In 1829, the «Journal für die Baukunst», edited in Berlin by Crelle, published an essay with the title «Description of the procedure in the making of light vaults over churches and similar rooms», where, referring to observations made on medieval buildings, a method of building vaults without centering is described.

The author of this essay, Johann Claudius von Lassaulx (1781–1848), was Royal Prussian building inspector at Koblenz (which in that time belonged to the Rhine province within the kingdom of Prussia). As architect he built numerous public buildings in that area, including several large parish churches in medieval style. He was strongly engaged in research, restoration and maintenance of medieval architecture, and a promoter of neo-medieval architecture in his projects and in his writings. In 1846 and 1847 he returned to the subject of vaults in lectures and articles.

The essay in question has been brought to attention by Fitchen (1961, 175ff.). A closer look to Lassaulx’s own vault constructions referred to in the essay may offer a more detailed understanding of his vaulting method and give an occasion to discuss the relevance of this publication and its position within the development of building technology in the 19th century.

The building we analyze, the first major project where Lassaulx put in practice his method of vaulting, is the Parish Church St. John at Treis, on the Mosel river, built in 1824–1831.

**Contents of the essay**

Lassaulx starts his essay declaring that, to his personal conviction, building churches in the medieval styles (gothic and «pre-gothic», i.e. «pointed arch style» as well as «round arch style»), is «not only the most suitable and dignified, but even the cheapest». To build churches in that style is closely linked to vault construction: if ever possible, he says, they should have vaults built of stone. Moreover, «light and wide spanned vaults belong without doubt to the most daring and sensible human inventions», they have high formal qualities, resist to fire and decay. Therefore, Lassaulx says he sought for long for a proper vault construction method. Knowing that at Vienna large domes were being constructed almost completely free-handed, and that in the vicinity flat ovens and fireplaces were built using only some weak rods, he was already for some time trying to imagine how large church vaults could be constructed with similar means.

In literature, there was no indication about how this could be done — «nothing referring to the point in question», apart from the well-known manners of tracing arches, says Lassaulx.

The solution could be found in observations made on medieval vaults. Lassaulx says that he understood the principle of free-handed vaulting by the observations he made on the vaults of St. Laurence’s Church at Ahrweiler. Seen from their extrados, these vaults appeared so irregular in their curvature that it
was impossible to imagine that they could have been built on a formwork; and as in some portions the plaster was broken, their structure could be studied in detail.

What Lassaulx had understood from these observations, he developed first in some experiments with thin slabs of pumice conglomerate, and then put into practice in his church projects.

Lassaulx formulates with great clarity the principle of the technique of free-handed vaulting he had explored: the single courses form arches that are stable as soon as they are completed, offering a stable base to the next course to be laid. "The whole secret" is that the single courses of the caps of the pointed vault, which are usually horizontal, are curved to the outside forming each of them an arch or, as Lassaulx says, "a small vault in itself" as soon as it has some abutments on its ends. The bed joints of pointed groin vaults are not too much inclined, as the caps are quite steep; therefore the slipping of the blocks can be prevented, and it is not difficult to set the blocks to a self-supporting, completely stable course as soon as the arch is closed, and then set the next course on it. The abutments of the arches formed by the single courses are the vault's ribs or the centering arches set up in the groins. The thrust from the arched courses is neutralized by those of the confining caps, as long as the courses of the entire bay are brought up together — the procedure is not basically different from that of erecting circular domes that obviously can be built with circular self-supporting courses.

If groin vaults are not pointed, but traced by intersecting cylinders (like in "old", i.e. Romanesque churches), the horizontal courses would form flat arches and therefore would be difficult to build. In medieval vaults of this kind, Lassaulx says, one can often observe that the courses, instead of being horizontal, are tilted, rising from the diagonal groin to the wall with an angle of up to 45° respect to the springing line. The reason to do so, according to Lassaulx, might have been to concentrate the pressure of the vault on the groins. Another reason would be that in this way the curvature of the courses increases. In fact even a barrel vault could be built in this way, "as all courses would then form tilted sections of a cylinder, thus consist in single elliptical arches" (p. 321). This pattern is usually called "dovetail-pattern" (Gilly, [1795ff.] 1805; etc.): Lassaulx does not use this term.

Lassaulx mentions two auxiliary means for building vaults that have become well-known; however, in the essay he dedicates only a few lines to each of them, and he explicitly attributes them to the case of constructing semispherical domes.

One is the stone-weighted rope device, well known through Fitchen (1961), which Lassaulx mentions to be used at Vienna: in the upper portions of a spherical dome, the bed joints get strongly tilted, and therefore the blocks have to be prevented from sliding by pressing them to their bed. This can be done by means of a rope fixed on the extrados of the vault and weighted with a stone, and that will be moved to hold the next block. Except for spherical domes, only very low cross vaults could need the use of this device (p. 319).
The other auxiliary device is the trammel—a pole rotating from the center of the sphere that helps to control the form of the dome if built without centering.

As advantages of free-handed vaulting, Lassaulx mentions that, apart from the costs of the formwork that can be saved, in this manner vaults can be built thinner and lighter: In very thin vaults, he says, the movements of the formwork that damage the rising vault can hardly be avoided, the immediate removal of the formwork from the fresh vault is dangerous, and the delay of its removal may cause cracks due to the shrinkage of the mortar.

In the essay, there are only two references to technical literature. One is Rondelet's «Art de Bâtir» (the edition used is obviously prior to 1829), namely a passage from the 3rd Volume, that confirms Lassaulx' opinion that vaults can have only little or even no horizontal thrust.

The other is Philibert de L'Orme; Lassaulx refers to an edition from Rouen of 1648. The long passages cited directly in the French original are brought first to give confirmation to Lassaulx' hypothesis about the date of invention of the free-handed vaulting method, based on observations made by him on the Cathedral of Cologne. There, says Lassaulx, the earlier vaults are straight, and only the later ones are domed, so that he assumes the invention to have been taken place during the 15th century, which he believes to fit well with the fact that De L'Orme calls the pointed vault «modern».

Second, it serves to introduce the nomenclature of the single ribs (croisées, liernes, tiercerons, formerets etc.) of a vault.

The buildings referred to at the end of the essay, where Lassaulx put in practice his vaulting technique, are the churches in Valwig—a small church in «round arch style»—, in Kobern—the choir has a spherical vault where the trammel was first introduced—and in Treis.

**DESCRIPTION OF THE CHURCH**

The new Parish Church at Treis (1824–1831) is beyond doubt the most prominent of the three churches mentioned. It was one of the very first churches in gothic style in modern age in Germany—it was built in the same years as Schinkel's Friedrichwerder Church at Berlin, and was brought to attention by several publications.

The general layout is that of a hall church with three aisles and five bays covered with pointed cross-ribbed vaults, a polygonal choir, a tower in the center of the façade with a tall wooden spire, and a compact exterior appearance which is structured only by the attached buttress piers.

The width of the central aisle is 10.36 m, of the lateral aisles 3.92 m, and the length of the bays is 5.34 m. The vaults of the central nave rise 6.98 m over their springing. The vaults have transversal, longitudinal and diagonal worked sandstone ribs of the same profile. The caps are plastered; they are built of blocks of pumice conglomerate, with a thickness of about 20 cm including the plasters.
For the cylindrical columns of the arcade, their details and those of the ribs as well as aspects of the entire layout, the model apparently has been the same church at Ahrweiler where Lassaulx claimed to have understood the art of vaulting.

**ANALYSIS OF THE MASONRY PATTERN OF THE VAULTS**

In 2001, the vaults of this church could be examined more closely, as, before the painting of the intrados was renewed, the courses of their masonry were visible through moisture marks that formed dark lines on the aged plaster.

In some caps, the lines of the bed joints have been measured with a digital tachymeter, as far as they were clearly visible. Along the visible lines, points were tracked with the laser and their three-dimensional position was measured; the resulting point clouds were then examined with a tool for geometric reverse engineering («Surfacer», now called «Ideas freeform modeler») in order to describe their geometrical properties. Apart from the geometry of the ribs and the vault on its whole, information about the masonry pattern of the vault, especially the geometry and the position in space of the courses could be obtained. The measurements and their interpretation regard only the bed joints of the courses on the intrados.

Observing the caps, one can see immediately that the pattern of the courses is far from being uniform throughout the vaults: different caps may present different meshes.

In some caps we can find a regular pattern of courses from the springing line to the top; in many others, though, some sudden changes in the direction of the bed joints are visible — above a certain course the following courses are tilted in a different direction, adjusting with triangular blocks cut *ad hoc*. These discontinuities may occur several times within the same cap. As the vaults were intended to be plastered and their fabric therefore was not expected to remain visible, such irregularities were not disturbing their appearance; for us, however, a closer look to these discontinuities may be interesting, as we may consider them as corrections in the growing.
masonry of the vault; hence, understanding their motivation might lead us to the recognition of some construction principles.

The vaults are strongly domed: all caps present a significant double curvature. Their surface, however, is not spherical. The ridge line in fact is not circular, but describes a characteristic curve with non-uniform curvature (figure 4). This proves that for the construction of these vaults the trammel (rotating pole device) has certainly not been used.

There is no continuity of the masonry bond from one cap to another, but every cap is built independently from the other: behind the ribs, the courses are not continuing, but their fabric is interrupted. This is not visible, but can be deduced by the fact that the bed joints of two neighboring caps are neither continuing in position, nor in direction, nor are they lying in the same or parallel planes. This interruption of the masonry bond between the caps is significantly different from the laying of the courses as it is proposed in the technical literature, especially the dove-tailed pattern (Ungewitter 1859–1864).

The advantage of such discontinuity is that the single caps can be built to a certain extent independently one from the other —in that case, however, some care must be taken to avoid that the growing domed masonry panel would push the centering arches to the sides, causing the collapse of the vault: in fact, Lassaulx writes that in such case the centering arches must be laterally supported. According to the building records, such an accident actually seems to have happened at Treis, after the masons, disobeying to their instructions, had attempted to bring a part of a bay to conclusion (Schwieger 1968, 41).

According to the results of measuring, the curves formed by the visible lines of the bed joints are very proximate to circular arches —in spite of the rather irregular appearance of the cap seen from the extrados. The radii of these circular courses, though, vary from one course to another, and throughout the same caps there are strong differences. Therefore, we can exclude the usage of any kind of sliding template, like the «cherche movible» mentioned by Viollet-le-Duc (1844 ff., and in the «Dictionnaire»).

Further, we observe that the bed joints are approximately lying in planes. These planes are tilted to the inside of the vault; in most cases, they are parallel. This parallelism of the bed joints' planes is surprising if one considers that in the technical literature throughout the second half of 19th century —namely Ungewitter and the manuals based on him— the plains containing the bed joints are described as being radial, all passing through the center of curvature of the vault.

At Treis, these planes are parallel, less or more tilted to the inside: only at the discontinuities mentioned above, their direction sometimes changes drastically. However, in masonry with curved bed joints it is reasonable (and automatic) that the planes are parallel. Otherwise, in case they formed an angle, the thickness of the joint would not be uniform, but would vary according to the local distance from the axis (e.g. the center of curvature in case the planes would be radial); such a variation in the thickness of the joint would be questionable not only in regard to the working process and the stability of the masonry fabric, but would also cause problems to the geometrical control of the rising structure. Therefore, the radial disposition of the pattern as proposed by Ungewitter and others appears more difficult and less practical.
As already mentioned, by diagonally tilting the planes of the courses, like in the dovetail pattern, in most cases it is easier to obtain curved (and therefore self-supporting) courses. In cylindrical caps, such tilted courses will be curved without giving a double curvature to the cap.

Building the vaults at Treis, Lassaulx renounced to this possibility—as mentioned, he gave a strong double curvature to the caps and apparently endeavored courses that begin and end approximately in the same height above the springing line. In some cases the courses seem to have resulted tilting towards the diagonal ribs perhaps because these are longer than the longitudinal and transverse ribs, and were then corrected, continuing with courses running parallel to the springing line. Some of the large caps in transversal direction to the nave have courses that are slightly tilted towards the longitudinal ribs, contrary to the scheme of the dovetail pattern.

In most cases, however, especially in the higher portions of the caps, the bed joints begin and end in about the same height above the springing, but their planes are tilted to the inside, so that in prospect the bed joints appear as curves.

In the summit, the courses of the neighboring caps meet each other and are bound together in a herringbone manner. There is no re-entrant groin; except for a small portion at the vicinity of the longitudinal or transverse ribs, the surface of the vault at the ridge is continuously curved.

At the locations where we observe the corrections of the masonry pattern, the changes to the inclination of the bed joints' planes appear to be of minor importance and altogether not systematic: in some cases the planes change direction, in some cases the inclination increases significantly. Hence, these corrections probably were not aimed to reduce the inclination of the beds.

The major alterations in these corrections regard the curvature of the courses, and they are definitely systematical. In those caps that have been measured and that present these corrections, the radii of curvature of the courses are drastically reduced above the locations where their direction changes. In some cases, even such corrections that are hardly visible to the eye lead to a considerable reduction of the radius of curvature. Therefore, Lassaulx' effort seems to have been oriented to organize the courses in such manner that, without affecting the geometry of the vault, their radius of curvature would be as small as possible. This is very consequent, as the basic principle of free-handed vaulting, according to what Lassaulx is writing, depends on the arch-like curvature of the courses.
The general strategy, as emerges from these observations, seems to have been to rise the caps in their lower part (starting from the corbelling spandrel) along the ribs, gradually inclining them towards the inside, but then, in the upper half, to proceed straight ahead, giving a uniform inclination to the cap over a greater portion. The resulting form of this portion is that of an upright cylinder inclined towards the inside of the vault — the courses are thus bowing more and more to the outside of the ribs, and their arches are closed to 1/3 circle or more. Only at the summit the direction changes, where the courses are meeting those of the neighboring cap and therefore become shorter: the inclination of the vault's surface strongly decreases and the vault is closed; in this area, the bond becomes rather irregular, and the bed joints neither form circular arches nor planes.

**LASSAULX’ CHOICE OF THE VAULTING PATTERN**

Within the examples of medieval vaults in Lassaulx' proximate sphere of action (Rhineland, northern Germany, the Netherlands) either dove-tail patterns may be encountered, as also patterns with courses running parallel to the springing line. In the last, at the summit of the domed caps the bed joints form a characteristic lens-like figure.

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**Figure 9**
The courses of the left cap, Figure 5, as point clouds, in prospect

**Figure 10**
The bed joints’ planes of the same portion

**Figure 11**
The bed joints’ curvatures of the same portion, showing considerable reductions of curvature after the corrections in the bond pattern
Applying the dovetail pattern, the doming of the caps can be reduced, and within a course to be built, any block is not only lying on the bed joint, but, because of the inclination of the course, is also being pressed to the preceding block, which could be helpful for free-handed vaulting. Another advantage is the continuation of the bond over the diagonal rib, avoiding a joint at the groin that weakens the structure.

As we have seen, Lassaulx well knew the dovetail pattern but chose not to use it.

Perhaps, he did not consider the continuity of the pattern as an advantage: The neighboring caps over the diagonal rib have to be built up together from the beginning, and the courses of the four corners due to their inclination come to meet rather early in the summit of the confining arches. This demands a rather tight coordination in the construction of an entire bay, which could have caused some difficulties to the building process especially in vaults with greater dimensions.

Another reason might arise from his opinion of how the bond pattern of a vault influences on the distribution of the loads and the resulting thrust—as it is quite obvious from the regarding passage of the essay, Lassaulx probably believed that a vault with horizontal courses would produce less horizontal thrust than if built in the dovetail pattern.

Another type of bond pattern that Lassaulx probably knew has its courses only slightly tilted towards the center, as described as typical for English vaults by Willis (1842, 8), and that present an intermediate solution to those mentioned. The drawing given by Lassaulx of a vault with tilted courses is much more similar to this typology, that to the current dovetail pattern.

THE LACK OF TECHNICAL INFORMATION

In his essay, Lassaulx states that neither he could find masons capable to build vaults without centering, nor was there any information available in literature. As to the first statement, obviously today it will be hardly possible to verify within what geographical range this might have been true. The second, though, can be interpreted on the basis of a comparative study of the technical literature available to him.

D’Espie’s book describing timbrel vaulting, for instance, was well-known in Germany; a German translation circulated since 1760, and it is cited in many of the literature of Lassaulx’ time. However, it was considered little useful because of the need of gypsum mortar, expensive and problematic at the local climate. To Lassaulx, this technique must have seemed of no interest, as, apart of the vault typology associated with it (and shown in the tables) being far from «medieval» or «gothic», he is strictly orientated to copying medieval architecture in his area, where only half-stone vaults and no examples of timbrel vaults are found.

In Rondelet’s treatise (widely known in Germany already prior to its translation), free-handed vaulting is not mentioned at all—even the D’Espie vaults are described to be built on centering.

As much as we know about Lassaulx, he certainly was well informed and highly interested in technical literature; he knows, cites and applies Rondelet’s treatise, and we have to imagine him as a bibliophile person. In his publications, he habitually gives extensive reference to the sources he used. Hence, we should consider seriously his statement on the lack of written instructions on free-handed vaulting.

We may be surprised, therefore, to find in David Gilly’s «Landbaukunst» the statement that cross vaults (and only those) can be built without formwork in the dovetail pattern, which is illustrated by a drawing. The third edition of this manual appeared in 1805, it was generally used and circulated within building professionals—its author had a determinant role in the development of the Royal Prussian building authority, and Lassaulx was an official of this same authority. Also the fact that Lassaulx had close contact to Schinkel makes it extremely unlikely that he might not have known this manual, even if there seems to be no evidence that he did.

And even if one might assume that he ignored it, one should expect that Crelle, the editor of the Journal that published Lassaulx’ essay (who certainly had known Gilly personally), would have intervened.

A possibility we may consider is that Lassaulx in fact knew this manual, but does not mention it, because he might not have found useful the information given in it, but would not be in position to refer to it in a critical manner. As a matter of fact, Gilly only writes that «skilled masons» are needed to build a cross-vault without formwork, without giving any precise description of the procedure. In the drawing, the masonry pattern is represented only in
A case of recovery of a medieval vaulting technique

the central part of the vault, where the bed joints form a square turned 45° respect to the plan; the lower courses, as they depart from the springing, are not shown—neither in the plan, where they would appear curved, nor in the section. Gilly does not offer any precise description of the masonry pattern in drawing or in text, and therefore would not offer sufficient information to build vaults like the one in Treis.

What Lassaulx found lacking, and what he contributed to the technical literature, is in fact a precise technical description of a construction principle that allows its reproduction. In his essay, avoiding any consideration about the geometry of vaults (he would dedicate his lecture published in 1846 on that topic) he describes in a very concrete and clear manner the principle, and formulates guidelines of this type of construction. Such an instruction gives the architect the possibility to interfere in the construction process, and to link construction and architectural design.

THE POSITION OF LASSAULX’ ESSAY IN THE TECHNICAL LITERATURE

As far as can be said today, Lassaulx’ essay met a rather broad attention. Beyond the distribution of the «Journal», translations of the essay were published in England and France. In England, it appeared in 1831 in the «Journal of the Royal Institute» (Schwieger 1986; Fitchen 1961), reported by Whewill (who had added a text by Lassaulx to his «Architectural notes on German churches» in 1842); this translation was cited by Willis (1842).

In France, it was published in 1833 in the «Journal du Génie Civil» (Schwieger 1986).

Apparently, its contents have also found their way into the technical literature. In Wolfram’s exhaustive «Complete Manual of the Entire Building Art» (1838) that is mainly depending on Gilly and Rondelet, the essay is cited and referred to. In the chapter about the building of the caps (vol.III.2, p.85), the principle of arched, self-supporting courses is explicitly pointed out (with reference to Lassaulx), and the drawings illustrating that chapter (fig.198a+b) are clearly depending on those of his essay (fig.5+6). In order to obtain the necessary curvature of the courses, the dovetail pattern is recommended.

Where Viollet-le-Duc explains the building of groin vaults in his essay on construction, published in several parts in the first numbers of the «Annales Archéologiques» (1844 ff.), apart from the use of a sliding template he mentions exactly the same principles as Lassaulx: «... chaque rang de moellons étant bandé, et formant un arc de l’arête diagonale au formoir, ou à l’arc-doubleau, pouvait être abandonné à lui-même s’étant que le dernier morceau était posé». (2.1845, p. 148). He mentions Lassaulx only in 1847; from 1846, however, in the «Annales» great attention is given to Lassaulx by Didron and other authors, and there is evidence for close contact. We can state that the French translation of Lassaulx’ essay had been published 1833, twelve years before, and that he had come to the attention of the readers of the «Bulletin Monumental» just a few years before (Lassaulx 1838; in the following number, he was mentioned as coeditor), and therefore we find it interesting to suppose but cannot prove that Viollet-le-Duc’s statement is depending from him.

Breymann (1849)—probably the most successful manual in Germany, published and republished in 7 editions, with two revisions, up to 1903—doesn’t mention the essay. We only find a reference to Lassaulx’ later essay from 1846, where a summary of the 1829 essay is given in a long footnote. But he cites (and mentions) Wolfram, so it is certain that he knew the contents of Lassaulx’ essay. Besides, Breymann also extensively cites Willis’ article on the geometric construction of vaults (1842)—without mentioning its author—where he could find a reference to Lassaulx’ essay (this also proves that Breymann is very selective in mentioning his sources). In fact, we can find a drawing showing the auxiliary devices mentioned by Lassaulx, the trammel and the hanging stone device (t.24, fig.1). As both are shown together, it is hardly believable that the source may be other than Lassaulx.

The principle of self-supporting courses is only implicitly mentioned, the text on (free-handed) building of the caps (p.68) is based mainly on Gilly—anyway, it is essential that it appears at all. For the rest, Breymann gives a much more detailed graphical representation of the cross-vault built in dovetail pattern than Gilly: in the plan, all courses are drawn, and their projection in the lower parts is carefully traced.

Its reproduction, therefore, is easier than following Gilly. A representation of the courses in elevation,
however, can be found only in the 4th edition revised by H. Lang, in 1868.

Ungewitter—his manual on gothic architecture appeared in several deliveries from 1859 to 1864, a revised and extended edition was published by Mohrman in 1890—doesn't mention Lassaulx. In the foreword, however, he mentions two building manuals: Gilly and Wolfram. As stated above, the lecture of Wolfram's manual gives knowledge of the contents of Lassaulx's essay, without needing to recur to this source directly.

Here, a detailed and exact description of the geometrical disposition of the courses is offered in the text and the illustrations, describing the overall geometry of the severy, the position of the bed joint planes, and the curves of the courses themselves, referring to the principle of self-supporting courses. In difference to Lassaulx, the dovetail pattern is preferred (as already in Wolfram).

Figure 12
Ungewitter 1859–1864, t.8 (details). Tracing of the courses of a groin vault with dovetail pattern

Such a precise description (leaving apart the question of its correctness) enables the architect to design all details of the vault, in general of a gothic construction, and gain complete control of the working process. The close link between the properties of materials and their working to the design and the appearance of the entire building, as it had been claimed already by the neo-gothic avant-garde of the early 19th century and aimed to namely by Lassaulx, finally becomes possible.

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NOTES

2. This is not the same edition David Gilly used and gave to the knowledge of the German public.

REFERENCE LIST


