults in modern buildings. Plate XXIII shows the dome of the Holy Cross Church, Heilig Kreuz-Kirche, Traunstein, built in 1952. Plate XXIV shows the cylindrical vaults of the Paul Gerhardt Protestant Church, Evangelische Paul Gerhardt-Kirche, in Munich Laim, 1953–56. Finally, in the 1960s, the company ceased to build vaults, probably due to a change of mentality and the massive influence of reinforced concrete.

CONCLUSIONS

The technique of tile vaulting has demonstrated, over a long history of almost 1,000 years, an enormous potential for technological transfer. Tile vaults originated in the Mediterranean area and spread from Spain to Iran; at the end of 19th century they “jumped” to America with the Guastavinos. After the Second World War they were used in several European countries (Spain, France, Italy and Germany) in the context of a great scarcity of materials during the Great War. In the 1960s they were also used in Cuba, producing the amazing spaces of the School of Arts in La Habana (Loomis 1999).

The history of the construction of these modest and economical vaults has many lessons for building practice. First, it demonstrates that it is possible to make durable and robust vaulted structures, with an enormous economy of means. Second, this economy in no way limits architectural and engineering expression. And thirdly, this technique can be learned very quickly by any mason coming from another building culture. Moreover, it can be learned within months by any unskilled labourer.

However, there is a “philosophy” behind this modest technique. It is a matter of building vaults without centering, with speed and safety. This implies certain limitations of forms and means. A vault “tiled” on top of a continuous formwork is not a tile vault; it is a concrete vault. Once it is decided to build with formwork all the advantages of tile vaulting disappear. This is not only a matter of money: tile vaulting implies simple means, but also simple geometrical forms that can be “materialised” in the air by the masons. This imposes some restrictions but, some say, there is no art without laws. Here the laws are the laws of equilibrium in compression. Recent experiences with “form-finding” structures, which lead to complicated surfaces with Gaussian negative curvatures, seem to me to be outside the tradition (López et al. 2016). However, the process of reviving tile vaulting in the 21st century is just beginning. We must learn as the old master builders learnt, by the critical evaluation of “experiments,” and any new built structure is an experiment.

NOTES

1. “Les 72000 mètres carrés de plancher que nous devons construire, sont formés d’une succession de voûtes plates de 4 mètres de portée reposant sur des poutres flexibles.”
2. “Cette triste nécessité a permis à M. Heurteau, plâtrier-entrepreneur, de donner une preuve nouvelle de l’intelligence et du goût qu’il déploie dans sa profession. Ses voûtes à nervures et ses colonnettes, en briques fabriquées ad hoc, ne laissent rien à désirer sous le rapport de la solidité de la construction et de la perfection du travail.”
3. “le but de cette étude est de montrer que l’art de la maçonnerie n’est pas sur son déclin, mais à l’aurore d’un renouveau gigantesque.”
4. “il semble que la maçonnerie de pierre et de briques soit devenue mineure, ou infirme; on ne la conçoit plus sans corset médical. Il faut réagir. La structure, ce n’est pas exclusivement des linteaux et des poteux; c’est aussi des arcs et des murs.”
5. “Ces carrelages courbes font voûte et sont d’une extraordinaire solidité. En Italie et surtout à Rome, on construit de nos jours des plafonds courbes à l’aide de briques ainsi posées à plat.”

REFERENCES

- Abraham, Pol. 1934. *Viollet-le-Duc et le rationalisme médiéval*. Paris: Vicent, Fréal et Cie.
- . 1941. “Les aires planes portantes en maçonnerie.” *L’architecture française* 2 (13): 37–43.
- . 1942. “Avant-projet d’une usine de mécanique. Étude faite en Décembre 1939, en vue du transfert en province d’une usine de la Région Parisienne.” *L’architecture française* 2 (26): 25–34.
- . 1943. “Défense et illustration de la maçonnerie.” *Techniques et architecture* 3 (9–10): 229–238.
- . 1945. “L’évolution des procédés traditionnels de construction dans la maçonnerie de bâtiment,” lecture presented on May 26, 1944. Institut technique du bâtiment et des travaux publics, Paris, Centre d’études supérieures, circulaire série A, no. 6, 15 May 1945.
- Alejos, Manuel. 1942. “Reconstrucción de la catedral de Vich.” *Reconstrucción* 3 (22): 129–138.
- Amico, Giovanni Biagio. 1726. *L’architetto pratico: in cui con facilita si danno le regole per apprendere l’architettura civile*. Palermo: Nella stamperia di Gio. Battista Aiccardo.
- Bails, Benito. 1783. *De la Architectura Civil. (Elementos de Matemática. Tom. IX. Parte I.)* Madrid: Joachin Ibarra.
- Bares, Maria Mercedes, and Marco Rosario Nobile. 2012. “Volte ‘tabicadas’ nelle grande isole del Mediterraneo: Sicilia e Sardegna (XV–XVIII secolo).” In *Construyendo Bóvedas Tabicadas*, edited by A. Zaragoza et al, 119–131. Valencia: Universitat Politècnica de València.
- Bannister, Turpin C. 1968. “The Roussillon Vault: The Apotheosis of a ‘Folk’ Construction.” *Journal of the Society of Architectural Historians* 27: 163–75.
- Basiner, Paul, et al. 2012. *150 Jahre Rank. Fünf Generationen, 1862–2012*. Munich: Koethen.
- Basiner, Paul, Katrin Basiner, and Franz Wimmer. 2012. “Das Flachziegel-Gewölbe von Rank im Wiederaufbau der Nachkriegszeit.” In *150 Jahre Rank. Fünf Generationen, 1862–2012* edited by Paul Basiner et al., 356–373. Munich: Koethen.
- Bassegoda, Buenaventura. 1947. *La bóveda catalana*. Barcelona: s.e.
- . 1952. *Bóvedas tabicadas*. Madrid: Consejo Superior de Investigaciones Científicas. Patronato Juan de la Cierva de Investigación Técnica. (2nd ed. 1956; reprint 1975).

- Blondel, Jacques-François. 1771–77. *Cours d'Architecture, ou Traité de la décoration, distribution et construction des bâtiments... continué par M. Patte*. Paris: Chez la Veuve Desaint.
- Bode, Udo Franz-Wilhelm. 2002. "Mauer- und Gewölbekonstruktionen in der Mark Brandenburg während des 18. und frühen 19. Jahrhunderts." PhD diss., Technischen Universität Carolo-Wilhelmina zu Braunschweig.
- Bosch Reitg, Ignacio. 1949. "La bóveda vaída tabicada." *Revista Nacional de Arquitectura* 9 (89): 185–199.
- Breymann, Gustav Adolf. 1849. *Allgemeine Bau-Constructions-Lehre, mit besonderer Beziehung auf das Hochbauwesen. Constructionen in Stein*. Stuttgart: Hoffmann'sche Verlags-Buchhandlung.
- Bühler, Dirk. 2017. "La constructora 'Hermanos Rank' y la introducción de las bóvedas tabicadas en Munich a partir de 1947." In *Actas del Décimo Congreso Nacional y Segundo Congreso Internacional Hispano-Americano de Historia de la Construcción*, vol. 1, edited by S. Huerta, P. Fuentes and I. J. Gil Crespo, 215–224. Madrid: Instituto Juan de Herrera.
- Bühler, Dirk, and Santiago Huerta. 2020. "Ziegelgewölbe. Die lange Wanderung einer Konstruktionstechnik vom Mittelmeer nach Deutschland." In *Mauerwerk Kalender 2020: Bauen im Bestand Befestigungen Lehmmauerwerk*, 45. Jahrgang, 141–163. Berlin: Ernst & Sohn.
- Buzonnière. 1862. "Rapport sur les restaurations opérées dans les églises d'Orléans." *Bulletins de la Société Archéologique de l'Orléanais* 3: 202–222.
- Cabrera i Masferrer, A., M. Sala i Marguï y C. Jordi i Collell. 2005. *Les voltes de quatre punts. Estudi constructiu i estructural de les cases barates*. Girona: Col·legi d'Aparelladors i Arquitectes Tècnics de Girona, Universitat de Girona, Diputació de Girona.
- Cassinello, Fernando. 1961. *Bóvedas de ladrillo*. Madrid: Insituto Técnico de la Construcción y del Cemento. (2nd ed. 1964, 3rd. ed. 1969).
- Cavalieri San-Bertolo, Nicola. 1826–27. *Istituzioni di architettura statica e idraulica*. 2 vols. Bologna: Cardinali e Frulli.
- Choisy, Auguste. 1899. *Histoire de l'Architecture*. Paris: G. Béranger.
- Churtichaga, Josá María G. de. 2001. "Aspectos constructivos de la reconstrucción de Villanueva de la Cañada. El uso de los sistemas de bóvedas tabicadas y su perspectiva histórica." In *Villanueva de la Cañada, historia de una reconstrucción*, edited by C. Quadra-Salcedo, 59–89. Villanueva de la Cañada: Ayuntamiento de Villanueva de la Cañada.
- Cisternino, Alfredo. 2005. "Viollet-le-Duc et le rationalisme médiéval. Le regard d'un moderne. À propos de Pol Abraham." *Livraisons d'histoire de l'architecture* 9 (1): 53–71.

- Collins, George R. 1968. "The Transfer of Thin Masonry Vaulting from Spain to America." *Journal of the Society of Architectural Historians* 27: 176–201.
- Collura, Concetta. 2008. "Pol Abraham: construire sans désamparer." In *Pol Abraham architect 1891-1966*, edited by F. Miraygou, 196–199. Paris: Centre Pompidou.
- Cunha, Arthur da. 1900. "Les voûtes sans cintres." In *Les travaux de l'exposition de 1900*, 70–74. Paris: Masson.
- Delemontey, Yvan. 2020. "Industrialiser le bâtiment sous l'Occupation: un 'repli' prolifique, entre restrictions et substitutions." In *Architecture et urbanisme dans la France de Vichy*, edited by Jean-Louis Cohen, 137–150. Paris: College de France.
- Delhumeau, Gwenaél. 2008. "Pol Abraham: construire sans désamparer." In *Pol Abraham architect 1891-1966*, edited by F. Miraygou, 28–37. Paris: Centre Pompidou.
- D' Olivier. 1837. "Relatif à la construction des voûtes en briques posées de plat, suivi du recherches expérimentales sur la poussée de ces sortes des voûtes." *Annales des Ponts et Chaussées, 1er série*: 292–309.
- Espié, Félix-François, Comte d'. 1754. *Manière de rendre toutes sortes d'édifices incombustibles, ou Traité sur la construction des voûtes, faites avec des briques et du plâtre, dites voûtes plates, et d'un toit de brique, sans charpente, appelé comble briqueté*. Paris: Duchesne. (2nd ed. 1776).
- . 1756. *The Manner of Securing all Sorts of Buildings from Fire, or A Treatise upon the Construction of Arches made with Bricks and Plaister, called Flat-Arches, And of a Roof without Timber called Bricked-Roof . . . Translated by L. Dutens*. London: H. Piers and Partner.
- . 1760. *Abhandlung von unverbrennlichen Gebäuden und der Art und Weise, wie solche vermittelt platter Gewölbe und Dächer aus Ziegelsteinen und Gips, ohne Zimmerarbeit, zu bauen sind*. Frankfurt: Michael Macklot. (2nd ed. 1774).
- Fatta, Giovanni, Tiziana Campisi, and Calogero Vinci. 2016. "Tiled Vaults in Western Sicily: Originality and Continuity of an Imported Building Technique." *Construction History* 31: 107–132.
- Favier, Jean. 1937. "Exposition Internationale Paris 1937. Pavillon de la céramique et de la verrerie." *La Construction Moderne* 53 (6): 105–109.
- Fontaine, M. H. 1865. "Expériences faites sur la stabilité des voûtes en briques." *Nouvelles Annales de la Construction* 11 : 149–159, lám. 45.
- Fornes y Gurrea, Manuel. 1841. *Observaciones sobre la práctica del arte de edificar*. Valencia: Imprenta de Cabrerizo.
- . 1846. *Álbum de proyectos originales de arquitectura acompañados de lecciones explicativas*. Madrid: I. Boix Editor.
- Frattaruolo, Maria Rosa. 2000. "Las bóvedas 'in folio': tradición y continuidad." In *Actas del Tercer Congreso Nacional de Historia de la Construcción*, vol. 1, edited

- by A. Graciani et al., 327–334. Madrid: Instituto Juan de Herrera, SEDHC, U. Sevilla, Junta Andalucía, COAAT Granada, CEHOPU.
- Fuentes, Paula, and Ine Wouters. 2019. “La construcción de bóvedas ligeras en Bélgica 1830–1940.” In *Actas del Undécimo Congreso Nacional de Historia de la Construcción*, vol. 1, edited by S. Huerta et al., 437–448. Madrid: Instituto Juan de Herrera.
- Fuentes, Paula. 2021a. “The construction of tile vaults in Belgium 1900–1940: Contractors and Patents.” *Construction History Journal* 36 (1): 97–121.
- . 2021b. “Auguste Fabre and the construction of tile vaults in France. The Industrialization of a Traditional Technique.” *International Journal of Architectural Heritage*. <https://doi.org/10.1080/15583058.2021.1894504>.
- . 2021c. “The Congo Museum in Tervuren: The Birth of Tile Vaulting in Belgium.” In *Brick Vaults and Beyond: The Transformation of a Historical Structural System*, edited by P. Fuentes and I. Wouters, 167–229. Madrid: Vrije Universiteit Brussel; Instituto Juan de Herrera.
- Fuentes, Paula, and Rosa Ana Guerra-Pestonit. 2021. “Tile Vaults in Belgium in the 1930s: The Churches of Léonard Homez.” In *Brick Vaults and Beyond: The Transformation of a Historical Structural System*, edited by P. Fuentes and I. Wouters, 231–287. Madrid: Vrije Universiteit Brussel; Instituto Juan de Herrera.
- Ger y Lobe, Florencio. 1898. *Manual de construcción civil*. Badajoz: Imprenta de José Santamaría.
- Gilly, David. 1798. *Handbuch der Land-Bau-Kunst, vorzüglich in Rücksicht auf die Construction der Wohn- und Wirthschafts-Gebäude für angehende Cameral-Baumeister und Oeconomen*. Berlin: Friedrich Vieweg dem älteren.
- Gil Crespo, Ignacio Javier. 2021. “Tile Vaults in the Architecture of Luis Moya (and Partners): Historical Context and Technical Elements.” In *Brick Vaults and Beyond: The Transformation of a Historical Structural System*, edited by P. Fuentes and I. Wouters, 433–485. Madrid: Vrije Universiteit Brussel; Instituto Juan de Herrera.
- Hermant, André. Pol. 1942. “Chantier d’application de la maçonnerie d’Andressy. Internat pour 150 élèves, P. Abraham et M. Brun, Architectes.” *L’architecture française* 2 (15): 25–34.
- Heyman, Jacques. 1995. *The Stone Skeleton. Structural Engineering of Masonry Architecture*. Cambridge: Cambridge University Press.
- Huerta, Santiago, ed. 2001. *Las bóvedas de Guastavino in America*. Madrid: Instituto Juan de Herrera, CEHOPU.
- . 2003. “The mechanics of timber vaults: a historical outline.” In *Essays in the History of Mechanics*, edited by A. Becchi et al., 89–133. Basel: Birkhäuser.

- . 2006. “La construcción tabicada y la teoría cohesiva de Rafael Guastavino.” In *Escritos sobre la construcción cohesiva*, by Rafael Guastavino, edited by S. Huerta, xv–lxii. Madrid: Instituto Juan de Herra, CEHOPU.
 - . 2009. “The Debate about the Structural Behaviour of Gothic Vaults: From Viollet-le-Duc to Heyman.” In *Proceedings of the Third International Congress on Construction History, Cottbus, 20–24 May 2009*, vol. 2, edited by K. E. Kurrer, W. Lorenz and V. Wetz, 837–844. Cottbus: Chair of Construction History and Historical Preservation of the Brandenburg University of Technology.
 - . 2017. “Las bóvedas tabicadas en Alemania: la larga migración de una técnica constructiva.” In *Actas del Décimo Congreso Nacional y Segundo Congreso Internacional Hispano-Americano de Historia de la Construcción*, edited by S. Huerta, P. Fuentes and I. J. Gil Crespo, 759–772. Madrid: Instituto Juan de Herrera.
- Huerta, Santiago, Gema López Manzanares, and Esther Redondo. 2001. “Bibliografía seleccionada y comentada sobre Guastavino y la construcción tabicada.” In: *Las bóvedas de Guastavino en América*, edited by S. Huerta, 373–393. Madrid: Instituto Juan de Herrera, CEHOPU.
- Kirchacker, P. 1936. “Les voûtes portantes (Système breveté S.G.D.G. FABRE).” *Algérie catholique. Revue mensuelle illustrée* 1(11): 26–27.
- Lassaulx, J. C. 1829. Beschreibung des Verfahrens bei anfertigung leichter Gewölbe über Kirchen und ähnlichen Räumen. *Journal für die Baukunst* 1: 317–330.
- Lasteyrie, Charles de. 1820. *Collection de machines, instruments, ustensiles, constructions, appareils, etc., employés dans l'économie rurale, domestique et industrielle*. Paris: Arthis Bertrand.
- Loomis, John A. 1999. *Revolution of Forms: Cuba's Forgotten Art Schools*. New York: Princeton Architectural Press.
- López López, David, Tom Van Mele, and Philippe Block. 2016. “Tile vaulting in the 21st century.” *Informes de la Construcción* 68 (544): e162. <http://dx.doi.org/10.3989/ic.15.169.m15>.
- Miraygou, Frédéric, ed. 2008. *Pol Abraham architect 1891–1966*. Paris: Centre Pompidou.
- Moreno Moreno, M. Pura. 2020. “Cerámica y arquitectura. Palais de la céramique de Sèvres, de la verrerie et de la monnaie en L'Exposition internationale de Paris, 1937.” *Cuaderno de notas* 21: 51–69.
- Moya Blanco, Luis. 1947. *Bóvedas tabicadas*. Madrid: Ministerio de la Gobernación. Dirección General de Arquitectura.
- Ochsendorf, John. 2010. *Guastavino Vaulting: The Art of Structural Tile*. New York: Princeton Architectural Press.

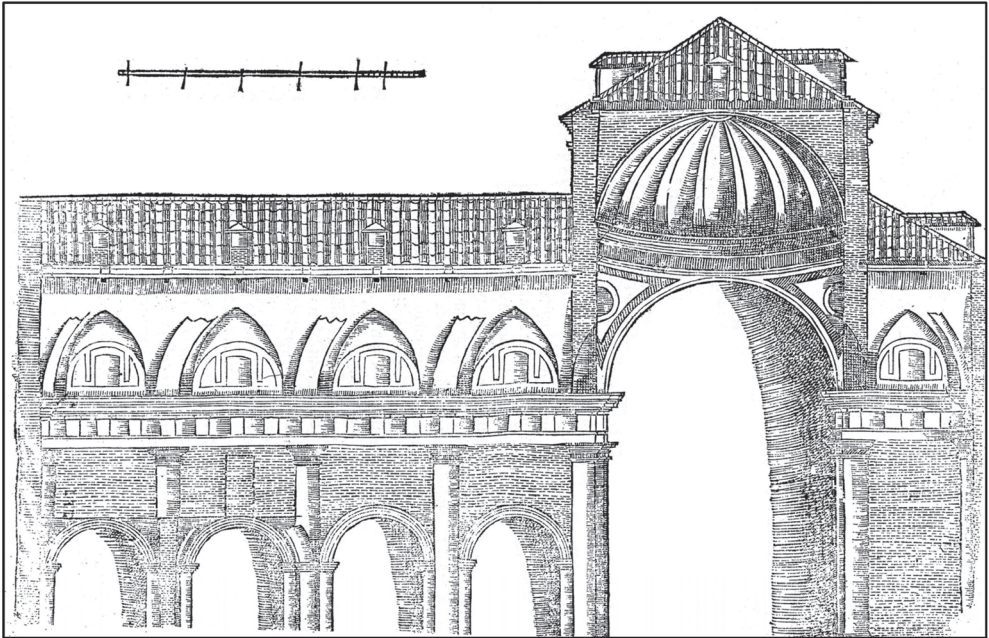
- . 2021. “Guastavino Vault Design and the Role of American Engineers.” In *Brick Vaults and Beyond: The Transformation of a Historical Structural System*, edited by P. Fuentes and I. Wouters, 127–165. Madrid: Vrije Universiteit Brussel; Instituto Juan de Herrera.
- Ragot, Gilles. 1987. *Robert Camelot: Architecte des Palais de la Céramique et du C.N.I.T.* Brussels: Mardaga.
- Rank, M. 1962. *Hundert Jahre Rank. 1862–1962*. Munich: Baugesellschaft Gebrüder Rank.
- Redondo Martínez, Esther. 2013. “La bóveda tabicada en España en el siglo XIX. La transformación de un sistema constructivo.” PhD diss., Universidad Politécnica de Madrid.
- . 2021. “Testing on Tile Vaults: The Need to Validate the System.” In *Brick Vaults and Beyond: The Transformation of a Historical Structural System*, edited by P. Fuentes and I. Wouters, 97–126. Madrid: Vrije Universiteit Brussel; Instituto Juan de Herrera.
- Rondelet, Jean-Baptiste. 1802–10. *Traité théorique et pratique de l’art de bâtir*. Paris: Chez l’auteur (and subsequent editions).
- Saint-Félix, Armand-Joseph-Marie de 1820. *Architecture rurale, théorique et pratique, à l’usage des propriétaires et des ouvriers de la campagne*. Toulouse: Jean-Mathieu Douladoure.
- San Nicolás, Fray Lorenzo de. (1639) 1989. *Arte y uso de arquitectura. Primera parte*. Madrid: s.i. Facs. Madrid: Albatros Ediciones.
- Sattler, Carl. 1941. “Leichtgewölbe in Italien.” *Das Bauwerk* 1: 1–5, 37–41.
- . 1948. “Leichtgewölbebau.” In *Steinverbände und Gewölbebau aus künstlichen Steinen*, edited by Friedrich Hess, 87–94. Munich: Verlag Hermann Rinn.
- Scherer, Benedikt Maria. 2007. *Der Architekt Carl Sattler. Leben und Werk (1877–1966)*. Munich: Martin Meidenbauer.
- Šerencis, A. A. 1945. *Tonkie kirpičnye svody* [Thin brick vaults]. Moscow: Izdatel’stvo Akademii Architektury SSSR. [In Russian].
- Sotomayor, Joaquín de. 1776. *Modo de hacer incombustibles los edificios sin aumentar el coste de la construcción. Extractado del que escribió en francés el Conde de Espié*. Madrid: Oficina de Pantaleón Aznar.
- Steiner, Johann Friedrich Rudolph. 1803. *Entwurf einer neuen durchaus feuervesten Bauart mit gewölbten Decken und Dachungen zur Sicherheit und Wohlfahrt der menschlichen Wohnungen und anderer Gebäude. Zweiter Theil*. Weimar: Hoffmannischen Buchhandlung.
- Techniques et architecture*. 1943. “Voûtes légères en maçonnerie.” 3 (9–10): 273.

- Truñó, Ángel. 2004. *Construcción de bóvedas tabicadas*, edited by S. Huerta and E. Redondo. Madrid: Instituto Juan de Herrera.
- Tupolev, M. S. 1944. “Tonkie somknuto-vsparušennye kirpičnye svody dla stroitel'stva maloproletnykh zdaniy” [Thin brick vaults for low-rise buildings]. *Stroitel'naja promyšlennost'*, no. 5–6: 16–17. [In Russian].
- Wendland, David. 2008. *Lassaulx und der Gewölbebau mit selbsttragenden Mauerschichten: Neumittelalterliche Architektur 1825–1848*. Petersberg: Michael Imhof Verlag.
- Wild. 1856. “Über die toscanischen Gewölbe, ‘Volterrane’ genannt.” *Zeitschrift für Bauwesen* 6: 182–183.
- Zaragoza, Arturo, Rafael Soler, and Rafael Marín, eds. 2012. *Construyendo Bóvedas Tabicadas. Actas del Simposio Internacional sobre Bóvedas Tabicadas*. Valencia: Universitat Politècnica de València.

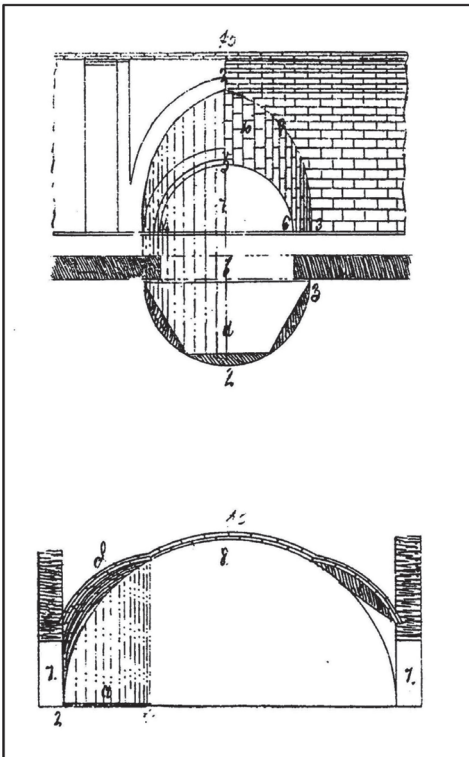
Plates

Plate I

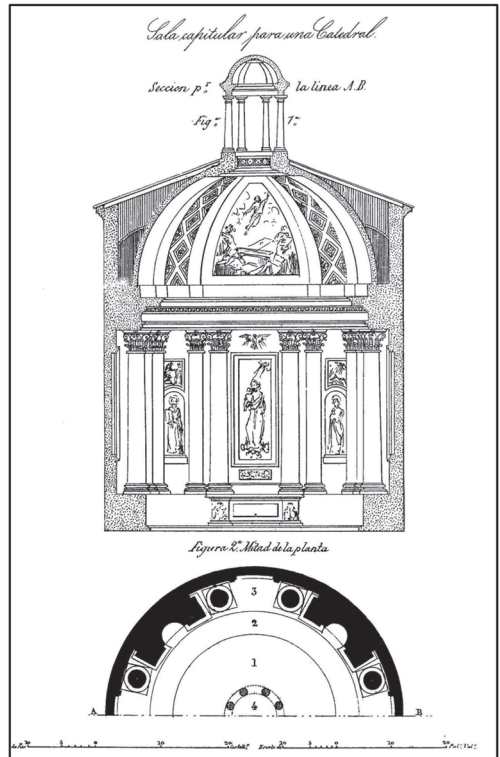
- A. Church with tile vaults. Note the thickness of the dome (San Nicolás [1639] 1989).
- B. Semicircular barrel tile vault with lunettes with double curvature (Fornés 1841, Plate VI).
- C. Chapter house with tile dome; a hidden tile vault provides a counterthrust to the dome (Fornés 1846, Plate XXVI).



A



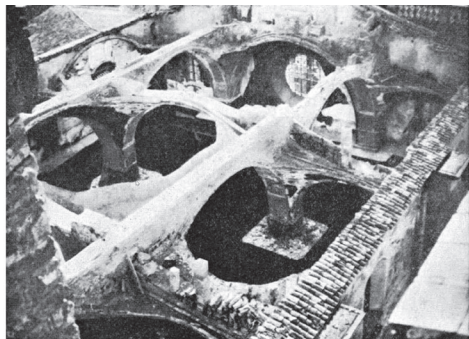
B



C

Plate II

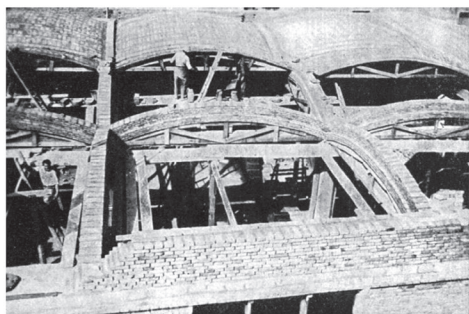
- A. Collapsed vaults of the cathedral of Vich (Alejos 1942, 131).
- B. Rebuilding with tile vaults finished in 1940 (Alejos 1942, 131).
- C. Building of sail tile vaults for a factory in Igualada, Barcelona (Bassegoda 1947).
- D. Great stair tile vault tested after completion. Bassegoda (1952, 44) comments: “The architect, the quantity surveyor, the contractor and the foreman defy, undaunted, a unique somatic load test. Of course, at the time, there was no family burden.”
- E–G. Construction of the dome and windows in the church of San Miguel de los Santos, Barcelona, 1950s (Truñó 2004).



A



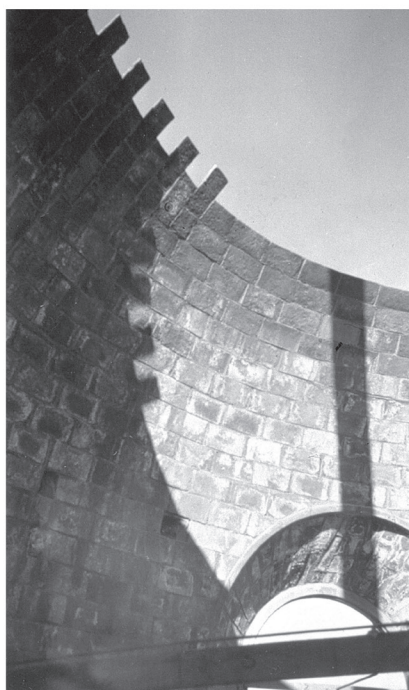
B



C



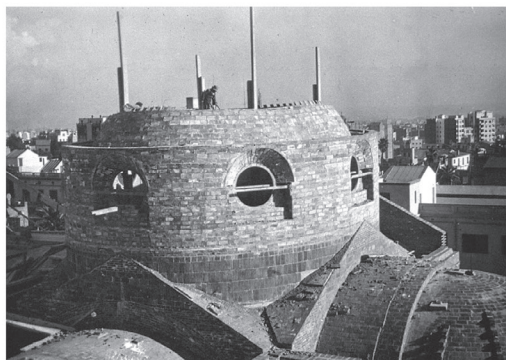
D



F



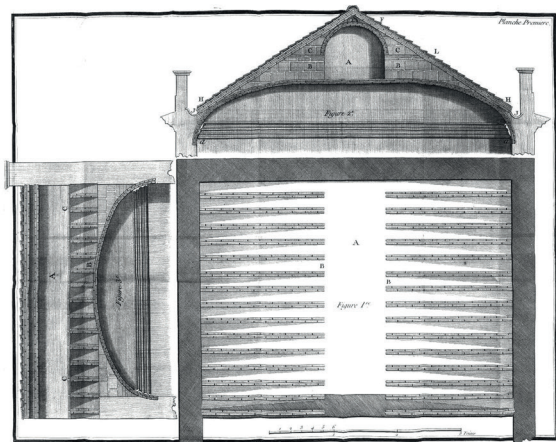
E



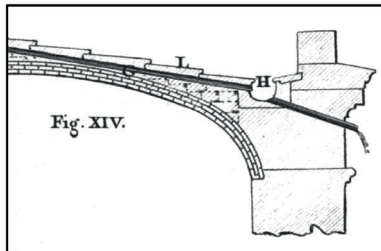
G

Plate III

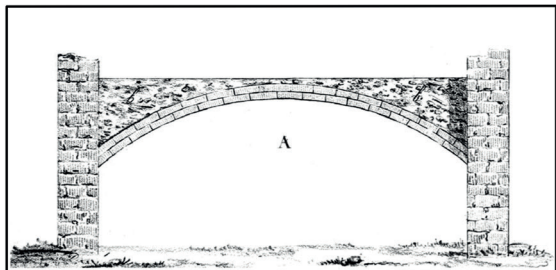
- A. Fire-proof tile roof, *comble briqueté* (Espie 1754, Pl. I).
- B. Terrace supported by a three-layer surbased tile vault (Blondel-Patte 1777, Pl. 99).
- C. Tile vault roof in the Palais-Bourbon (Blondel-Patte 1777, Pl. 104).
- D. Use of tile vaults in rural construction (Lasteyrie 1820, Pl. III).
- E. Section through the Hôtel des Affaires Étrangères et de la Marine, built by Jean-Baptiste Berthier in 1762. The tile vaults, which support the library and archives, have a height of 1/10 of the span (Abraham 1941, 37).



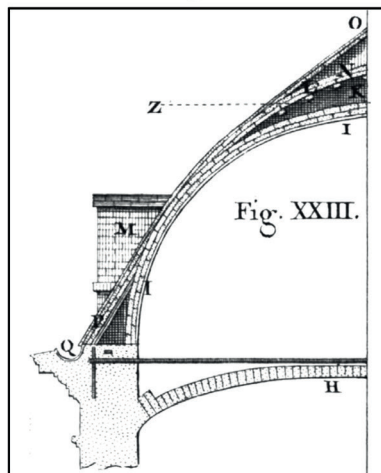
A



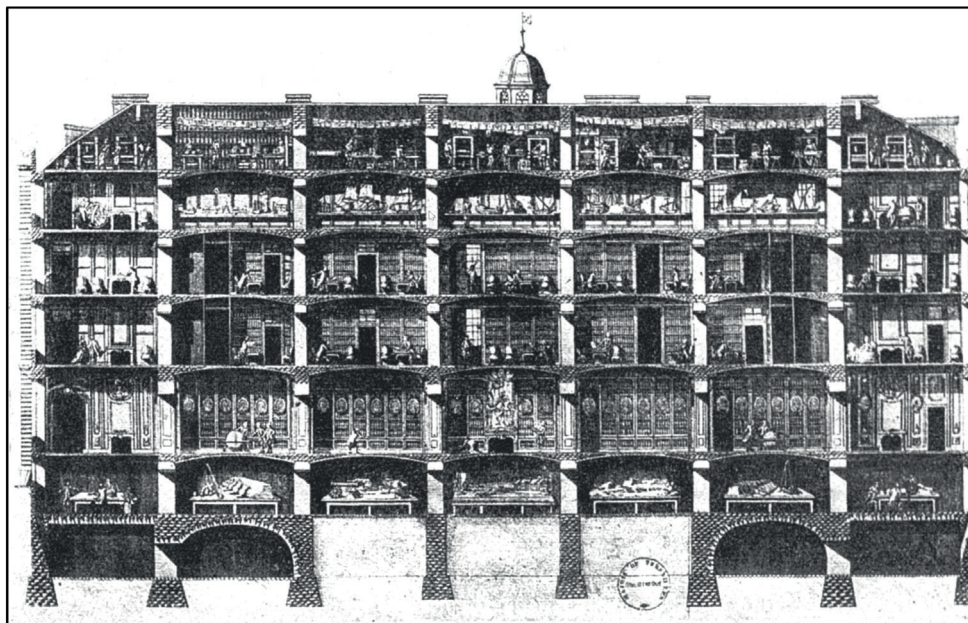
B



D



C



E

Plate IV

A. Parish church of Saint-Germain. Tile vaults rebuilt after the *procédé Heurteau* in 1873 (Conseil général des Yvelines).

B. Advertisement of tile vaults of the Bocquereau system (*Annuaire du bâtiment et des travaux publics*, 1893).

C. Construction of the webs of cross vault employing tile vaults (Cunha 1900, 73).



A

VOUTES ÉCONOMIQUES EN BRIQUES
PAS D'OSSATURE, NI FER, NI BOIS, NI CINTRE

BOCQUEREAU & C^{ie}
ANCIENNE MAISON POTHIN
Successeur de E. HEURTEAU (d'Orléans)
PARIS — 6 bis, rue des Écoles, 6 bis — PARIS

LÉGÈRETÉ — SOLIDITÉ

A. Doubleaux. — B. Nervures. — C. Formerets.

Voutes, nervures, arcs tout en brique creuse, enduits en plâtre avec joints creusés et remplis en plâtre teinté, simulant appareil pierre ou moellon.

Des certificats de plusieurs éminents architectes de Paris et de la Province sont un sûr garant de la valeur de mon système.

Le Palais du Trocadéro construit en 1878, plus de 500 églises à Paris et dans toute la France fournissent des spécimens de l'exécution et de la solidité de ce travail spécial; à Versailles, voutes de 12 mètres d'ouverture.

Economie : pas de cintre, pas d'ossature; de là, des voutes exécutées dans le vide de toutes formes, elliptiques, sphériques, annulaires, gauches, de tous diamètres et la brique de 0,045 d'épaisseur suffit.

Restauration d'anciens édifices, ravalements et joints sur vieux murs, vieilles voutes, assises, colonnes, chapiteaux, etc., pierre ou moellon.

Plâtrerie en général, moulages, stucs, etc.

Plâtre réduit à l'état d'épave ayant la dureté de la roche, de toutes couleurs, imitant la laïence et en ayant la dureté et le brillant, surchauffés en même mortier imitant l'importance quel dessin, gravure, mosaïque, etc. Soubassements, bases, socles, marches, dallages et revêtements de murs.

B



C

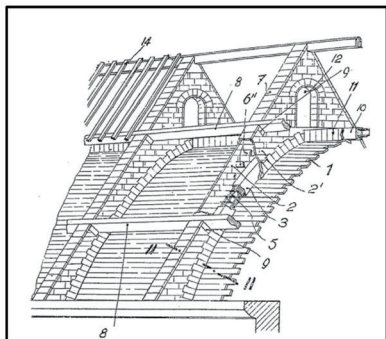
Plate V

A. Fabre's patent of 1935 for tile-vaulted roofs (Fuentes 2021b, fig. 7).

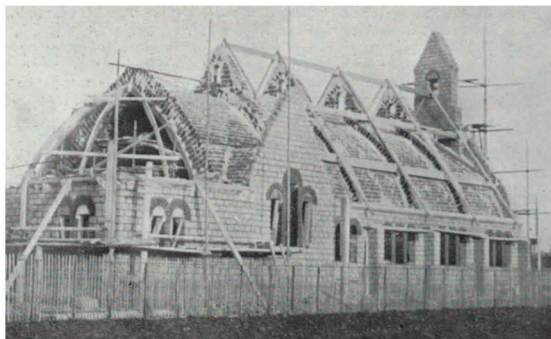
B. Roof of the Chapelle de Taverny, vaulted following Fabre's patent (Kirchacker 1936, 26).

C–F. Great dome and vaults of the Palais de la Céramique in the Exposition Internationale of 1937 in Paris built by Fabre (Ragot 1987).

G. The great dome under construction (*L'architecture d'aujourd'hui* 1937, nov., p. 16).



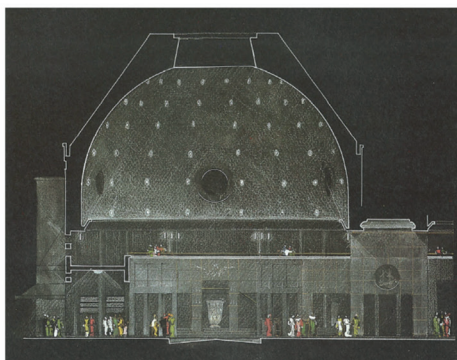
A



B



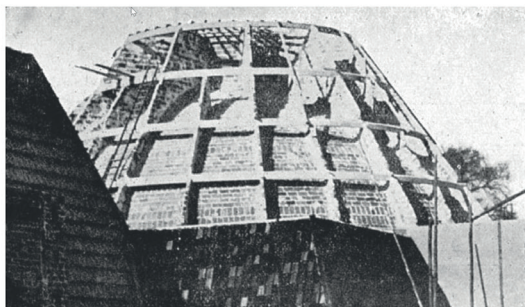
C



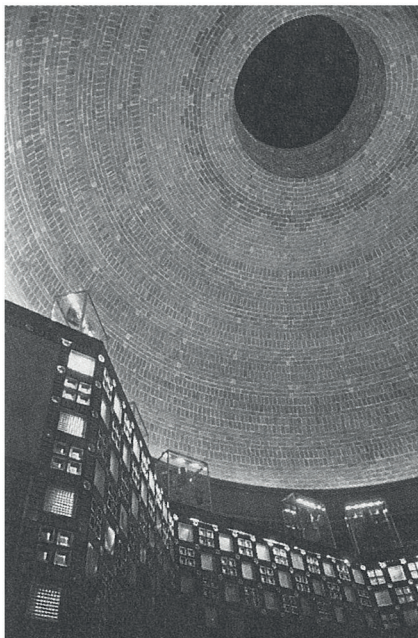
D



E



G



F

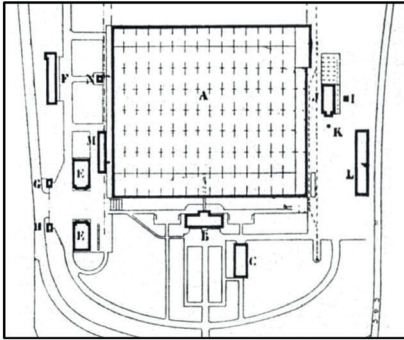
Plate VI. Avant-project by Pol Abraham for the transfer to the provinces of a factory in the Paris region in 1939 (Abraham 1942).

A. General plan.

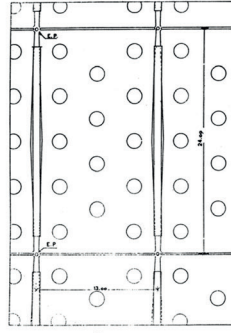
B. Module.

C. Perspective view of the system of tile vaults, covering circa 35,000 m².

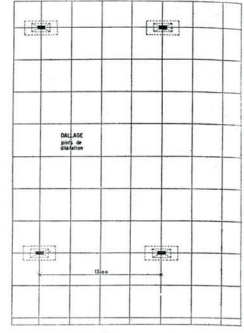
D. Detail of the double tile vault shell.



A

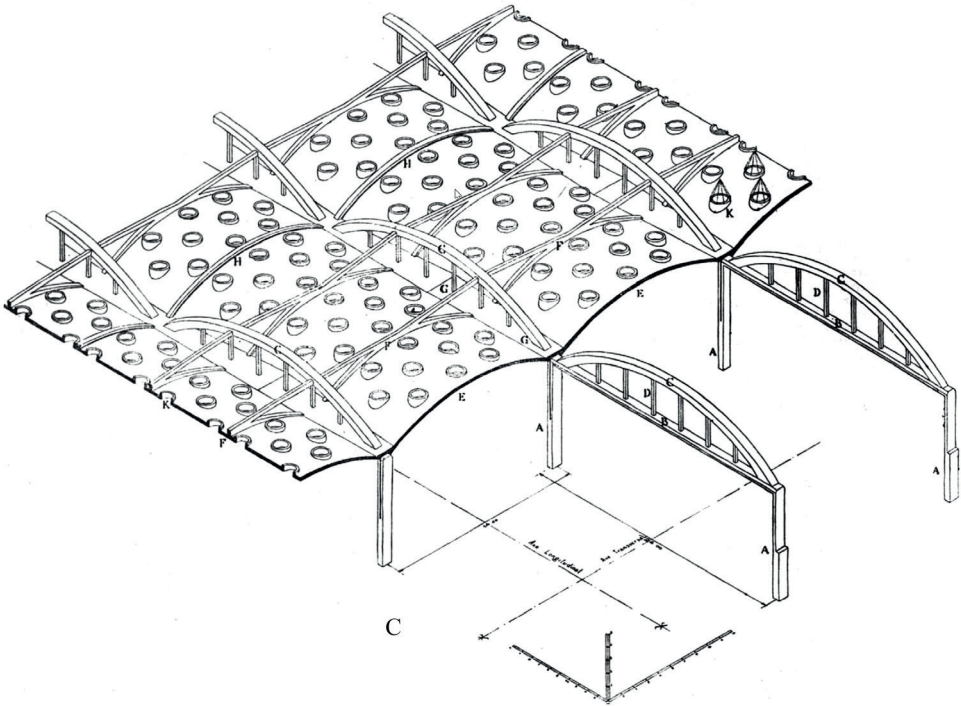


PLAN DES TOITURES.

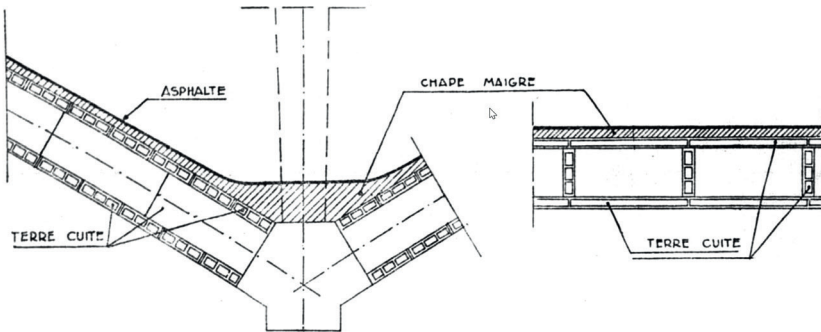


PLAN AU SOL.

B



C

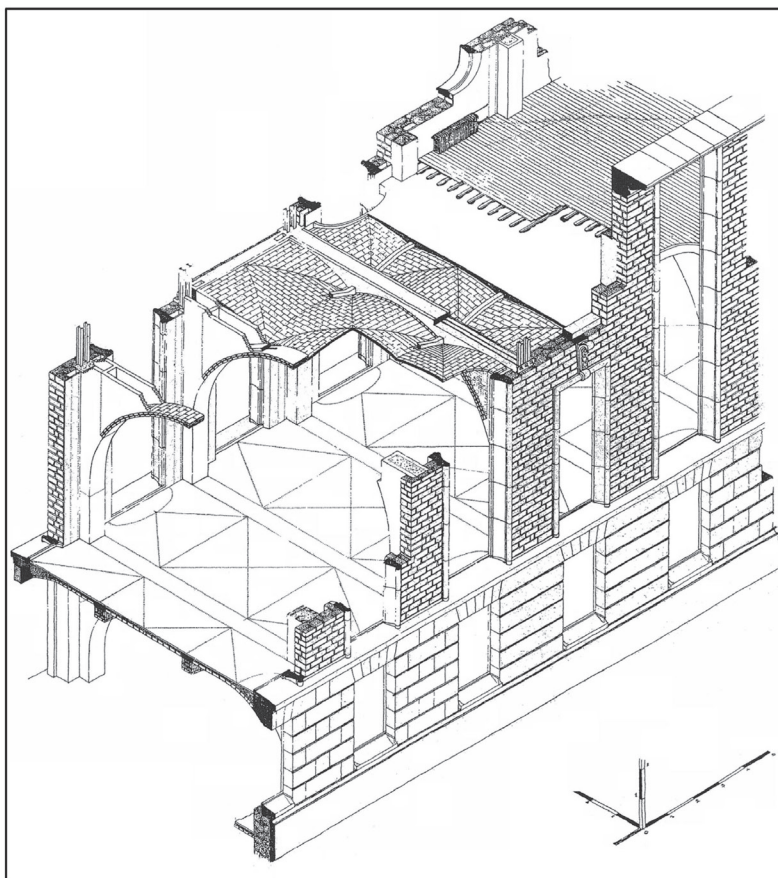


D

Plate VII. Musée de la Maçonnerie in Rue Saint-Lambert, Paris (Abraham 1941).
A. Construction of the grillage of reinforced concrete beams to support the tile cloister vaults.
B. Perspective view of the vaults showing their relation with the reinforced concrete skeleton.



A



B

Plate VIII. Musée de la Maçonnerie in Rue Saint-Lambert, Paris. Photos of the vault construction published in the special issue on *Maçonnerie* (Masonry) published by the journal *Techniques et architecture* in 1943 (3 (9–10), 228).

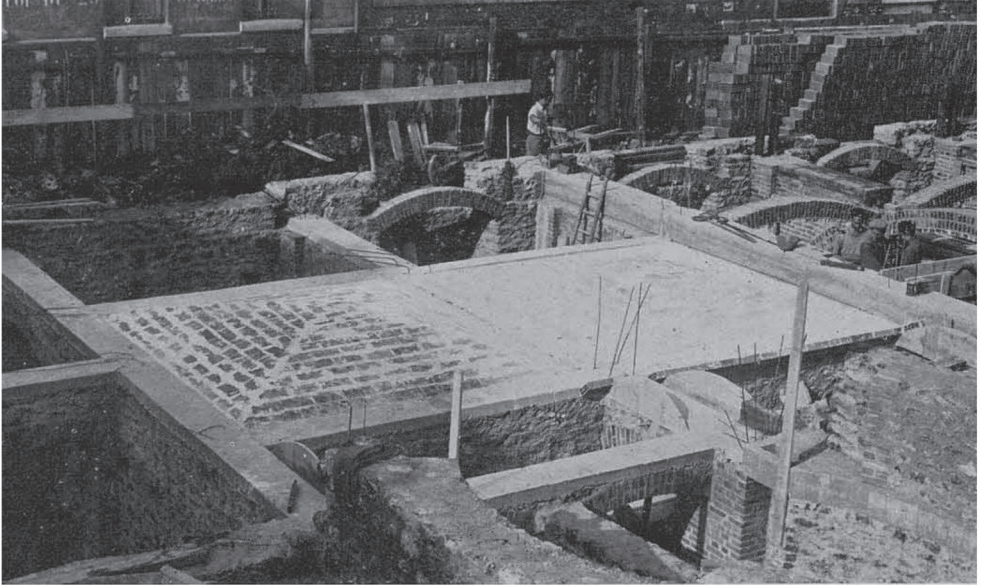


Plate IX. Project of School for 150 Apprentices in Andressy designed by Pol Abraham exclusively using tile vaults for floors and roofs. The project was not built (Hermant 1942).

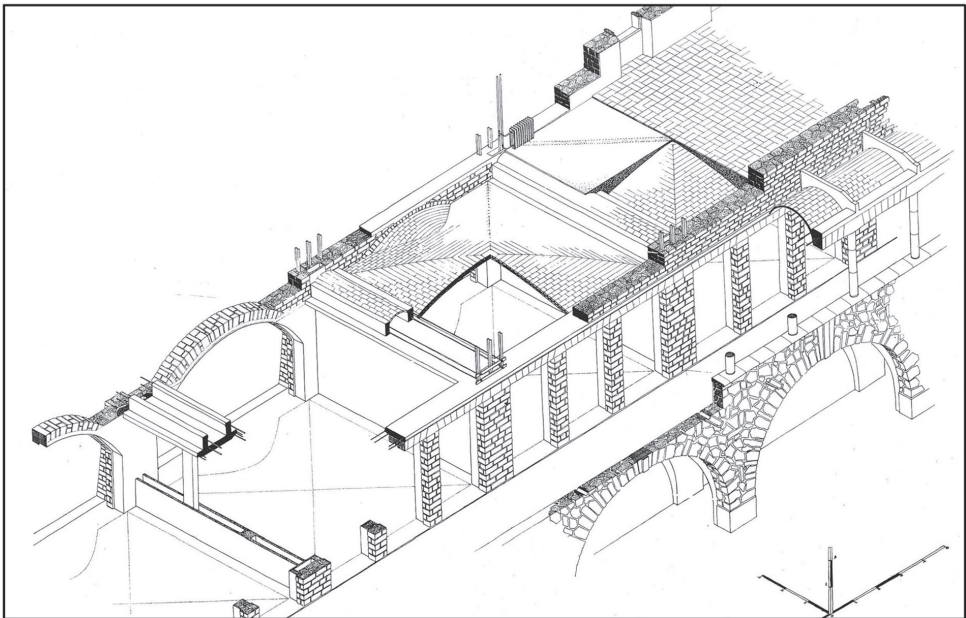
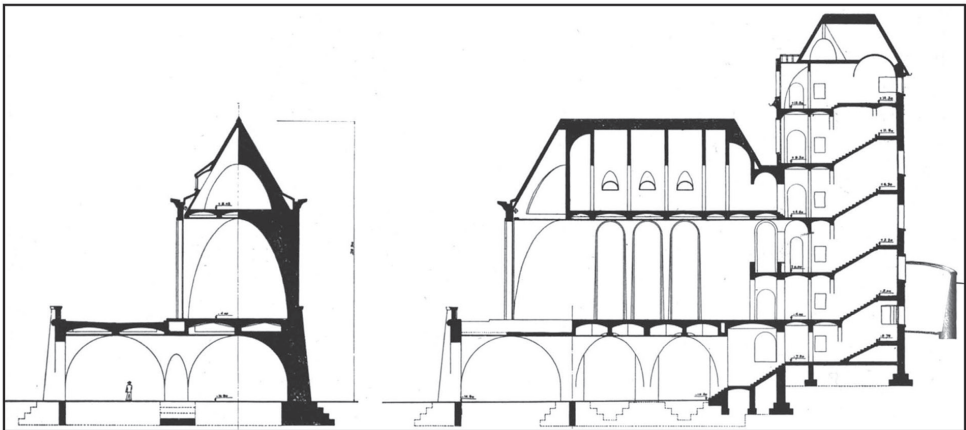
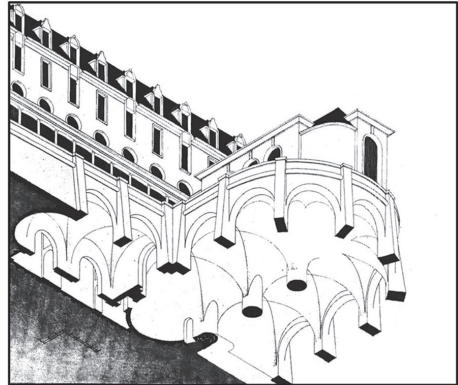
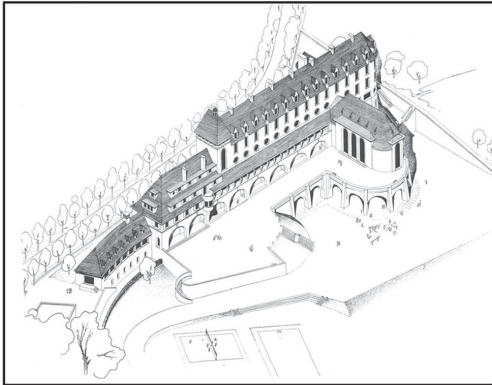


Plate X. Photos made by Sattler (1941) of the construction of a series of tile vaults by an Italian master.

A. Building of a cloister vault with lunettes.

B. Springing of a sail vault.

C. Springing of a cross vault.



A



B



C

Plate XI

A–C. Stair tile vaults built in the Institute of Agriculture for Italian Africa in Florence, photographed by Sattler in 1941. The type is the so-called *scala alla romana* (Roman vault), which was widely diffused in Italy.

D. Analytical drawing of its construction (Frattaruolo 2000)

E–F. Load tests on the stairs (Sattler 1941).



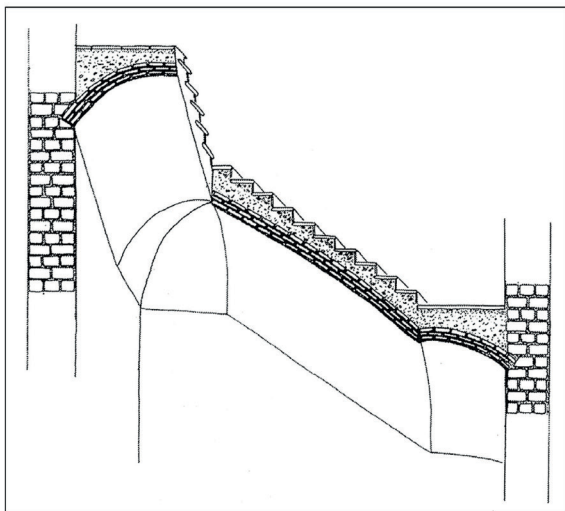
A



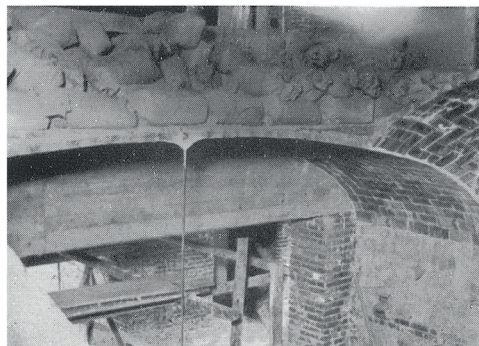
B



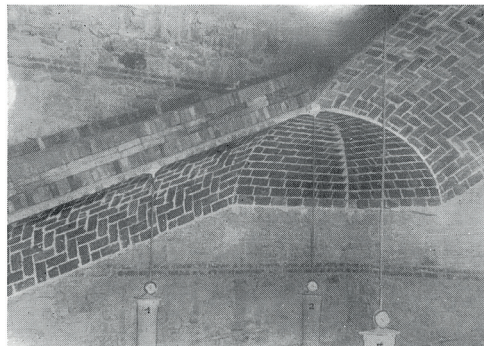
C



D



E



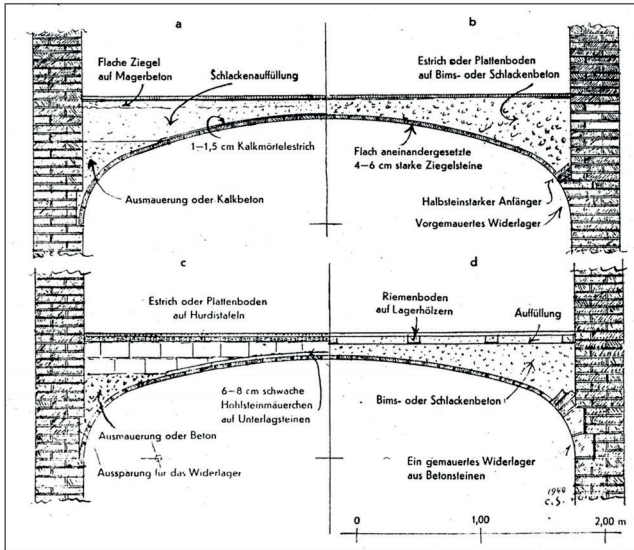
F

Plate XII. Details of Italian tile vaulting.

A. Possible solutions for a barrel vault supporting a floor (Sattler 1941).

B. Cloister vault supporting a floor. First little walls are built and then small surbased vaults span from wall to wall. Eventually, a filling would make the horizontal floor (Sattler 1948).

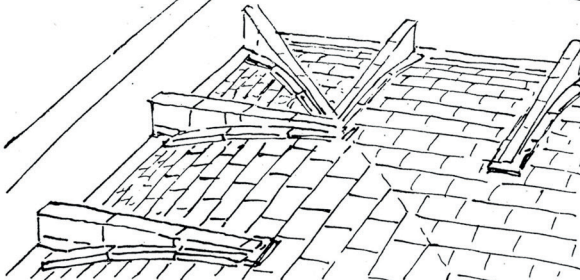
C. Different solutions of brick bond, with parallel joins or herringbone bond, *spina pesce* (Sattler 1948).



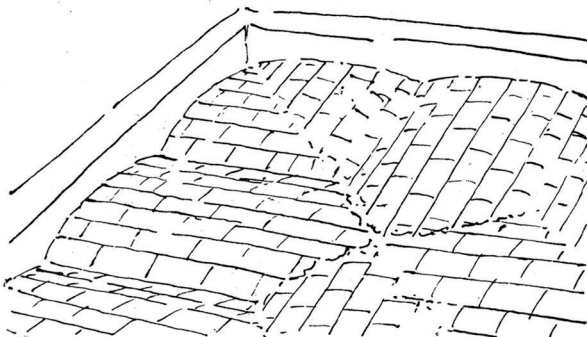
A



Aufmauerung eines Klostergewölbes



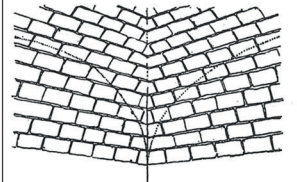
a) Langlochhohlsteinmüerchen hochkant auf Unterlagsziegelschicht
3,5/12/25 cm



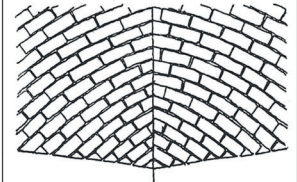
b) Flachgewölbe darüber zur Aufnahme der Auffüllung

B

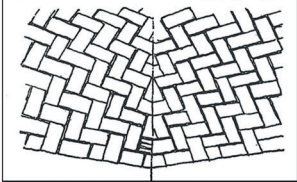
KLOFVERBAND SCHICHTEN PARALLEL ZUR GEW. AXISE



KLOFVERBAND MIT SCHRÄGESTELLTEN SCHICHTEN



SCHWALBENSCHWANZVERBAND SCHICHTEN PARALLEL ZUR GEW. AXISE



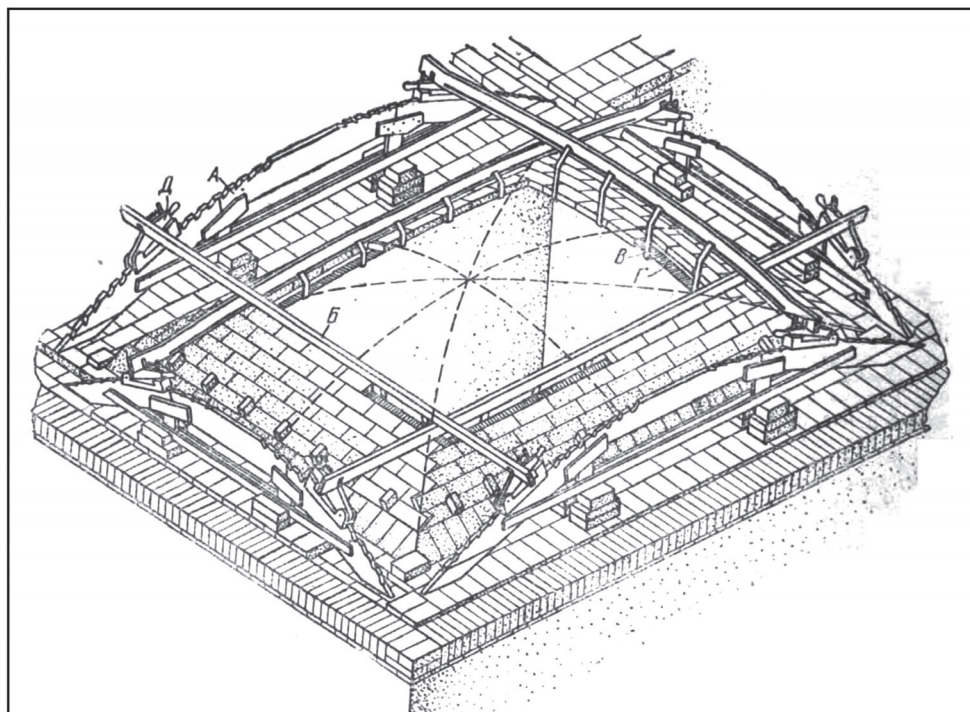
C

Plate XIII. Construction of tile vaults in the 1940s in Russia.

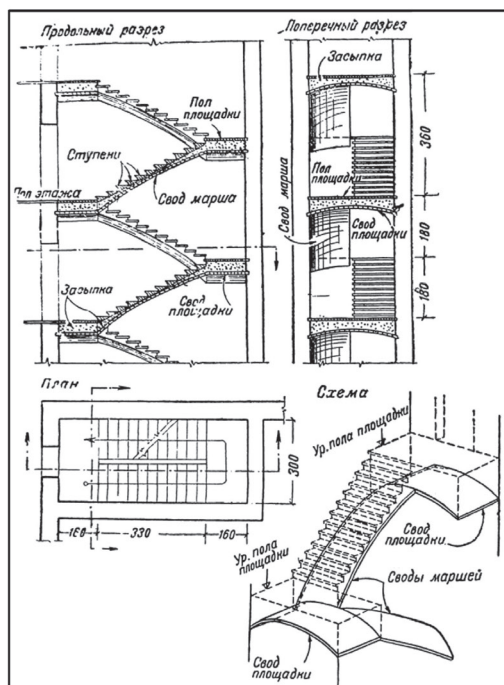
A. Detail of the construction of a translation vault with the centering device to complete the elementary tile arches (Tupolev 1944).

B. Tile vault stairs in a multi-storey building (Šerencis 1945).

C. Cross and barrel tile vaults (Šerencis 1945).



А



В

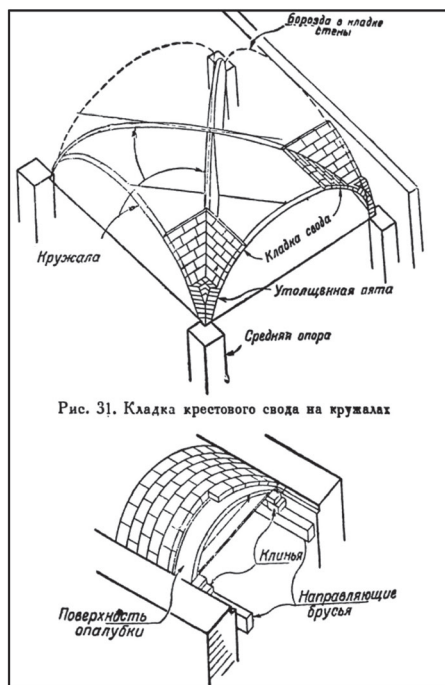


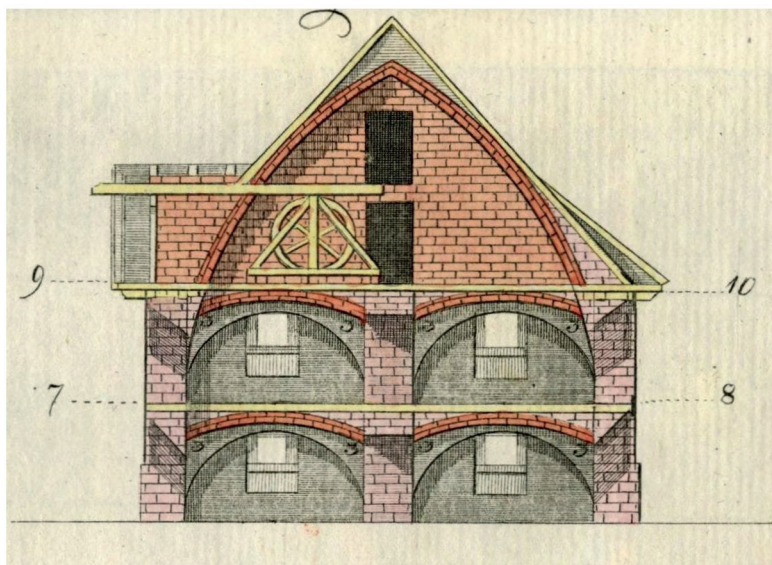
Рис. 31. Кладка крестового свода на кружалах

С

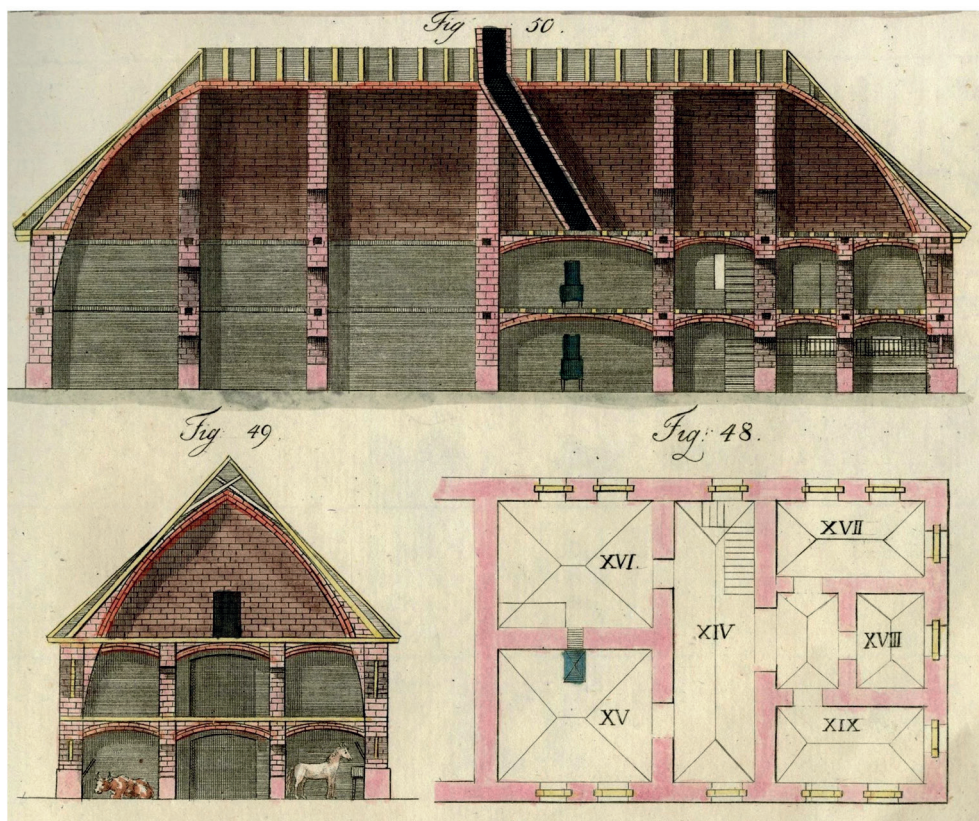
Plate XIV. Design of buildings entirely made of masonry, using tile vaults instead of wood for the floors and roofs.

A. Steiner 1803, Tab. XI.

B. Steiner 1803, Tab. XII.

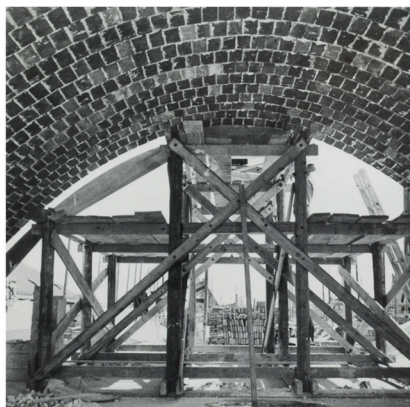
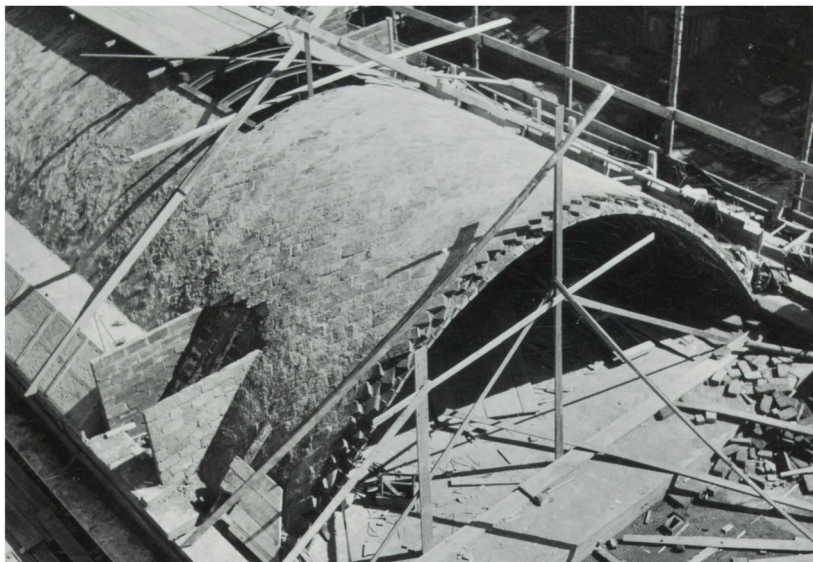


A



B





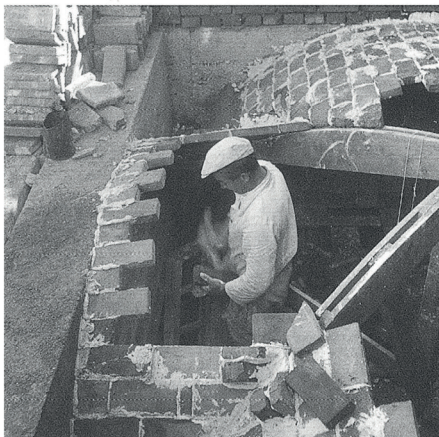
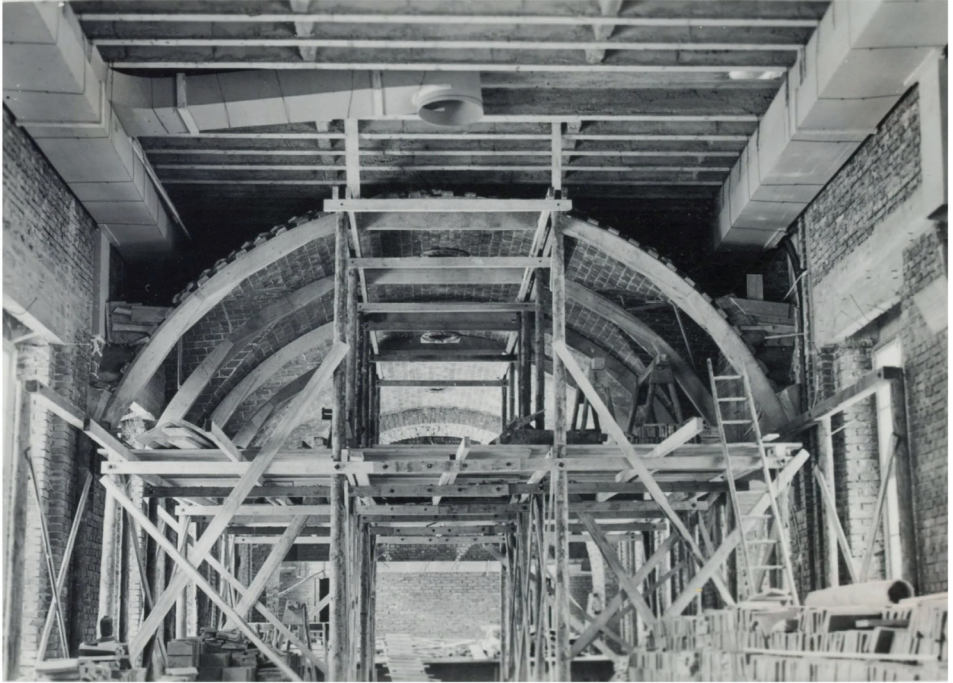


Plate XVIII. Casino in the Landeszentralbank in Munich. Barrel vault with lunettes of one shell of bricks (Archive Basiner).

A. Under construction.

B. Finished state.



A



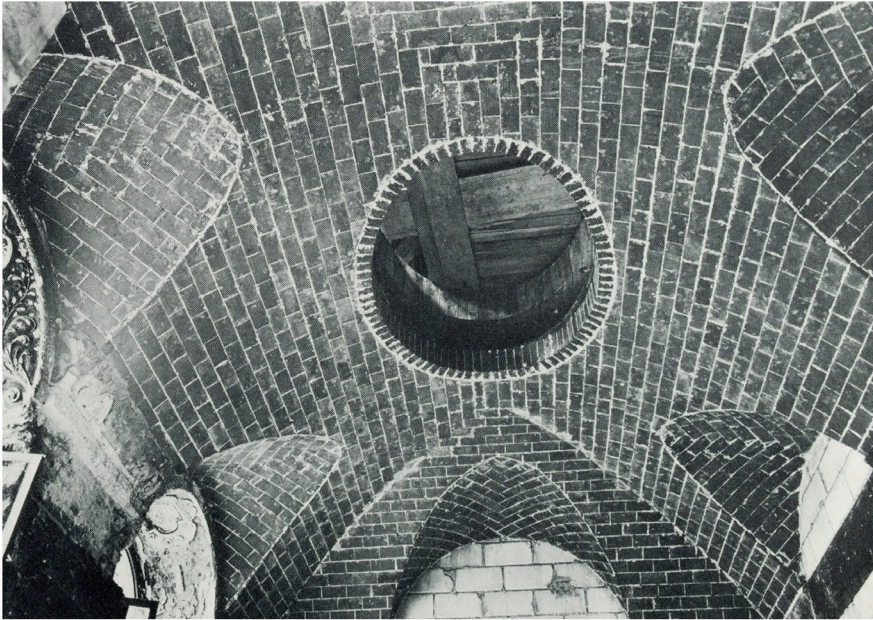
B



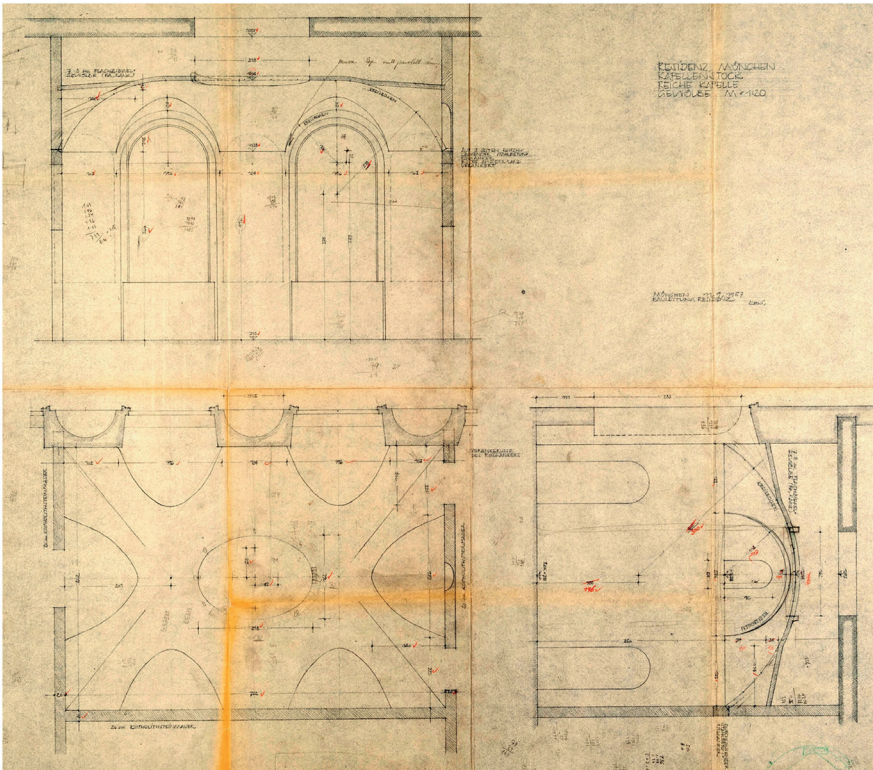
Plate XX. Rebuilding of the vault of the Reiche Kapelle in the Residenz, Munich, 1957 (Archive Basiner).

A. The finished baroque vaulting before adding the decoration.

B. Blueprint for the vault construction.

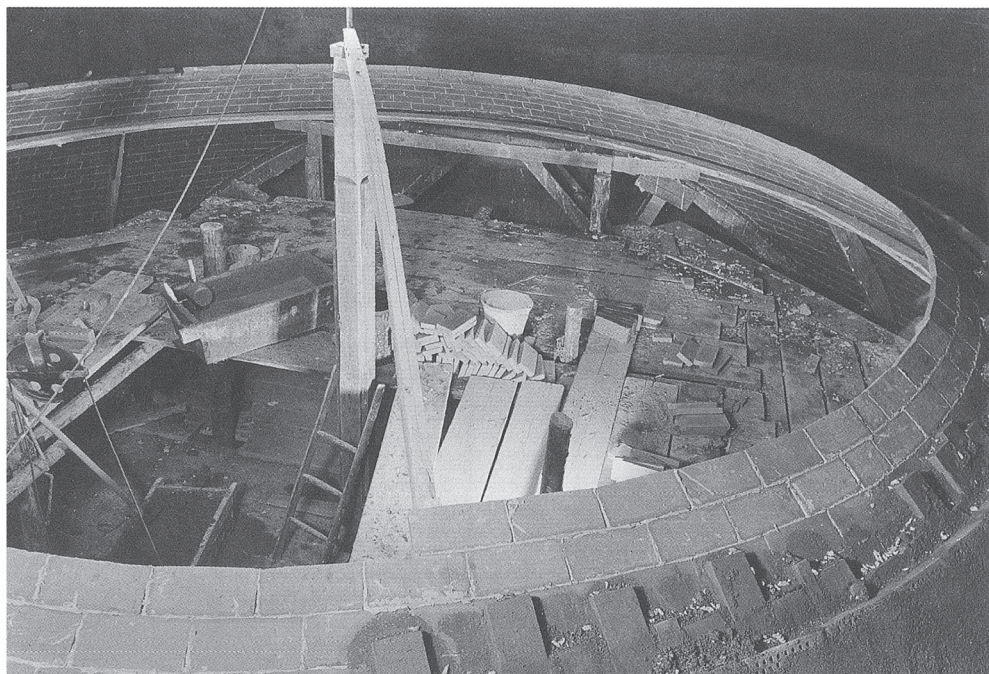


A



B

Plate XXI. Church of St. Anna, Ehemalige Kloster-und Damenstiftskirche St. Anna. Reconstruction of the dome, between 1957 and 1958, using a simple rotating guide (Basiner et al. 2012, 364).



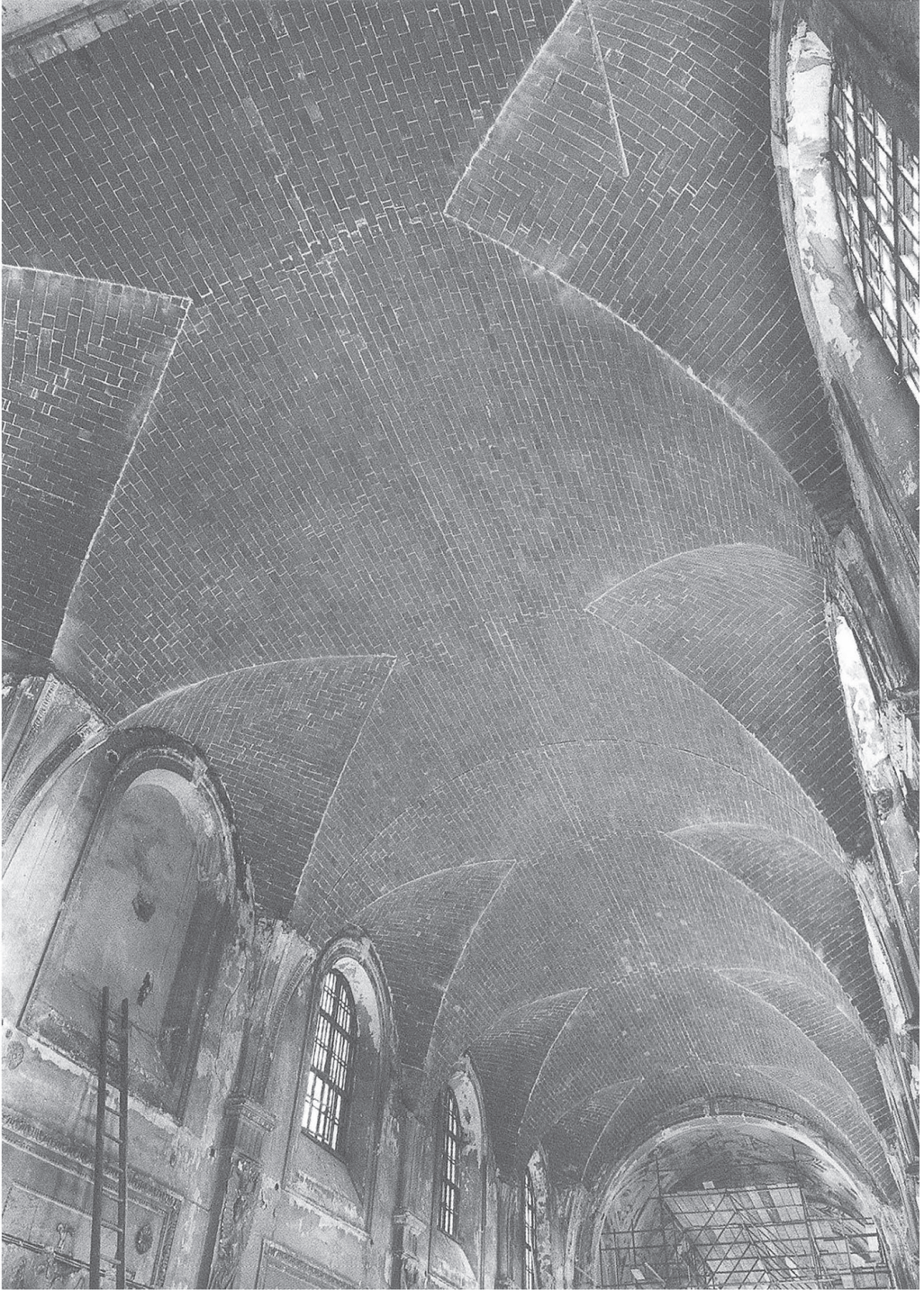
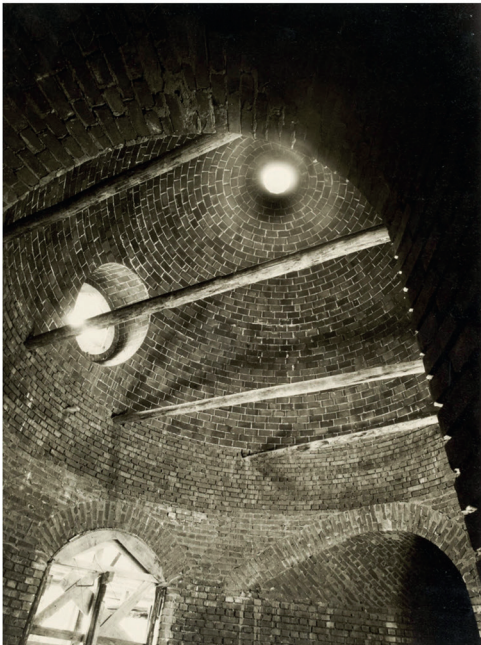
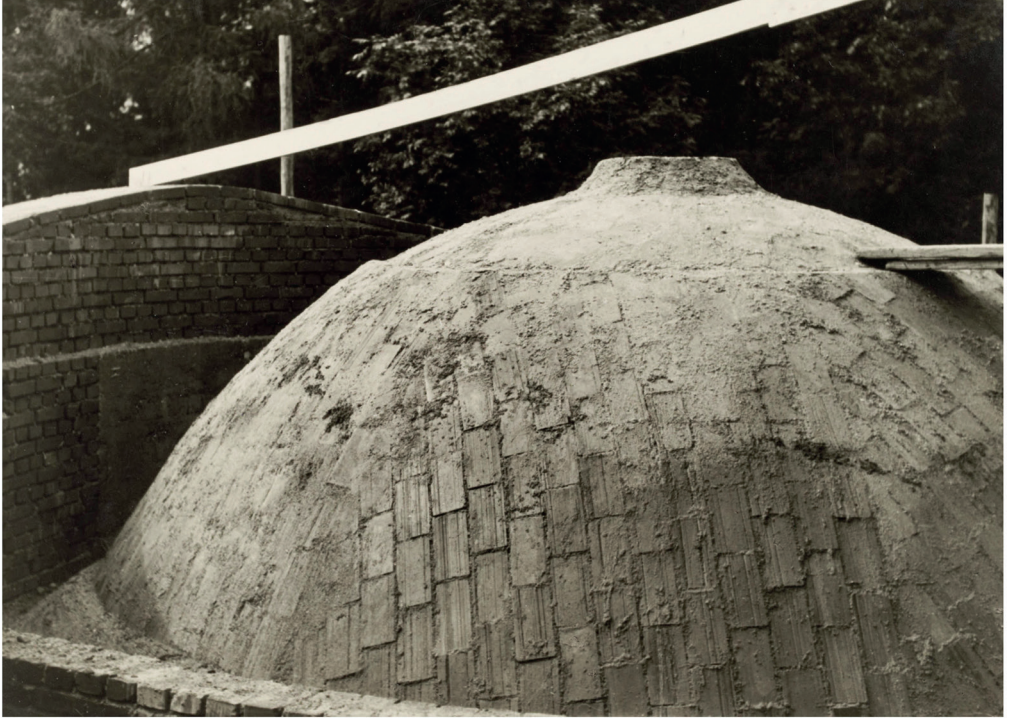
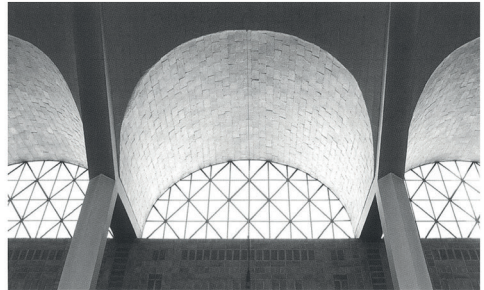
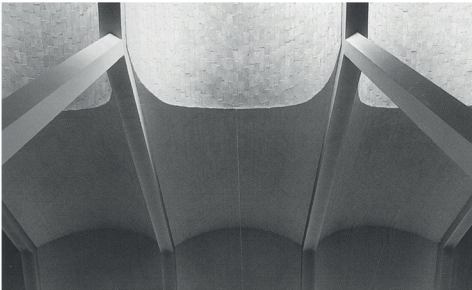
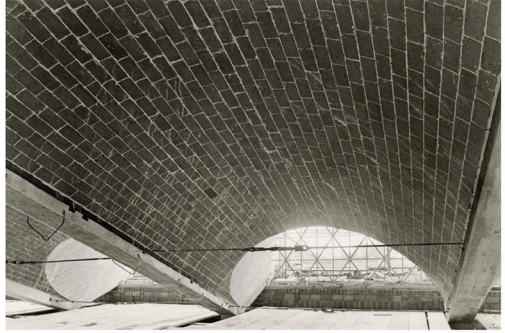


Plate XXIII. Dome of the Heilig Kreuz-Kirche (Holy Cross Church), Traunstein, built in 1952. Note the difference between the tile bonding of the internal shell, apparent, and the outer shell of tiles set breaking joints with the former (Archive Basiner).





Brick Vaults and Beyond

The Transformation of a Historical Structural System from 1750 to 1970

Edited by Paula Fuentes and Ine Wouters

INSTITUTO JUAN DE HERRERA
VRIJE UNIVERSITEIT BRUSSEL

The project *Brick Vaults and Beyond: The Transformation of a Historical Structural System (1830–1930)* has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 833030.



ARCHITECTURAL
ENGINEERING

© 2021 For each chapter the author(s)

Editors: Paula Fuentes and Ine Wouters

Copyediting: William Hatherell and Sara E. Wermiel

Cover illustration: Construction of the dome of the Royal Museum for Central Africa (HP.1968.10.6-52, collection RMCA Tervuren; Charles Girault archives)

ISBN: 978-84-9728-587-2

Depósito legal: M-12734-2021

Layout and printing: Gracel Asociados S.L.L.

Contents

Preface	ix
Between Reinterpretation and Experimentation The Evolution of Hollow-Clay-Pot Vaulting in Paris (18th–19th century) <i>Lia Romano</i>	1
Brick vaults by J. C. von Lassaulx and A. Antonelli An Ancient Building Technique for the Industrial Age <i>David Wendland</i>	33
Vaults and Roofs in Belgian Churches (1890–1910s) Pointed Barrel Vaults with Metal Arches and Their Interaction with Roof Trusses <i>Romain Wibaut</i>	61
Testing of Tile Vaults. The Need to Validate the System <i>Esther Redondo Martínez</i>	97
Guastavino Vault Design and the Role of American Engineers <i>John Ochsendorf</i>	127
The Congo Museum in Tervuren The Birth of Tile Vaulting in Belgium <i>Paula Fuentes</i>	167

Tile Vaults in Belgium in the 1930s	
The Churches of Léonard Homez	
<i>Paula Fuentes, Rosa Ana Guerra-Pestonit</i>	231
Tile Vaults in Post-War Germany	
<i>Santiago Huerta</i>	289
Tile Vaults in the Spanish Modern Movement, 1925–1965	
<i>Ana Rodríguez García, Rafael Hernando de la Cuerda</i>	371
Tile Vaults in the Architecture of Luis Moya (and Partners)	
Historical Context and Technical Elements	
<i>Ignacio Javier Gil Crespo</i>	433
List of Authors	487