On the Subsequent Vaulting of Churches in the Late Gothic Period: The Collegiate Church of San Vittore Mauro in Poschiavo, Switzerland

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On the Subsequent Vaulting of Churches in the Late Gothic Period: The Collegiate Church of San Vittore Mauro in Poschiavo, Switzerland

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Introduction

While the Late Gothic construction boom had already covered large parts of southern Germany and Austria, on the territory of today's canton of Grisons in south-eastern Switzerland no Late Gothic churches were built before the mid-fifteenth century. However, as in many other Central European regions, construction activity increased considerably in the fifteenth century due to economic prosperity and the resulting population growth. In Grisons, many new judicial communities and church congregations emerged in a state of ever-increasing autonomy. After the separation from their 'mother churches', the newly founded congregations needed their own church buildings that would reflect the pride and ambitions of their respective community, often far exceeding their actual needs.

Even more decisive for the later considerable increase in construction activity was the devastating conflagration of the city of Chur in 1464 [1] and the consequent reconstruction of the lost structure, for which experienced master builders were commissioned, most importantly Steffan Klain from Austria. Master Steffan was responsible for the reconstruction of the parish church of St. Martin, whose chancel, completed in 1473, for the first time showed a vault of comparable design, technique and precision to the contemporary European standard. Thus, it was Master Steffan's merit to have transferred and spread the complex architectural knowledge in the region, with his initial work justifying the demand and ambition for the over 115 Late Gothic churches built until 1522.

Consequently, the high demand for the new architectural forms led not only to the construction of new buildings, but also to several established churches being modified and vaulted according to a Late Gothic scheme. Hereinafter, this practice of vaulting pre-existing structures, which were originally never intended to withstand such forces and thrusts, will be referred to as 'subsequent vaulting'. In the present paper, the challenges arising from such approaches are to be exemplified by the collegiate church of San Vittore Mauro in Poschiavo (Figs 1–2).

Fig. 1: The collegiate church San Vittore Mauro in Poschiavo from the north side (M. Maissen)

Fig. 2: Interior of the collegiate church San Vittore Mauro (M. Maissen)

Building history

The first record of a church in Poschiavo is found in a document dated 3 January 824 [2], however, it is no longer possible to determine whether the *'ecclesiae baptismales'* mentioned in this document referred to the collegiate church of San Vittore Mauro or the nearby chapel of San Pietro. In the early thirteenth century, a conversion or maybe even a complete rebuild of the church seems to have occurred, whereby the frequently mentioned date of 1212 could not be verified by either inscriptions or documentary sources. Throughout the Middle Ages, the Val Poschiavo was repeatedly the centre of feuds between the lords of Matsch in the north and the Milanese Visconti family in the south, due to its natural resources as well as the considerable income from the pass traffic. As a result of these feuds, the valley also frequently changed its ecclesiastical affiliation between the diocese of Chur and the diocese of Como. After another brief transfer of sovereignty to Milan after the mid-fifteenth century, both the political and ecclesiastical jurisdiction ultimately returned in 1486 to the 'Three Leagues' – an alliance that eventually lead to the foundation of the canton of Grisons – and the diocese of Chur. The then incumbent bishop

Ortlieb von Brandis saw this opportunity to establish the church San Vittore Mauro as a representative outpost of the diocese. The choice of the northern Alpine architectural design for the church was therefore by no means a coincidence, and its regional singularity further indicates the influence of the diocese of Chur.

The Late Gothic construction phase can be traced back to several dates and inscriptions that can be found both inside the church and even on the extrados of the nave vault (Fig. 3). First, the chancel was rebuilt until 1497 by Master Andreas Bühler, a native of Carinthia, who already practised under Master Steffan, whereas the nave was completed until 1503 by an otherwise unknown Master Sebold Westtolf. The newly built chancel with its characteristic star vault was already aligned with the nave ground plan adjusted to the vaulting (Fig. 4), which may indicate that the plans for the nave were also designed by Master Andreas and later realised by one of his stonemasons. A similar division of tasks, where the master rebuilt the chancel while the head mason later completed the nave, can also be observed in the late work of Master Steffan, e.g. in the two churches of Silvaplana and Samedan, as will be shown later.

Fig. 3: The date 1501 (maybe 1503) on the extrados of the nave vault (M. Maissen)

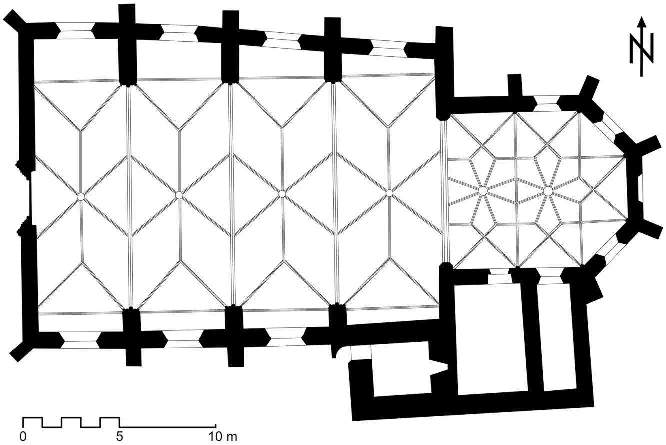

Fig. 4: Ground plan with vault patterns created from laserscans and total station surveys (M. Maissen)

The nave was almost certainly not newly built, as is sometimes still claimed. Indeed, the perimeter walls of the previous building were reused during the conversion of the nave, but whether the masonry is Carolingian, Romanesque or partially even Gothic cannot be decided for the time being. The reuse of the walls for the conversion caused severe complications, as the north wall is not parallel to the south wall, and deviating two metres from the initial direction from east to west (see Fig. 4). These irregularities are best seen on the north wall, where the curvature is compensated by the inner buttresses, which, as we will see later, only allowed the construction of a vault in the first place. At the same time, the nave was extended by one bay to the west, which is again evident from the ground plan, as the walls here are aligned parallel to each other.

The chancel vault

Both the vaults in the chancel and in the nave show rib patterns that were widespread throughout Europe. Due to its geometric composition, the vault pattern in the chancel is in some German-speaking regions – particularly in Switzerland – referred to as a *'Haspelstern'*, alluding to the shape of a spinner's wheel. Essentially, this vault pattern consists of a circular repetition of a single kinked rib sequence composed of one tierceron and one lierne rib, from which a star or stellar pattern with squat diamonds evolves (Fig.5).

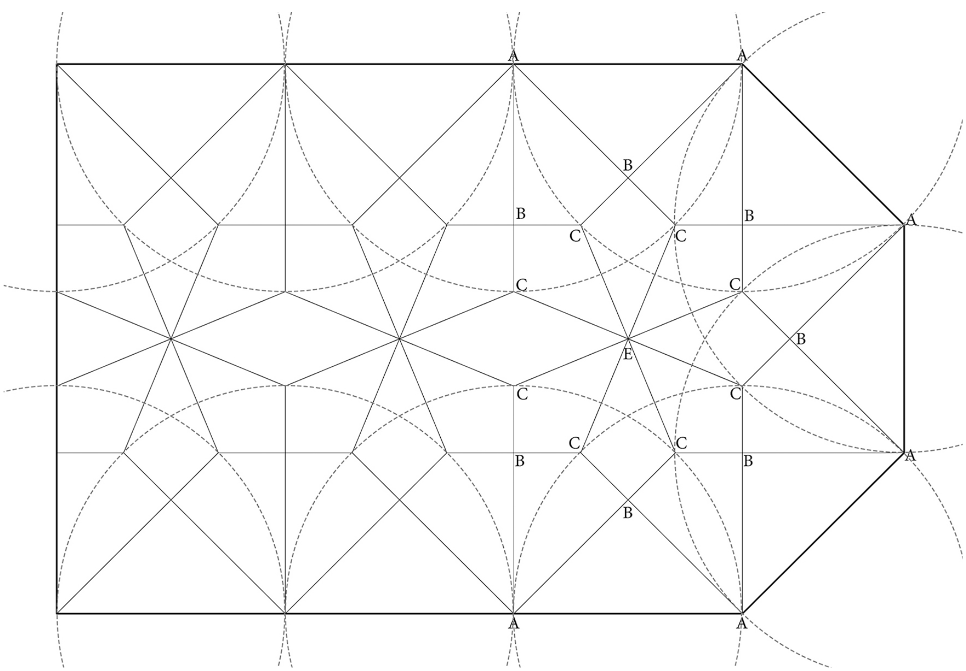

Fig. 5: Schematic ground plan of a typical 'Haspelstern' vault (M. Maissen)

As impressive and complex as this type of vault may seem at first, as simple is the planning of such a rib pattern. First, the ground plan has to be strictly dimensioned by a constant bay width of AA (Fig. 5). By connecting the points A or springers in longitudinal and transverse direction, an auxiliary grid can now added to the ground plan. Next, a compass is used to draw the bay width AA of each springer A, resulting in the points C at the intersections of the circles with the auxiliary grid. By connecting the springers A with the intersection points C, the dimensions of the lunettes ABA are automatically defined. Finally, the intersection points C need to be connected crosswise in order to obtain the points E for the keystones – the few still missing short rib sequences now all lie on the auxiliary grid lines and can be added easily [3].

Geometry

The elegant simplicity of the vault pattern is reflected not only in its minimalist two-dimensional design, but even more so in its transfer into the three-dimensional space. By reducing the pattern to one identical rib sequence ACE, which is repeated circularly from a defined centre point at a constant distance, the constant rib sequences describe perfect quarter circles in the three-dimensional space from the springers to the keystone. Since these few parameters can be used to determine the predominant part of the vault geometry, the radius for all ribs in the three-dimensional construction must also be identical, which has already been proven with comparable vaults [4].

In order to examine the geometry of the ribs and the applied radii in the chancel vault, 600 individual positions were measured axial along the ribs with a total station (Fig. 6) and later analysed with a computational program developed by Prof. Dr.-Ing. Stefan M. Holzer. Due to the high altarpiece in the rear chancel area, the lower parts of the ribs above the springers were concealed, so that these rib sequences could not be completely registered. Nevertheless, a series of twelve complete rib sequences from springer to keystone could be analysed. As expected, the individually calculated radii of the rib sequences are almost identical, with the individual points deviating only slightly from the ideal circle. The mean value of the twelve analysed rib sequences corresponds to a radius of 4.990 m with an average absolute deviation of 0.064 m and a maximum deviation of the individual points from the ideal circular arc of only 0.0055 m.

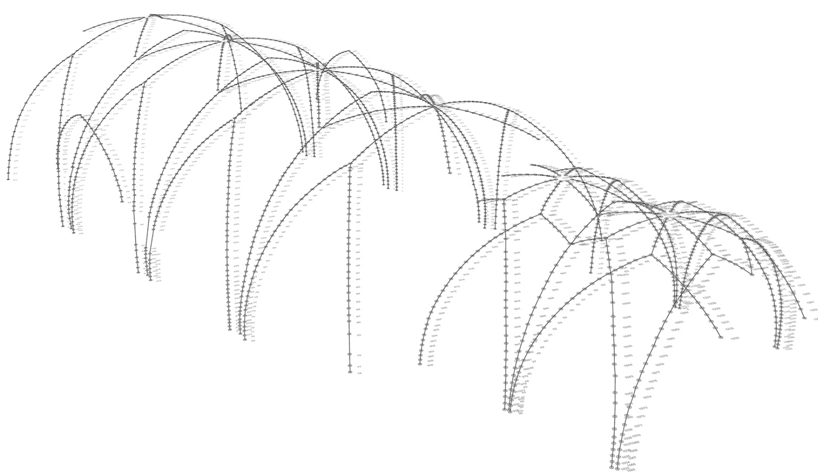

Fig. 6: Visualisation of the rib sequences measured with a total station (M. Maissen)

Using a radius of approx. 5 m seems rather questionable at first, especially when considering that the regionally used unit of length of 1 foot is exactly 0.3 m. However, the radius simply results from the proportions of the chancel ground plan: since the bay width in the chancel is constantly 3.3 m or 11 feet, the radius is equal to one and a half times the bay width.

The nave vault

The subsequent vaulting of the nave (Fig. 3) caused far greater problems for the master builders, mainly due to the existing walls. Not only were the walls not parallel to each other, but the masonry was not intended to counter the additional thrust of a vault. With a crafty trick, both problems were solved simply by dimensioning the inner and outer buttresses (see Fig. 4). The buttresses increased the cross-section of the wall at the impost level of the vault from 0.8 m up to 3 m, in the westernmost bay on the north side even to 4 m, allowing the massive additional thrust forces to be counteracted. By dimensioning the inner buttresses, the trapezoidal ground plan could then be adjusted, resulting in an inner rectangular area of approximately 16 x 12 m. This area was then again divided into three bays of 5.3 x 12 m with the westernmost fourth bay being added afterwards with the same dimensions.

For the offset rectangular ground plan, a simple vault pattern consisting of several regular diamonds was chosen (see Fig. 4). This pattern can be designed with a compass by dividing the clear span of the bay into thirds, which gives the corner points of the central diamond on the transversal rib. The distance from the centre of the bay to these corner points can now be measured and drawn with the compass from the springers to define the intersection points of the lunettes, which already completes the vault pattern in the nave. At this point, it is worth noting that the chamfered transversal ribs were designed to be twice as wide as the other ribs, which is rather unexpected for the Late Gothic period, since the contemporary vault patterns were usually not limited by the bays.

Geometry

As briefly indicated above, the individual segments of the rib sequences from the springers to the keystone either along the lunettes or along the transversal rib are of approximately equal length. This gives reason to assume that uniform radii were used here as well. To verify this assumption, a series of 1301 individual points along the intrados of the ribs in the nave were measured according an identical approach as in the chancel vault (see Fig. 6), and again the radii of the rib sequences were calculated afterwards.

To cover all possible rib sequences from the springers to the keystone, the radii of the sections along the lunettes as well as along the transversal rib crossing the central diamond pattern, and the transversal ribs themselves were taken into account. A sum of fifteen different complete rib sequences could thus be analysed, which produced surprisingly homogeneous results: the mean radius is 6.676 m with an average absolute deviation of 0.054 m. A radius of 6.6 is equal to 22 feet and further corresponds to half the diagonal of a bay in the ground plan. Even more striking in terms of the more difficult subsequent vaulting and the clear width of 12 m is the accuracy of the individual points within the rib sequences to the ideal circle. The maximum distance of a single point to the calculated ideal circle of the rib sequence is 0.0275 m, which is not much, considering the 1300 points and an average radius of more than 6 m. Even the mean absolute deviation of the distance of all points to their calculated circles is only 0.0072 m.

Both in the chancel and in the nave vault, the master builders operated with uniform radii, which greatly simplified the preproduction of the ribs as well as for the fabrication of the falsework, since the crucial heights of all intersection stones could easily be read from the ground plan. However, the use of a uniform radius for the rib sequences along the lunettes to the keystone as well as for the transversal ribs also had a significant effect on the shape of the vault webs.

Vault webs

In the Late Gothic period, the geometry of the ribs predetermined the shape of the vault webs. This becomes evident when considering the technique of freehand vaulting with bricks, which did not require any formwork but instead formed self-supporting, double-bent surfaces between the ribs. The ribs thus temporarily functioned as the scaffolding until the respective brick layers were complete and carried themselves. Although this was a common and widespread technique throughout Europe [5], it was not used in the Grisons region, where among over one hundred Late Gothic vaults only three were even made of brick, which are all located in the capital Chur. However, the vault webs of the two parish churches St. Martin and St. Regula in Chur suggest that, despite the use of bricks, the vault webs were built on formwork. This is a suspicion resulting from the geometric shape of the vault webs, which show negative curvatures that may have been caused by compression settling after the stripping of the formwork [6].

Traditionally, the preferred material for all masonry constructions in Grisons was natural stone, which was locally available everywhere in inexhaustible quantities. Except for the three brick vaults in Chur, the vault webs were always made of rubble stone with a high amount of mortar, similar to the Roman construction *technique 'opus caementitium'*. Usually gravel stones were used, which then were mixed with a high amount of mortar and poured or thrown onto the shaping formwork. In the church of Poschiavo, however, the extrados shows coarse flat slate slabs that were additionally pressed into the rubble stone mortar compound (Fig. 7). The almost regular arrangement of the slate stones further indicates that the vault webs were made here as alternating layers of mortar and pressed-in slates. Again, regionally available materials were chosen, since slate stone traditionally was used in the local construction industry, especially in the southern Grisons valleys, e.g. as roof covering or as cladding material [7].

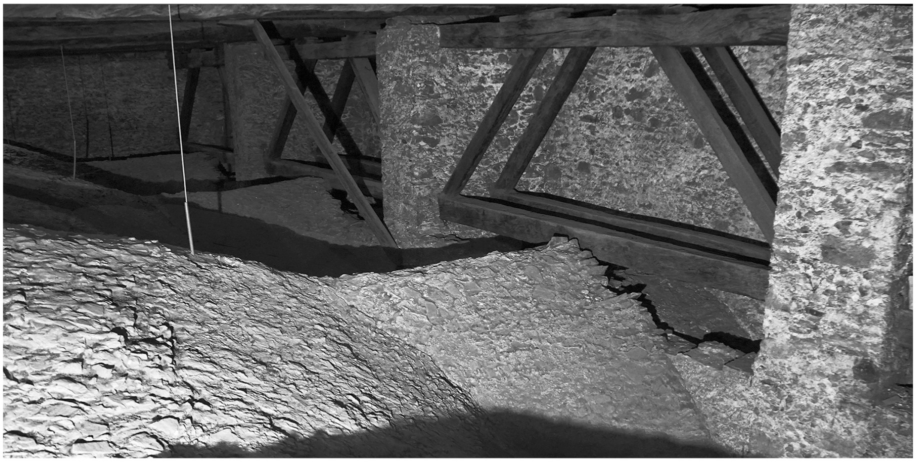

Fig. 7: Extrados of the rubble vault webs with view to the north-western corner (M. Maissen)

Since the shape of the vault webs is predetermined by the geometry of the ribs, both the vault webs in the chancel as well as in the nave should show slightly domed shapes, each limited by the proportions of one bay. To verify this, a laser scan of the entire church was conducted and thereafter the contour lines were calculated at 0.10 m height intervals for the entire soffit of the vaults (Fig. 8). Both the vaults in the chancel and in the nave show very regular webs, which as expected are shaped as curved domes. The contour lines also show how straight the layers between the rib sequences are, since this space was formed using strong boards, whose removal during the stripping of the formwork apparently did not cause any major compression settling.

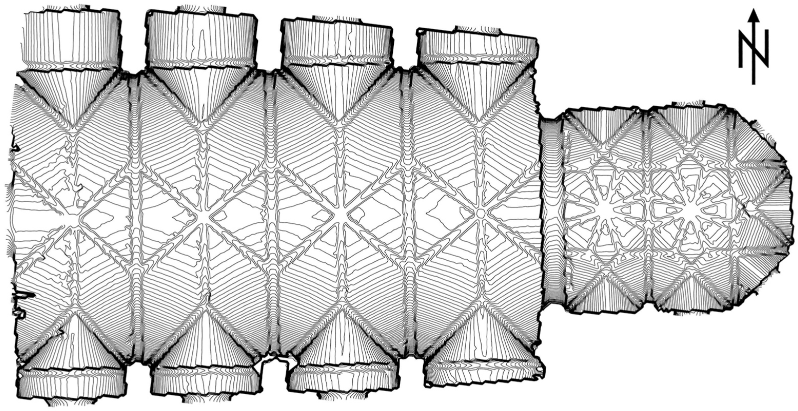

Fig. 8: Contour lines extracted from a laserscan at height intervals of 0.10 m – the irregularities in the western part were caused by the built-in organ (M. Maissen)

Unfortunately, the thickness of the vault webs could not be measured exactly at any point from the extrados, but the thickness of all the previously in the same region and period examined rubble vaults ranged between 0.20 and 0.30 m. The ratio between radius (R = 6.6 m) and thickness (t = 0.2–0.3 m) for the nave vault in Poschiavo is therefore in the range of 22 to 33, whereby a ratio $R/t > 20$ is today already considered a thin shell [8].

Subsequent vaulting

Early visitors have already noticed that the nave of the collegiate church of San Vittore Mauro appears to be squat, as the interior – even without the inclusion of the side niches created by internal buttresses – is much wider (12 m without the niches) than it is high (10 m from the ground to the keystones). In one the of the few relatively detailed descriptions of the building history of the church, the author complained that the Late Gothic master builders had built the nave vault too low either due to lack of money or due to a lack of permission [9]. However, the reason for the low height of the nave vault is neither the financing nor the lack of permits, but is again related to the fact that the nave was vaulted subsequently.

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As already mentioned, the wall thickness is only 0.8 m, which seemed to the master builder to be too thin considering a clear width of over 12 m: from the few surviving contemporary *'Werkmeisterbücher'* (master builder's books) it appears that the wall thickness should correspond to 1/10 of the clear width when using ashlars

[10]. A rather thin and curvilinear rubble masonry wall with a thickness to span ratio of about 1/15, which was supposed to counteract the thrust of a wide-span rubble stone vault, was deemed too high a risk by the master builder of Poschiavo, so various precautions were implemented from the beginning. One of these structural measures has already been touched on briefly, namely the construction of the inner and outer buttresses, which increase the cross-section of the wall at the points where the thrust is most severe. Furthermore, the niches created between the inner buttresses are covered by pointed barrel vaults, which are lower than the lunettes of the nave vault and hence facilitate the compensation of the thrust, again by increasing the cross-section of the wall and achieving a similar effect as the rubble filling of the vault conoids (Fig. 9).

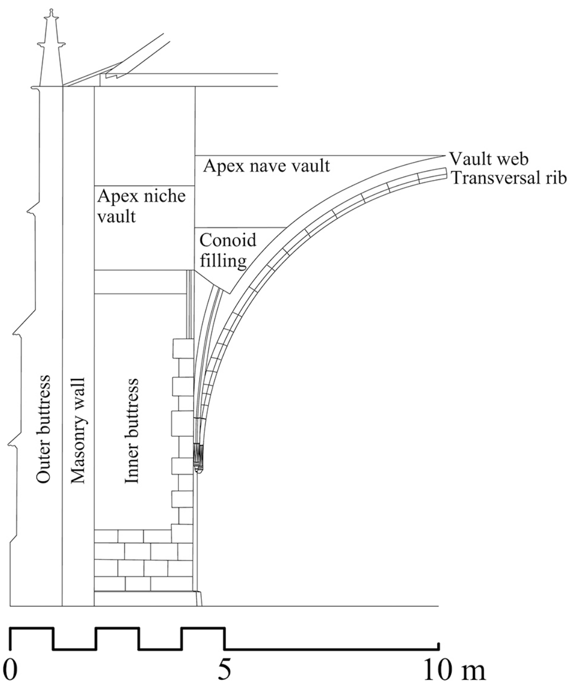

Fig. 9: Cross-section at the westernmost buttress on the north side (M. Maissen)

However, another aspect is responsible for the squat impression of the interior: the springers of the vault were deliberately placed low on the wall, at a height of about 4 m. The reason for placing the springers of a vault low is rather simple: the lower the springers are positioned, the greater the superimposed load above [11]. In Poschiavo, there are another 8 m of masonry above the level of the springers and additionally massive 1.8 m high pinnacles on top of all outer buttresses (see Fig. 1). This is further supplemented by the structural load of the roof – a rather flat inclined Italian type purlin roof with a king post, probably dating from the Late Gothic construction period – whose tie beams either sit directly on top of the buttresses or on wooden supporting structures in the niches that are embedded in the buttresses (see Fig. 7).

Although precise data, such as the exact vault thickness, are lacking for an exact calculation of the occurring forces, an approximate idea can be calculated with the help of the tables prepared by Georg Ungewitter [12]. Based on an assumed thickness of 0.3 m, this results in a weight of approx. 38 tons and a thrust of 15 to 17 tons for the entire half of a bay. The vaults of the nave therefore required carefully planned and executed modifications, especially the reinforcement of the abutments. To counteract the thrust, the wall could theoretically have been strengthened along its entire length. However, the natural abutment of the Gothic and Late Gothic vault is not the massive, but the dissolved wall. In Poschiavo, we find an extreme example of such a structural skeleton, in which the wall between the abutments is not merely dissolved by window surfaces, but is completely missing. The entire thrust of the vault is thus transferred solely to the width of the buttresses, where the thickness of the wall is widened by the inner and outer buttresses up to 4 m (see Fig. 9).

The implementation of a buttressing system thus provided a number of advantages. First, substantial amounts of material could be saved by not widening the wall along its entire length, but only at certain points. At the same time, the previously irregular ground plan was rectified by the inner buttresses, which greatly facilitated the construction of the vault. However, the craftiest trick was the stringent formulation of the structural skeleton and the simultaneous massive widening of the abutments, which both counteracted the thrust of the vault and carried most weight of the roof load, which meant that a large part of the occurring forces could be transferred from the thin walls to the inner buttresses.

Comparisons

The collegiate church of Poschiavo was not the first subsequent vaulted church in the region, two comparable buildings are located directly on the other side of the Bernina Pass the churches of St. Mary in Silvaplana and St. Peter in Samedan (Fig. 10). Both churches were constructed by the already mentioned Master Steffan, who completed the new built chancels and their respective vaults in both churches between 1491 and 1492. The two nave vaults, however, were only built subsequently, incorporating parts of the existing walls, and were each completed by a head mason: The nave vault in Silvaplana by an unknown stonemason and the one in Samedan by Master Andreas, who later also built the chancel in Poschiavo.

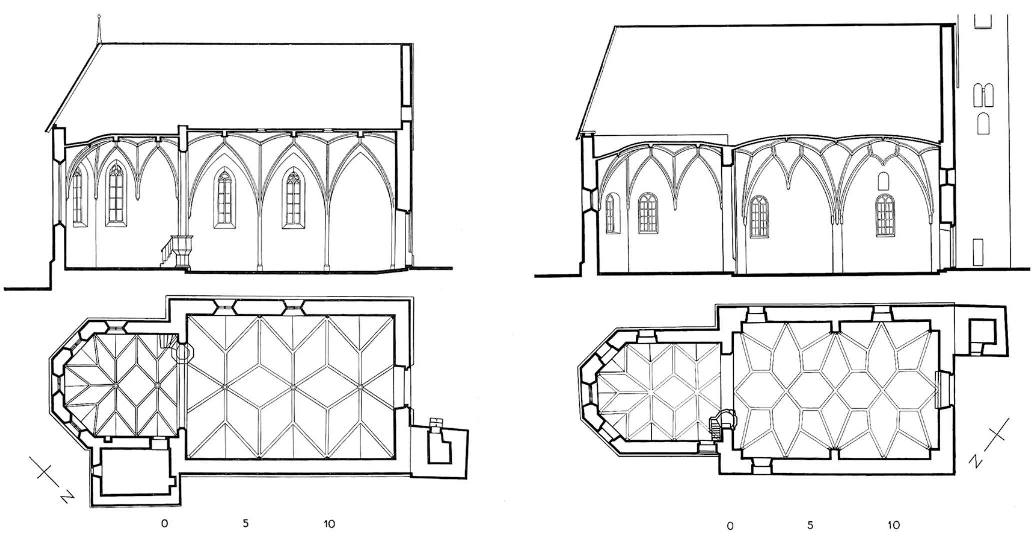

Fig. 10: Ground plans and longitudinal sections of the churches St. Peter in Samedan (left) and St. Mary in Silvaplana (Poeschel, Kunstdenkmäler, Note 13, p. 376 and pp. 414–415)

In Silvaplana, the buttresses were fully integrated into the interior, and dimensioned rather massive in relation to the clear width of 8.4 m and the actually sufficiently proportioned walls. Here, two details clearly indicate the subsequent vaulting of the nave: one of the buttresses covers part of an older fresco on the north wall, and the original position of the high window openings did not allow the ribs to be extended down further in the middle of each bay. The shape and position of today's windows is the result of a renovation in 1873 [13]. The stonemason therefore had to find a way to counterbalance the horizontal thrust and to build the vault high enough so that the large original windows would not be covered. Lower positioned springers were thus not an option here and massive buttresses had to be placed in front of the old walls to increase the cross-section of the abutment. Not only the modifications made to the interior prior to the vaulting refer to the church of Poschiavo, but also another peculiarity: at the buttresses, the ribs do not converge in a single springer but end on their own corbel stumps. This detail is found in this region only in these two churches (see Figs 2 and 10), which may indicate that the nave vault in Silvaplana has been built by the same master who later vaulted the nave in Poschiavo.

The church St. Peter in Samedan is located almost exactly 10 km northeast of Silvaplana and represents a slightly different situation. Until recently, it was generally assumed that the nave was also rebuilt from scratch. An excavation carried out in 2017 [14], which unfortunately has not yet been published, revealed remains of the foundations of a north-facing Romanesque predecessor building, whereby parts of its masonry may have been used in the 1492 conversion. In contrast to the church of Silvaplana, neither inner nor outer buttresses are present here, but the springers of the vault ribs are set very low at about 1/3 of the wall height (Fig. 10), similar to the position to the springers in Poschiavo. In addition, the ribs end very steeply at the springers, which creates a somewhat peculiar spatial impression, which would be rather unusual for a completely rebuilt nave by Master Andreas. Consequently, there are several indications that the nave was subsequently vaulted, although at this point precise statements are hardly possible without the results of the excavation.

Conclusions

The re-use and integration of masonry elements from predecessor buildings into new structures was common practice in the Late Gothic period. Already during the reconstruction of the largest Late Gothic church in the region, the parish church of St. Martin in Chur, the Carolingian masonry of the south wall was preserved. These older structures were not designed to withstand the extra loads and additional forces resulting from the construction of a vault with a massive horizontal thrust. Whereas the walls of a new building could be proportioned accordingly, any subsequent vaulting processes required the existing structure to be adapted, modified and in most cases to be reinforced.

The most remarkable example of subsequent vaulting in south-eastern Switzerland is the collegiate church of San Vittore Mauro in Poschiavo, whose original substance of the predecessor building actually necessitated a complete new construction. However, through the implementation and further development of already known and proven techniques, a unique solution could be created here, which solved both the structural as well as the design problems. Since subsequent vaulting has hardly been acknowledged in research on vault constructions, and the phenomenon itself was often just considered a marginal note, comparative examples outside the region discussed above are missing. It would be interesting to see whether the solutions described were also applied in other church buildings and whether there were regional differences. Until these questions can be addressed, however, more in-depth studies on further objects are required.

The two most fundamental and frequently used solutions for the subsequent vaulting of existing structures – the widening of the abutment cross-section and the low positioned vault springers to increase the superimposed load

– show the profound structural engineering expertise of the contemporary master builders. Both solutions did not only save material and transport costs, but they also effectively reduced the amount of work and time required. Accordingly, conversion was sometimes preferred to new construction. Through their understanding of construction technology and the resulting practical solutions 500 years ago, master builders had introduced approaches for material-, time- and cost-efficient construction processes, all of which have become more relevant today than ever, albeit for different reasons.

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