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Real Net Vault or Pseudo-Ribbed Net Vault?

Geometry, Construction and Building Technique of the Vault of the Reformed Church of Nyírbátor and the Nave Vault of the Franciscan Church of Szeged-Alsóváros

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ORIGINAL RESEARCH ARTICLE

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SUMMARY

In the present article, we revisit the question of the structural characteristics and building methods of two of the most famous Hungarian Late-Gothic net vaults, the nave vault of the Franciscan Church of Szeged-Alsóváros and the vault of the Reformed Church of Nyírbátor. Based on the data gathered by laser-scanning the two buildings, the geometric system of the two vaults, as opposed to the former state of research, differ significantly from each other. While the rib system and webbing of the vault of Szeged-Alsóváros have features characteristic of pseudo-ribbed net vaults and net vaults with webbing built with formwork, the vault of Nyírbátor is likely a real net vault structure with webbing built freehand. Furthermore, the rib system of the vault of Szeged-Alsóváros can be described by a single curved surface deductible from a circle segment, the rib junction points' spatial positions in the vault of Nyírbátor are only describable by coordinates in the three directions of the space, not by an even surface. Based on the geometric descriptions, we also attempted to reconstruct the plausible building methods in both cases. Finally, we considered the results of the geometric analysis and the underlying construction ideas deduced from it and gave a new evaluation regarding the earlier reasonings for the strong building connections of the two churches in regard to the guilds and master builders.

KEYWORDS

Late-Gothic net vault, pseudo-ribbed net vault, Gothic construction principles, Gothic vault building methods, Gothic building technique, geometric vault analysis, building archaeology, Reformed Church of Nyírbátor, Franciscan Church of Szeged-Alsóváros, building scanning

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1. INTRODUCTION

The vault of the Reformed Church of Nyírbátor and the nave vault of the Franciscan Church of Szeged-Alsóváros were often discussed in the literature as closely related structures and the possibility that the same guild or master builder worked on both buildings was suggested numerous times. The foundation of these claims is mainly the similar features of their rib systems.

However, as we had the opportunity to scan both vaults, their exact geometry became known for the first time, supplying the research with new data regarding the structures. In this article, we detail and evaluate the results of the scanning and, based on these results, revisit the question of the two vaults' connection to each other.

1.1. Historical summary of the nave vault of the Franciscan Church of Szeged-Alsóváros

The present Franciscan Church of Szeged-Alsóváros was presumably built in the second half of the 15th century, however, the exact date of the construction works is debated (commenced in 1493–1494,[1] from 1465 to 1503,[2] started shortly before 1480,[3] or took place somewhere between 1459 and 1503[4]). 1503 as the conclusion date of the church is supported by an inscription on the wall,[5] however, some claim that the monastery ensemble was not finished until 1543, the Ottoman occupation of Szeged.[6] The present church's relation to the antecedent sacral buildings of the site is also not yet decided. According to some researchers, the nave contains remnants of the former Saint Peter Church,[7] but it could be under the present apse,[8] east of the apse,[9] or only near the present church[10] as well.

The most significant of the controversies regarding the periodisation of the building is the dating of the nave vault *(Fig. 1)*. Balázs Szőke states that according to current scientific knowledge, the vault was built at the beginning of the 16th century.[11] István Harsányi wrote that the construction works of the nave and the apse, including their vaults, were finished by 1543 (the beginning of the Ottoman occupation).[12] However, multiple researchers accepted the idea that the nave vault is a 17th-century construction – based on the communications of the catholic congregation of Szeged and the Ottomans[13] – and the once generally accepted view that the vault is a barrel vault subsequently decorated with ribs, thus not a real Gothic structure. Yet, others claim that the above-mentioned communications were formerly misunderstood, thus no

1 Nagy 1944. 92.
2 Levárdy 1980. 7.
3 Lukács 1999. 3.
4 Harsányi 2001. 297.
5 Levárdy 1980. 7.
6 Lukács 1999. 3.
7 Bálint 1966. 26.
8 Harsányi 2001. 303.
9 Lukács 1999. 3.
10 Lukács 2000. 144.
11 Szőke 2005. 889.
12 Harsányi 2001. 297.
13 Bálint 1966. 17.

Figure 1. The nave vault of the Franciscan Church of Szeged-Alsóváros

17th-century alterations occurred.[14] According to this view, the letters referred to the vault on the tower's ground floor.[15] (In 1624, the monks asked the Ottomans for permission to "roof" the church as its "roof sagged and its walls got drenched" and in 1625 they asked for permission to "destroy the church's vault".[16] Both permissions were granted, however, in 1626 the permission "to repair the church" was rejected.[17]) Previously, the formerets visible from the roof, above the present nave vault were interpreted as the remnants of a former net vault,[18] thus strengthening the idea of the 17th-century alterations. Nonetheless, Zsuzsa Lukács claims that these formerets only suggest a plan alteration, not a former vault period.[19] Plan alteration, supposedly due to the change in the vault's plan,[20] occurred by the apse as well: the lower regions of the plan are hexagonal, however, the upper part changes into an octagonal ending.

In 1749, the monastery's and the church's roofs were ruined in a conflagration.[21] In 1870 and 1937 minor preservation works were carried out on the church, without considerable research.[22]

14 Lukács 2000. 145.
15 Szőke 2005. 876.
16 Lukács 2000. 145.
17 Lukács 2000. 145.
18 Levárdy 1980. 7.
19 Lukács 1999. 14.
20 Lukács 1999. 12.
21 Lukács 2000. 147.
22 Levárdy 1980. 10.

1.2. Historical summary of the vault of the Reformed Church of Nyírbátor

Although in the case of the Reformed Church of Nyírbátor, the exact time of the construction works and the builder of the church are also subject to scientific debate, the church – and its vault – was certainly built at the end of the 15th or at the beginning of the 16th century *(Fig. 2)*. László Császár[23] and Géza Entz[24] both claim that the construction works started in the 1480s, thus the benefactor was István Báthori (voivode of Transylvania, 1430–1493), whose name is inscribed in a blazon in the southern gate's lunette.[25] This idea is also supported by a charter from 1484, which suggests the want of the church's building.[26] On the other hand, in an inscrip-

Figure 2. The vault of the Reformed Church of Nyírbátor

[23] Császár 1987–1988. 153.
[24] Entz 1994. 1.
[25] Papp 2005. 67.
[26] Papp 2005. 67.

tion on the frieze of the gate's cornice András Báthori (István Báthori's nephew) appears as the donator of the construction works from the very beginning.[27] Supporting the latter statement, in the lower region of one of the easternmost buttresses the inscription of the number "94" is visible – presumably, the date 1494, signing the beginning of the construction works.[28] Also, the autobiography of Siegmund Herberstein records how he spent three weeks as the guest of András Bonaventura Báthori (the son of András Báthori) in Nyírbátor in 1551 and describes the church as the work of his host's father.[29] According to Szilárd Papp, signs of a plan alteration may also be detected as the two westernmost bays as shorter than the others, however, he also accentuates that the alteration occurred before the building of the vault.[30]

The damages caused by an earthquake in 1834 were repaired in 1837 and between 1931 and 1934 structural strengthenings planned by István Möller were carried out.[31]

1.3. The two vaults' connections based on the literature

The close connection between the vault of the Reformed Church of Nyírbátor and the nave vault of the Franciscan Church of Szeged-Alsóváros was suggested in multiple publications: they are said to be the work of the same guild[32] (which supposedly also carried out the royal buildings in Visegrád and the Reformed Church in Farkas Street in Kolozsvár) and the same master builder called Brother János.[33] (Regarding the church of Nyírbátor and the church in Farkas Street, Brother János is also mentioned by Géza Entz[34] and Szilárd Papp.[35]) However, studying the literature, it seems that these connections are not based on written sources. They are supported merely by similar details (e.g. the shaping of the wall columns in the case of the church of Nyírbátor and the church in Farkas Street[36]) or "architectural-historical analyses".[37]

To complete the comparison of the two vaults which are the subject of our analyses presented in this paper, the question of the structure of these vaults must be mentioned as well. In the 20th-century literature, the claim that both vaults are barrel vaults in the structural sense and the ribs merely serve as decoration mounted on the barrel vault was a widely accepted idea.[38] The nave vault of Szeged-Alsóváros was thus described among others[39] by István Harsányi,[40] who based his statement on his elaborated structural research and minute observations. However, Szilárd Papp highlighted that in the case of the church of Nyírbátor, the top side of the vault

[27] Papp 2005. 67.
[28] Papp 2005. 68–69; However, Entz explained the date as the conclusion of the construction works, thus it supports his theory. (Entz 1994. 1.)
[29] Papp 2005. 69.
[30] Papp 2005. 70.
[31] Entz 1994. 3.
[32] Nagy 1944. 92.
[33] Bálint 1966. 13; Levárdy 1980. 7.
[34] Entz–Szalontai 1959. 47.
[35] Papp 2005. 11–12.
[36] Entz–Szalontai 1959. 47.
[37] Császár 1987–1988. 153.
[38] Nagy 1944. 93; Bálint 1966. 26.
[39] Levárdy 1980. 8; Lukács 1999. 14.
[40] Harsányi 2001. 302; Harsányi 2005. 14.

clearly shows the elevations of the individual webs instead of the single curved surface of a barrel vault's back.[41] In the case of the nave vault of Szeged-Alsóváros, Balázs Szőke rejected the barrel-vault theory (first as a possibility,[42] later as a statement[43]).[44]

Based on the numerous statements regarding the two vaults, we think that their comparison based on their laser-scanned exact geometry could lead to relevant new results in the field of Hungarian Late-Gothic architecture.

2. METHODOLOGY

In the present article, our conclusions are drawn from the exact geometries of the two analysed vaults, which were surveyed with Leica BLK360 laser scanner. The point cloud was processed in Leica 360 Cyclon Register and analysed in AutoCAD. The Leica BLK laser scanner is only capable of 4 mm nominal accuracy in a 10 m distance[45], which in this case may cause 1–2 cm inaccuracy (depending on the height of the spaces). As the building technology at the time of these structures' construction implies a more significant imprecision, we claim that the accuracy of this scanner is adequate for the purpose of the present research. Related to this, the degree of deviation we accepted as regular when examining the structure's orderliness must be defined. Based on the supposed precision of the original construction times[46] and our experiences from our former case studies, we accept an approximately 5 cm deviation as accurate. It must be noted that during our data recording from the point cloud, certain inaccuracies in the measurements may occur as well. However, we claim that in comparison to the orderliness of the structure's geometry (mainly resulting from the technological possibilities of its construction time), the potential unevenness of our measuring accuracy does not result in errors of such a degree which influence the outcome of our research.

To find out the connection between the vaults' ribs and webbing, the point clouds were cut by horizontal planes resulting in the "mapping" of the system *(Fig. 3)*. ("Mapping" as an empiric method to describe vault surfaces was already used by Choisy in 1883[47] and Rave in 1955.[48]) In this step of the analysis, three fundamentally different results are conceivable. If the section of the webbing is a straight line parallel to the longitudinal walls and does not respond to the positions of the ribs, the structure is likely a pseudo-ribbed net vault *(Fig. 4. a)*. If the webbing's section line is close to a straight line (or is slightly introflexed), is not necessarily parallel to the wall, and reflects the rib's position, the structure is presumably a real net vault, where the webs were

41 Papp 2005. 199.
42 Szőke 2005. 890.
43 Szőke 2009. 449.
44 As the use of the terminology differs in the sources, we hereby define that in the present paper, by "real net vault" we mean the vault structure where the rib system is antecedent to the webbing, and the webs are built on the ribs (either with or without formwork), and by "pseudo-ribbed net vault" we mean the structure where the ribs are mounted subsequently (however, not necessarily in a different building period) on a barrel vault.
45 Krähling–Fehér 2019. 147.
46 Fehér–Halmos 2017. 222 presents a number of discrepancies in the geometry of vault's rib elements, some of which are due to the inaccuracy of the original work. Such discrepancies most likely occurred not only on the scale of individual elements, but on the scale of the global geometry as well.
47 Choisy 1883. 54. fig. 60.
48 Wendland 2007. 345.

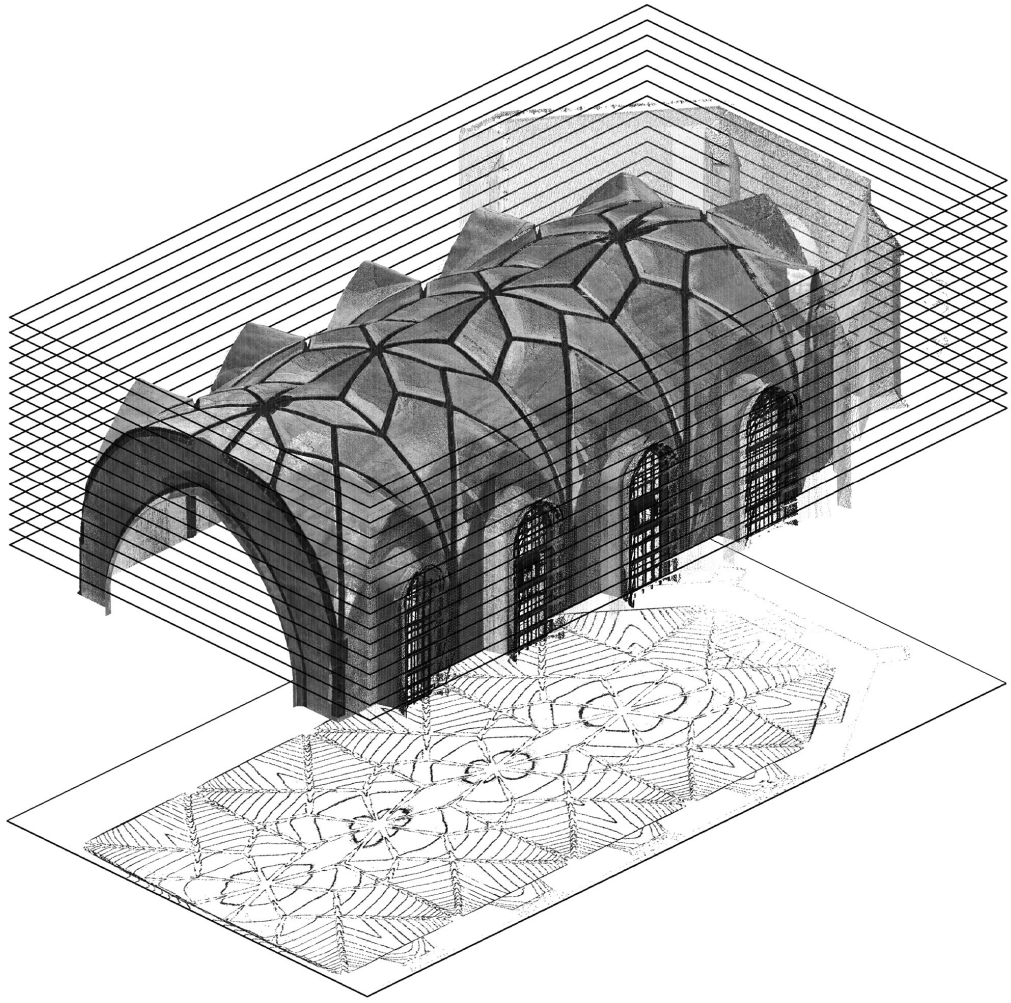


Figure 3. 'Mapping' of a vault

built with formwork *(Fig. 4. b)*. If the section line of the webbing is curved (therefore responds to the ribs' position as well) the probable structure is a real net vault with webs built without formwork *(Fig. 4. c)*. (Clemens Voigts drew conclusions about the use of formworks with a very similar method.[49])

After deciding the likely strategy of the vault's building technology by mapping, we carried out the analysis of the vault's rib system. In this step, we first examined the plan of the rib system and looked for an underlying construction idea. We think this is a necessary step, as although the literature on the net vault's building technique mostly accepts the construction of the plan

[49] Voigts 2014. 248.

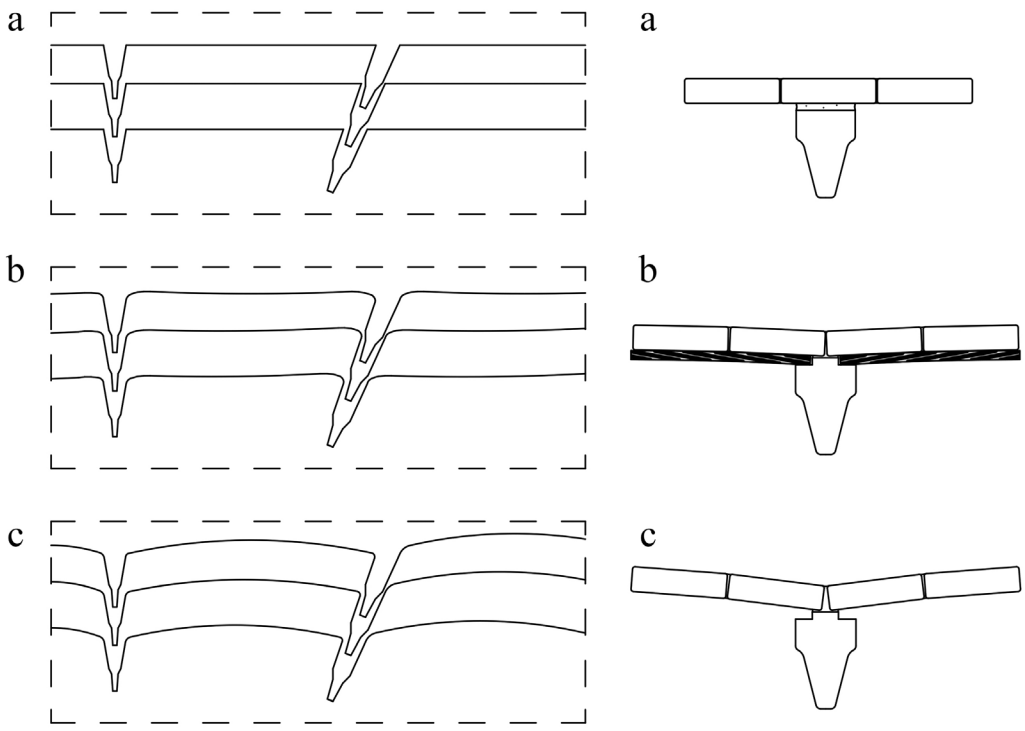


Figure 4. Theoretic outcomes of a net vault's mapping with the sketch of the structural solution it indicates (top to bottom: pseudo ribbed barrel vault, real net vault with ribs built on formwork, real net vault with ribs built without formwork)

pattern as the initial step for creating the rib system (e.g.: the works of Bartel Ranisch,[50] Friedrich Hoffstadt,[51] Otto Warth,[52] Georg Gottlob Ungewitter[53]), during our former vault analyses, we realised that different methods may exist as well. In certain cases (Church of Szászbogács,[54] Church on the Hill of Segesvár[55]) – mainly due to the irregular building plans – the first step was the construction of a "vertical" quadrate net determining the rib junction points' heights and positions in the vault's cross directions (thus, the vault's cross-section) *(Fig. 5. a)*.

The next step is the analysis of the rib junction points' spatial position, by examining the interdependence of their projected pictures to the longitudinal and cross-sections. *(Fig. 5. b–c)*. In this step, we analyse the corresponding junction point's positions relative to one another. This, together with the plan analysis, may lead to conclusions about the temporary supporting structures of the vault's constructions. (It is to be noted that the approximation of the junctions' spa-

50 Ranisch 1695.
51 Hoffstadt 1840.
52 Warth 1896.
53 Ungewitter 1901.
54 Jobbik–Krähling 2022.
55 In press.

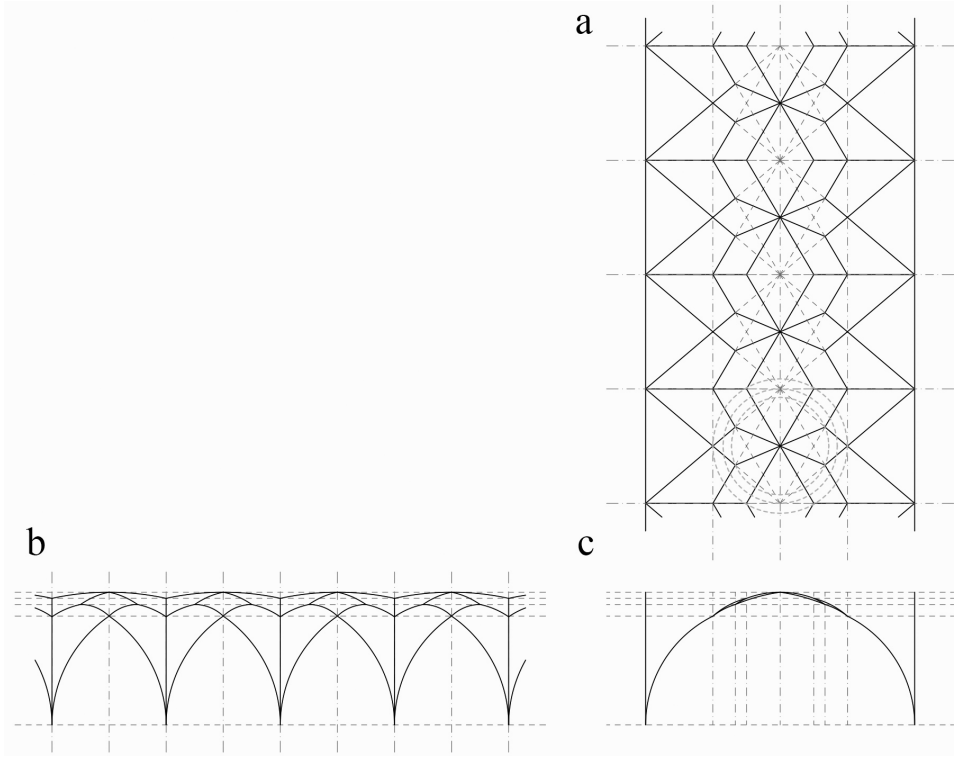


Figure 5. Analysis of a net vault's rib system.
a) Plan analysis, b) Longitudinal section analysis, c) Cross-section analysis

tial positions as points on a hemicylinder – as often represented in the literature[56] – most likely is not to be interpreted as the actual supporting structure during the building works. Using surface structures for that purpose is not beneficial either economically or workload-wise.) During this part of the research, it must be taken into account, that even though the importance of ratios and orderly construction methods in Gothic architecture is often accentuated, the results of modern survey methods sometimes suggest that these do not always characterise each detail of a building.[57]

The last step of our analysis concerns the individual ribs. We measure the rib curvatures since based on the newest research, the "Prinzipalbogen-theory", on which formerly the majority of the researchers relied when describing net vaults (e.g. Ranisch,[58] Hoffstadt,[59] Meckel,[60]

[56] E.g. Warth 1896. 258–259; Ungewitter 1901. 64.
[57] Fehér–Halmos 2019. 110.
[58] Ranisch 1695.
[59] Hoffstadt 1840.
[60] Meckel 1933.

Müller,[61] Tomlow[62]), was not used exclusively by the Late-Gothic net vault structures[63]. (It is to be noted that measuring the ribs' curvatures, especially in the case of shorter ribs, is a difficult task, as a small change in the arch's height results in a great change in the value of the radius of the curvature. However, this applies not only to the measurements but to the initial fabrication of the ribs as well. Thus, if such a variation is acceptable as inaccuracy during the building process, it must be accepted as measurement inaccuracy as well.)

Based on our above-detailed geometric observations we were able to compare the two vaults on a level which was hitherto not possible, and we attempted to reconstruct the plausible building methods in both cases based on our minute examinations.

3. RESULTS

3.1. Geometric analysis of the nave vault of the Franciscan church of Szeged-Alsóváros

As described in the Methodology chapter, the first step of the point cloud's analysis is the mapping of the vault *(Fig. 6)*. Regarding the result of the mapping, we made four major observations.

- At the lower part of the vault (grey on *Figure 6*) the webbing's section lines are parallel to the longitudinal (northern and southern) walls and do not respond to the positions of the ribs.
- On the higher part of the vault (white on *Figure 6*) the webbing's section lines are mostly slightly introflexed and turn in to the ribs.
- By the imposts, the webbing's section lines are straight, and an obvious effort can be observed to reach a continuous, straight line by the splice of the lunettes to the main body of the vault.

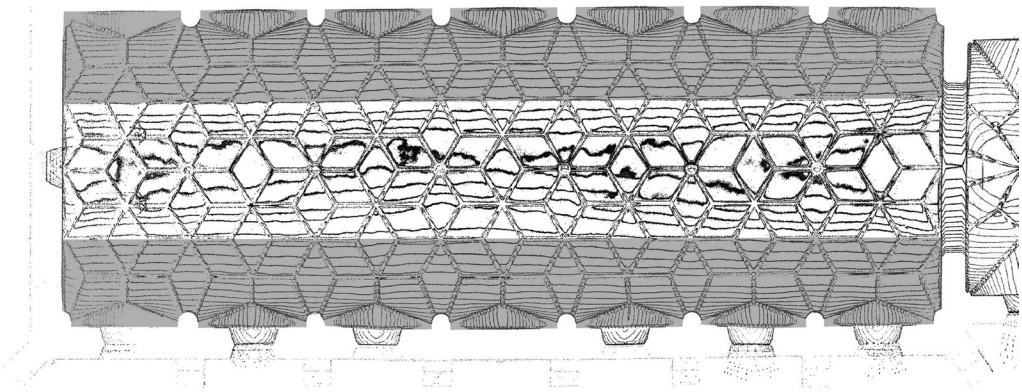


Figure 6. The mapping of the nave vault of the Franciscan Church of Szeged-Alsóváros, the colours indicate the change in the vault's character

[61] Müller 1990.
[62] Tomlow 1991.
[63] Jobbik–Krähling 2022.

- On the southern side of the vault, a significant dint can be detected, which extends through multiple ribs and the webbing in between them. (The phenomena was described by István Harsányi as well.[64]) An important addition to this deformation is that according to the scanned data, the northern and southern walls of the nave are nearly perfectly vertical. (Thus, the vertical shift due to the outward leaning of the walls, which was the most plausible cause for the southern side's dint, does not exist) *(Fig. 7)*.

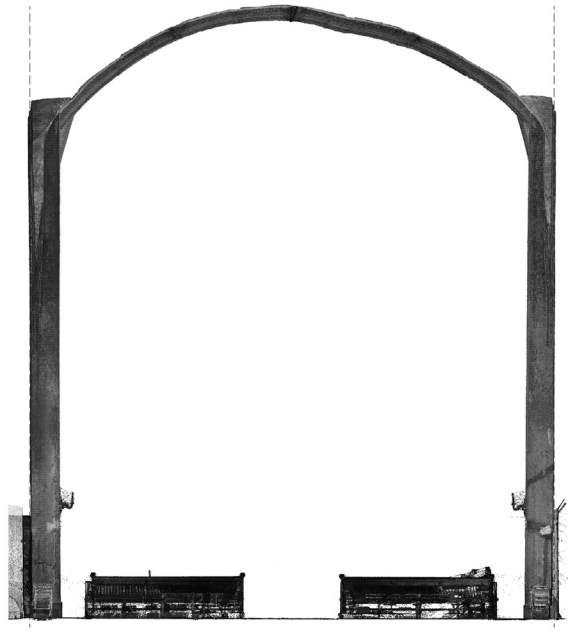


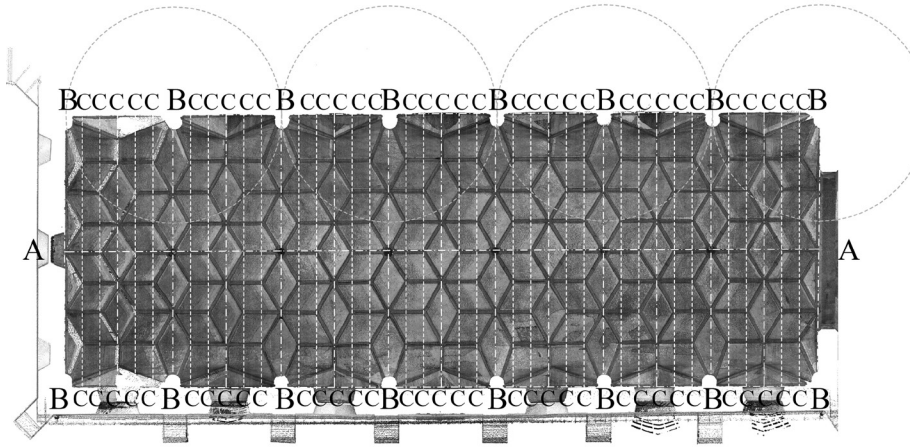
Figure 7. The cross-section of the inner space of the nave of the Franciscan Church of Szeged-Alsóváros, the vertical direction indicated by the walls

Our next examination targeted the plan of the rib system. In this step, we made the following observations:

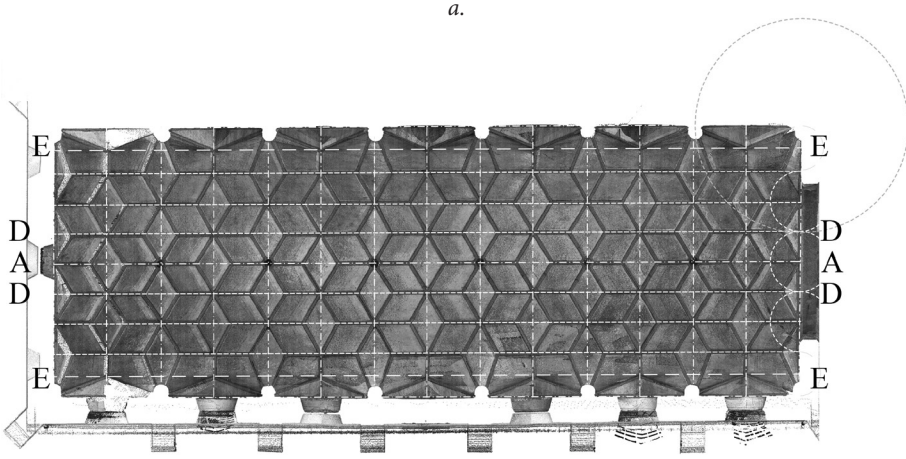
- The crown line[65] of the vault is identical to the line connecting the midpoints of the two short walls of the nave *(Fig. 8. a,* line *AA)*.
- The imposts are distributed evenly along the longitudinal walls. The plan views of the ribs' junction points fall on the lines connecting the corresponding imposts (*Fig. 8. a,* lines *BB*). Dividing the neighbouring imposts' distances by six, and drawing the lines between the corresponding division points, each junction point's position in the vault's longitudinal direction can be determined *(Fig. 8. a,* lines *CC)*.
- Straight lines on the plan, on which the corresponding junction point's picture fall, can be detected in the longitudinal direction as well. Projecting the distance of the imposts to the

[64] Harsányi 2005. 26.

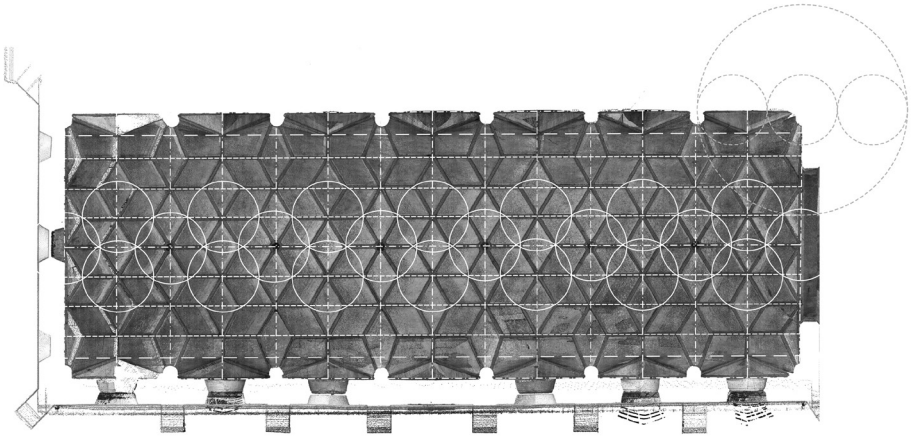
[65] In our article, the term 'crown line' means the line composed of the uppermost points of the vault's webbing, on which the uppermost rib junctions fit as well.



a.



b.



c.

Figure 8. a–c. Analysis of the rib system's plan in the nave of the Franciscan Church of Szeged-Alsóváros

short (eastern and western) walls, the endpoint of the two lines closest to the crown line can be found *(Fig. 8. b,* lines *DD)*. The distance between the neighbouring longitudinal lines equals the length difference between half of the short walls' length and the distance of the imposts on the long walls. The exceptions are the points where the lunettes meet the main body of the vaults: there the lines fall in the middle of the remaining distance to the walls *(Fig. 8. b,* lines *EE)*.

Numerous other orderly features can be detected on the plan (e.g. circles with a radius equal to a third of the imposts' distances can be drawn to determine the rib pattern's junction points – *Figure 8. c*). Since the rib system's plan proved to be highly regular, we think that finding the underlying construction idea used by the original builders is not possible, since no irregularities occur which could exclude certain possibilities. However, we see it proved, that the rib system's plan was indeed constructed.

Regarding the rib junction's picture projected to the longitudinal sections, we found that the corresponding points fall on the same straight lines on both sides (except the dinted parts of the vault's southern side). These lines are parallel to each other and they are slightly sloping to the west *(Fig. 9)*.

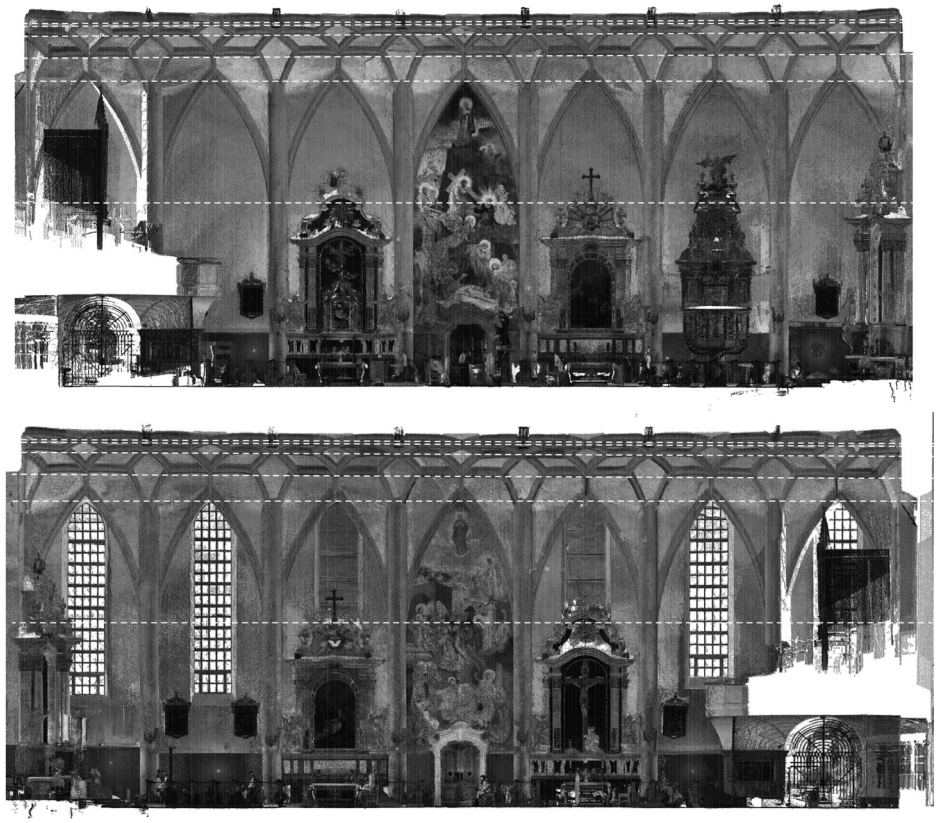


Figure 9. Analysis of the rib junction's positions on the longitudinal sections in the nave of the Franciscan Church of Szeged-Alsóváros (upper: longitudinal section looking to the north; lower: longitudinal section looking to the south)

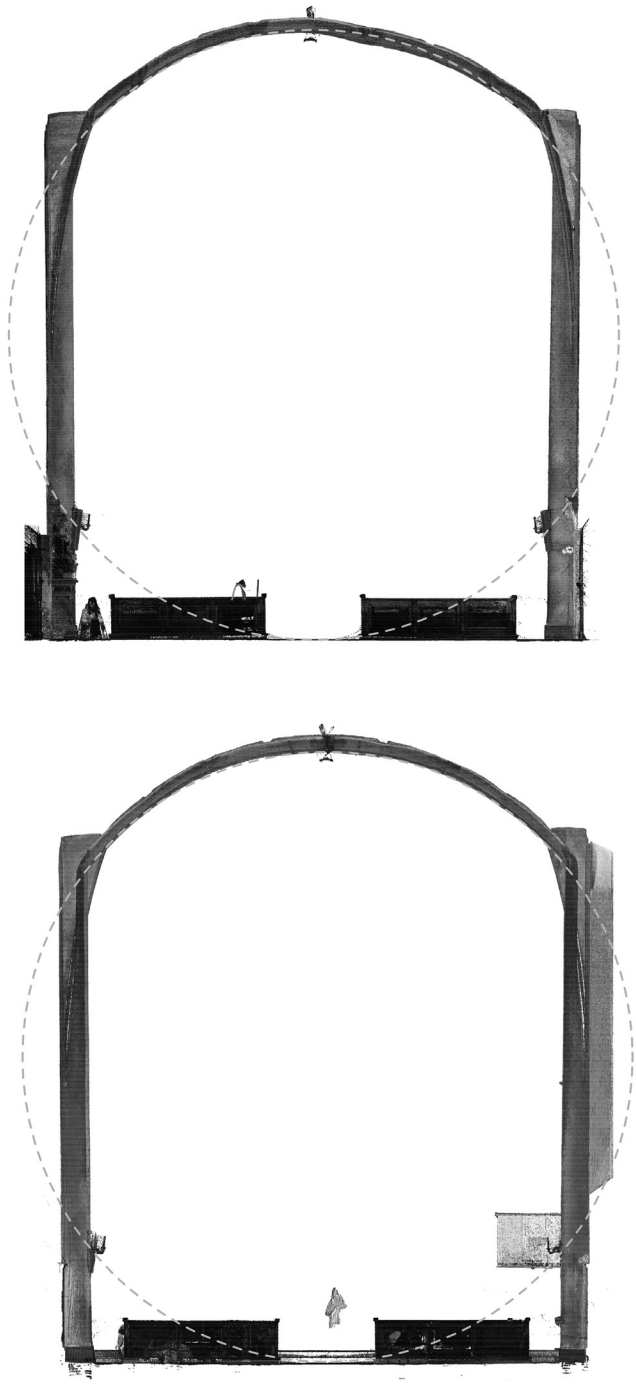


Figure 10. Cross-sections of the nave of the Franciscan Church of Szeged-Alsóváros, in the middle (where the vault is deformed) and on the eastern part (where the deformations cannot be detected)

Analysing the cross-sections of the vault, we reached the following conclusions:

- The rib junctions' lower surfaces on the cross-sections of the vault follow a circle segment. Drawing the full circle, we found that its diameter equals the distance between the lower surface of the highest rib junctions and the floor of the church. Two and a half times the same diameter equals the length of the nave (and one and a half times the diameter is the length of the apse). The latter observations indicate that the circle fitting the height is not a coincidence *(Fig. 10)*. (As the cross-section is a circle segment, on the diagonal sections in the direction of the system's diagonal ribs, the rib junctions' lower surfaces must fit horizontal ellipses. This premise proved to be true as well, as *Figure 11* presents.)
- Analysing the position of the points, where the lines found on the longitudinal sections and the plan intersect the wall of the triumphal arch, we found that the height of the imposts equals the height of the midpoint of the circle the segment of which determines the rib junction's positions *(Fig. 12)*.

Carrying out the individual ribs' analysis[66] we concluded that the ribs' radius of the curvature can be accepted as uniform. However, as we detailed in the Methodology chapter, a degree of uncertainty always occurs in such measurements. In this case, the measured curvatures varied between 7.95 and 9.88 meters, while the rib's chord lengths fell within the range of 1.90–2.00 meters (except the ribs of the lunettes). Considering that with a chord length of 2.00 meters, the height difference between two arches, with curvatures of 7.95 meters and 9.88 meters, is 1.2 centimetres, the measured curvatures are well within the accepted range of inaccuracies, thus can be accepted as uniform.

The rib system of the vault contains ribs which are parallel to the longitudinal walls. This feature of the vault was described by multiple researchers. László Császár stated that these are straight, therefore they can not have a load-bearing role in the system.[67] However, according to our laser-scanned survey, these ribs have a similar curvature as all the other ones in the system, thus the Prinzipalbogen principle may apply to the vault.

3.2. Theoretic reconstruction of the building process of the nave vault of the Franciscan Church of Szeged-Alsóváros

István Harsányi has already given a reconstruction of the vault's building method. He described the vault as a pseudo-ribbed net vault. That is, he wrote that the building process started with the building of a barrel vault, under which the rib system was built, and the gap between the two was filled in with mortar.[68] During his on-site observations, he found the mortar fillings. However, his reasoning that the weight of the webbing (which he calculated) would be way too high for the masonry ribs to carry, according to the present state of knowledge, is not correct. The ribs and webbing of a ribbed vault hold a dynamic equilibrium thus the inner forces are capable of rearranging if the circumstances change,[69] and multiple equilibrium states exist for the same structure.[70] Therefore, after concluding the building of all elements of the vaults, the ribs' capa-

[66] The measurements were carried out on a third of all the individual ribs, in even distribution along the vault.
[67] Császár 2002. 159
[68] Harsányi 2005. 14
[69] Lengyel–Bagi 2015. 58.
[70] Heyman 1995. 20–22; Huerta 2012. 183.

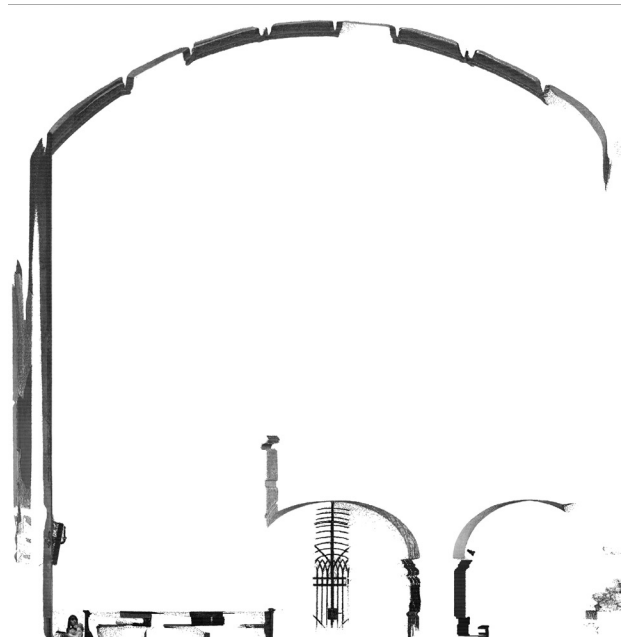


Figure 11. Elliptical-shaped diagonal section of the nave of the Franciscan Church of Szeged-Alsóváros

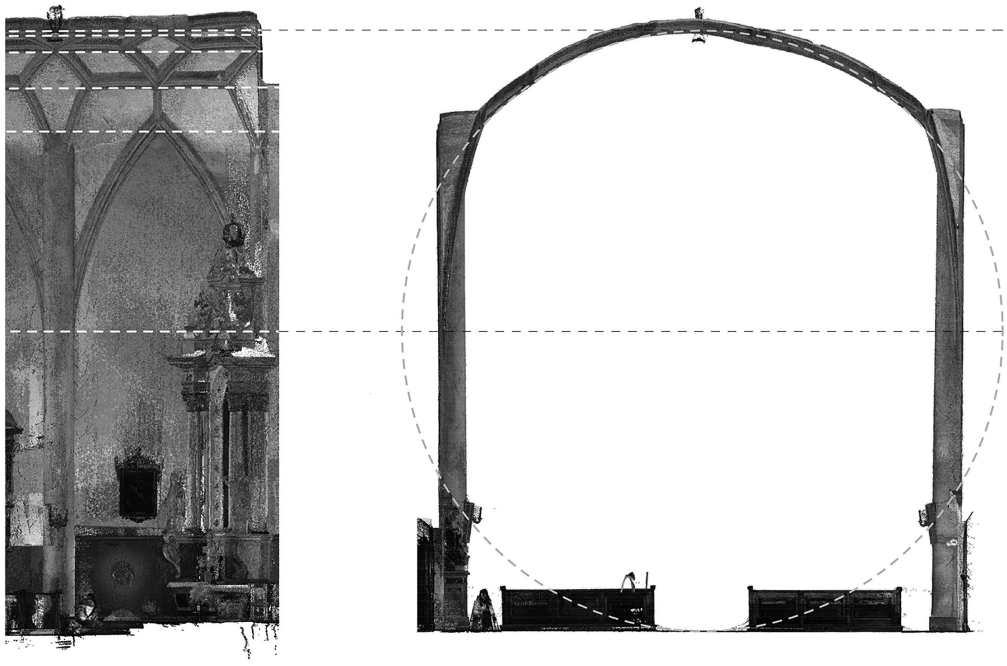


Figure 12. The relation of the imposts' position to the circle determining the vault's construction in the case of the nave of the Franciscan Church of Szeged-Alsóváros

bility to support the weight of the whole webbing is not necessary. Besides, the building process described by Harsányi leads to technical difficulties. To build such a flat segment-arched barrel vault, full surface formwork is necessary *(Fig. 13. a–b)*. Then, to build the rib system, this must be taken off, and a new, linear formwork must be erected to build the rib system *(Fig. 13. c)*. Inserting the rib elements between the barrel vault and the centrings *(Fig. 13. d)* is a problematic technique in itself. (The building process described by Harsányi can be seen on *Figure 13.*)

Harsányi's method also does not explain two geometric ascertainments, which were found by analysing the point cloud: On the one hand, the different qualities of the vault's lower and upper parts detected on the mapping, and on the other hand, the fact that the spatial position of the ribs' lower surface seems to be initially determined (although calculating with the ribs' height could have been possible, if difficult).

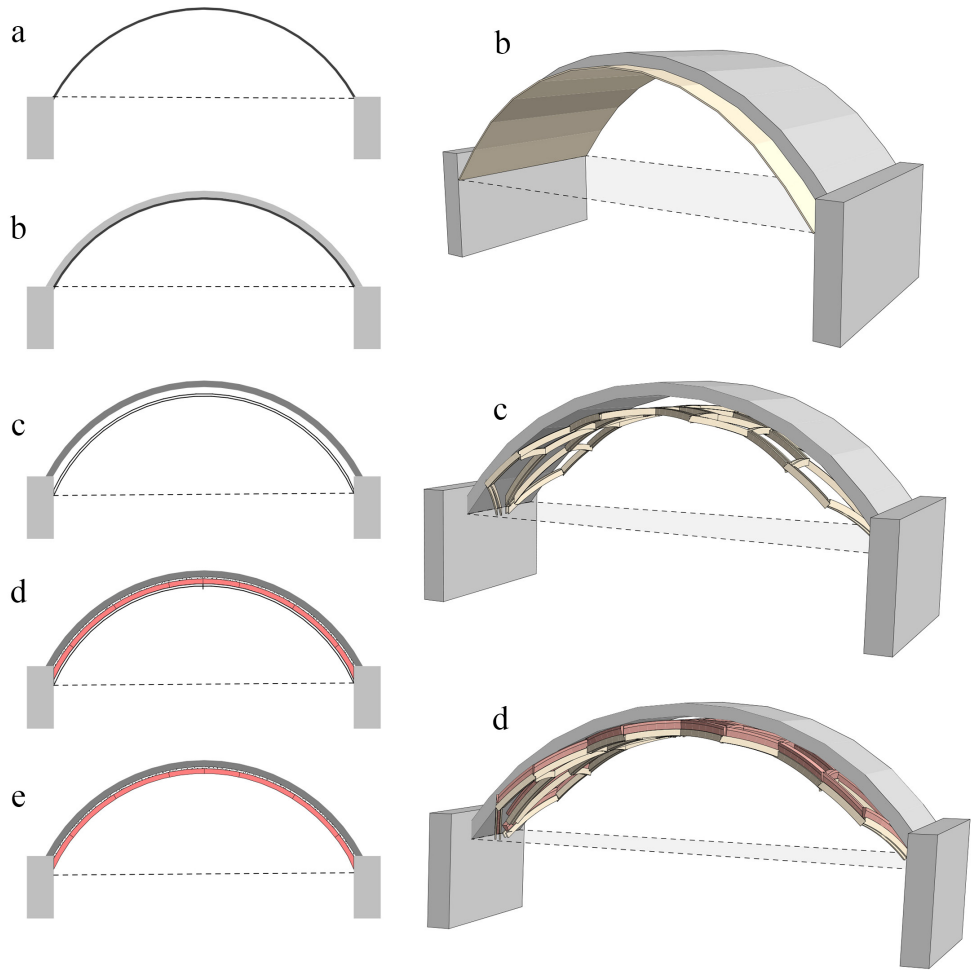


Figure 13. István Harsányi's theoretic reconstruction of the nave vault of the Franciscan Church of Szeged-Alsóváros's building process. The figure does not attempt to reconstruct the exact temporary supporting structure, just those elements which determine the vault's geometry (the authors' illustration)

Based on the geometric regularities we found, we also attempted to reconstruct the original building method *(Fig. 14)*:

- First, a full-surface circle segment-shaped formwork was built, at the height of the rib system's lower surface *(Fig. 14. a)*. On this, the rib system was built *(Fig. 14. b)*. (The regular plan of the rib system makes it reasonably simple to plot the position of each rib and rib junction even on a slightly curved surface.) Thus, it is explained, why the lower surface of the ribs is carefully positioned. The significant dint of the vault's southern side (which, as we stated above, presumably did not occur due to the walls' displacement) also supports the idea of a temporary structure, which supported both the rib system and the webbing, as the deformations extend gradually through multiple ribs and the webbing in between them.
- Then, the lunettes' own formwork was made, and the lunettes were built.

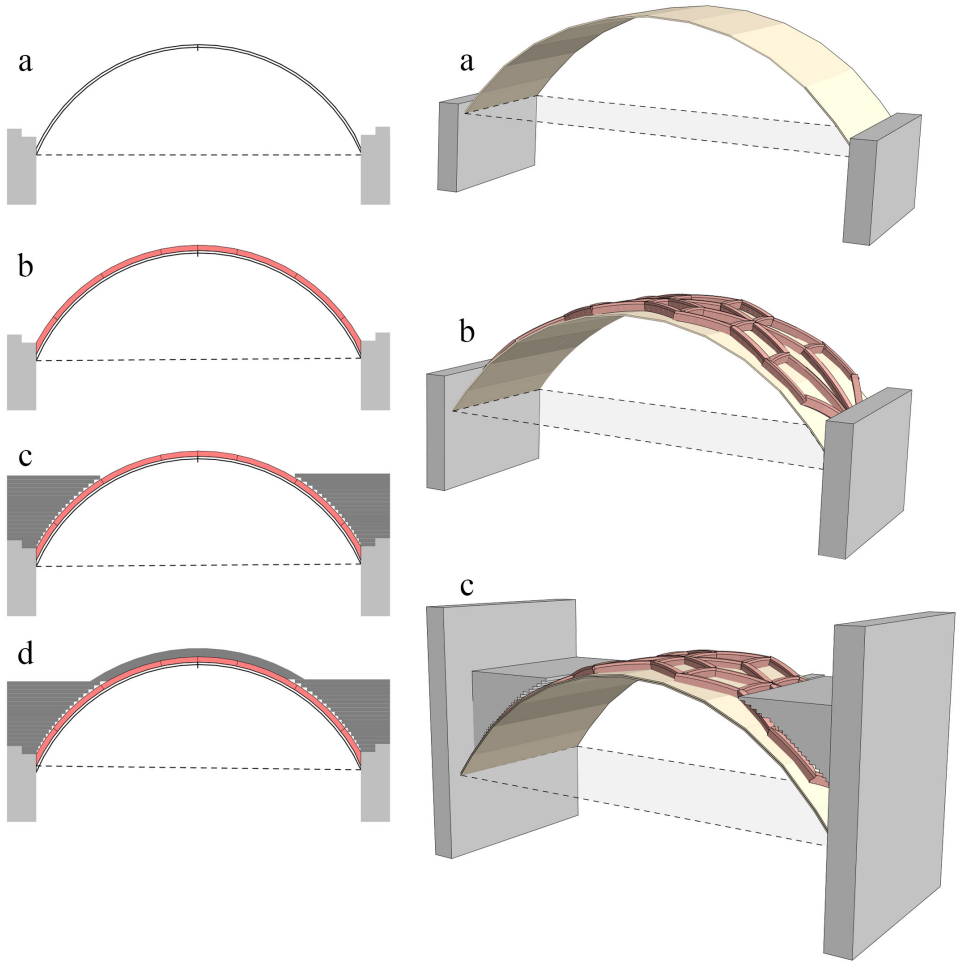


Figure 14. Theoretic reconstruction of the nave vault of the Franciscan Church of Szeged-Alsóváros's building process. The figure does not attempt to reconstruct the exact temporary supporting structure, just those elements which determine the vault's geometry

- The next step was to build the lower part of the webbing *(Fig. 14. c)*. This was presumably carried out as the impost zone of a barrel vault, the structure gradually (course by course) "consoles" out from the wall. This explains why the lower region of the vault shows the characteristics of a pseudo-ribbed net vault, as can be seen on the mapping. Also, the borderline of the lower region falls slightly before the third of the circle segment's arch length, which is approximately the point where an arched structure first loses its stability. In addition, at this part of the vault, the mortar filling between the webbing and the ribs is still necessary, thus Harsányi's findings during his on-site research can be explained. (It is also to be noted that the top side of the lower region of the vault is covered with the filling materials, thus the actual direction of the masonry courses cannot be examined.)[71]
- Reaching the point where the webbing could not be built by consoled courses without a full-surface framework any more, the technique was altered, as the mapping indicates as well. Presumably flat secondary centrings were implemented between the ribs, on which the building of the webbing could be finished *(Fig. 14. d)*.
- Finally, the temporary supporting structures were taken down.

3.3. Geometric analysis of the vault of the Reformed Church of Nyírbátor

The mapping, the first step of our vault analysis was carried out in the case of the vault of the Reformed Church of Nyírbátor as well *(Fig. 15)*. In this case, we found that the section lines of the webbing distinctly change directions by each rib and have a significant arch. Thus, we concluded that this vault is a real net vault.[72]

Regarding the rib system's plan, we concluded the following statements:

- The plan pictures of the corresponding ribs' junction points fall on straight, parallel lines both in the longitudinal and cross-directions of the vault.

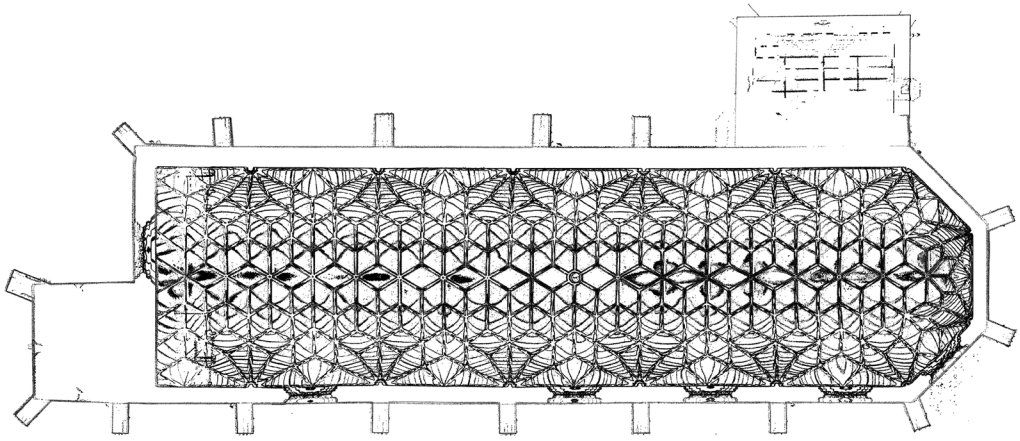


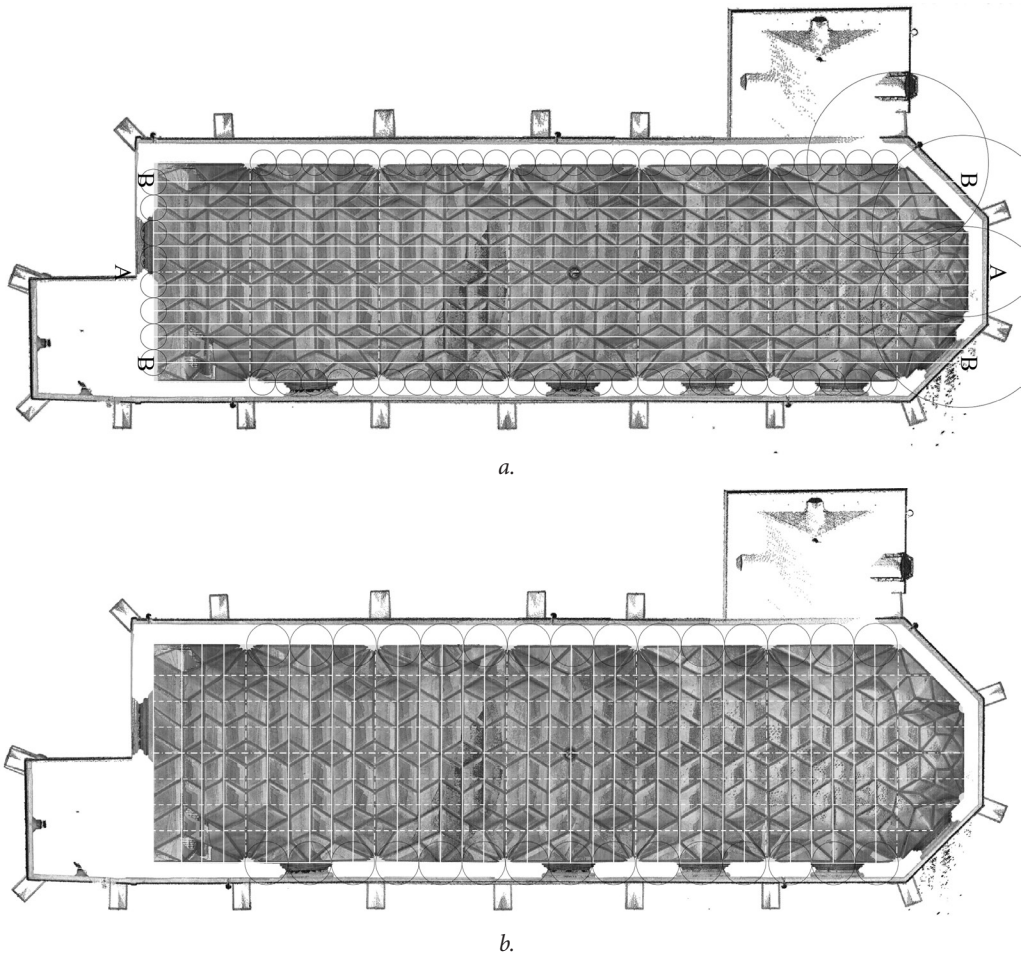
Figure 15. The mapping of the vault of the Reformed Church of Nyírbátor

[71] The similarity of the reconstructed idea and that of the tas-de-charge of the vaults (see in: Fehér 2021) shows that this kind of thinking was no stranger for the Gothic master builders.

[72] According to our own definition.

- The crown line of the vault coincides with the line connecting the midpoint of the western wall and the apse's end wall. (*Fig. 16. a*, line *AA*) The distance of the longitudinal lines from each other equals a tenth of the distance between two neighbouring imposts (except the lowest lines on both sides [*Fig. 16. a*, lines *BB*]). Seven times the tenth of the neighbouring imposts' distances equal the length of the apse-polygon's sides (inner sizes). (It is to be noted that the westernmost bay is indeed shorter, as Szilárd Papp described.[73]) *(Fig. 16. a)*.
- The cross-direction lines divide the distance of the imposts into six equal parts *(Fig. 16. b)*.

Similarly to the nave vault of the Franciscan Church of Szeged-Alsóváros, the above-described lines determine the junction points' plan positions, however, circles may also describe the geometric pattern of the vault's rib system. Thus, even though the original construction method cannot be found with certainty, we concluded that the existence of an underlying construction method is very likely.



a.

b.

Figure 16. a–b. Analysis of the rib system's plan in the case of the Reformed Church of Nyírbátor

[73] Papp 2005. 70.

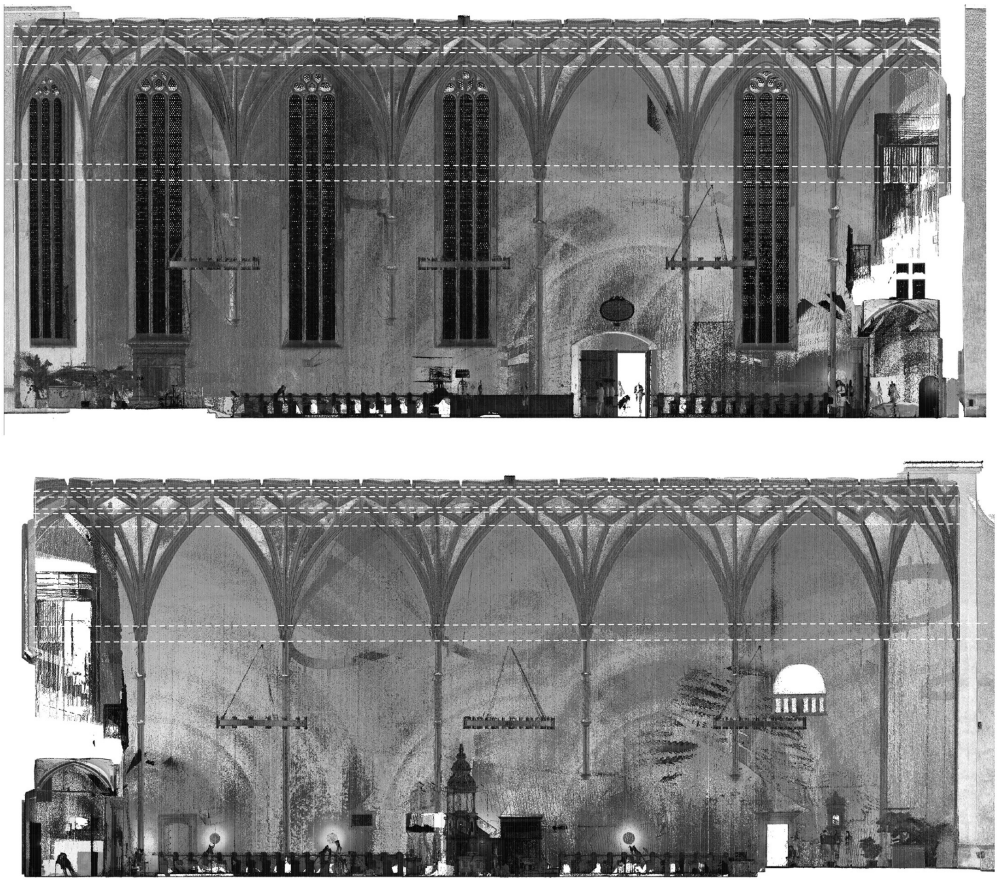


Figure 17. Analysis of the rib junction's positions on the longitudinal sections in the case of the Reformed Church of Nyírbátor

Regarding the longitudinal sections, we found that the corresponding junction points are at the same heights *(Fig. 17)*.

Examining the cross-sections, our observations are the followings:

- On the cross-section of the vault neither the lower surface of the ribs nor that of the webbing can be described with a circle segment *(Fig. 18. a)*. (The section in the direction of the diagonal ribs cannot be described with a single arched line at all [*Fig. 18. b*])
- Regarding the points representing the longitudinal lines (the spatial positions of which were presented on the plan and the longitudinal sections) on the cross-sections, we could reconstruct a quadrate-net construction. The height of the vault from the imposts to the lower surface of the rib system's crown line equals the neighbouring imposts' distances. By taking a sixth of the side length of a quadrate of the net, each junction type's height value can be constructed *(Fig. 19)*.

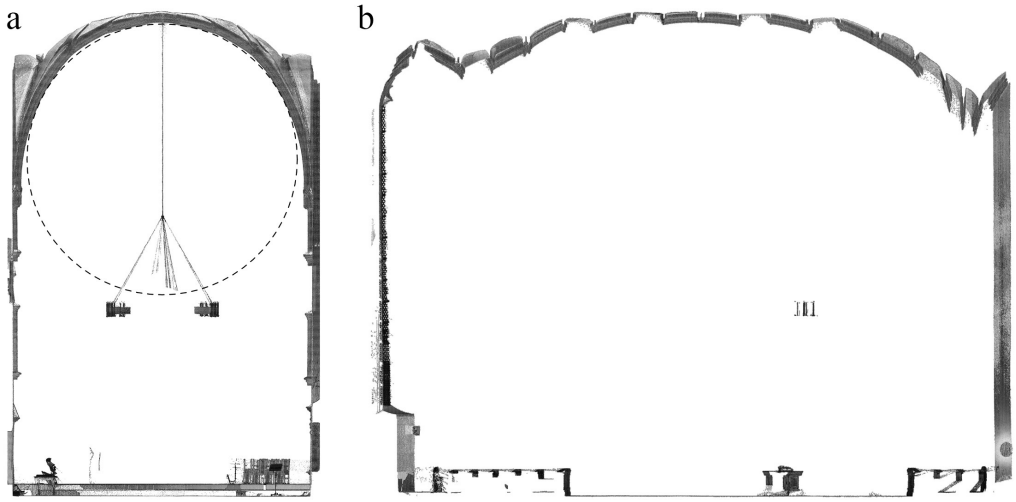


Figure 18. Cross-section and diagonal section of the nave of the Reformed Church of Nyírbátor

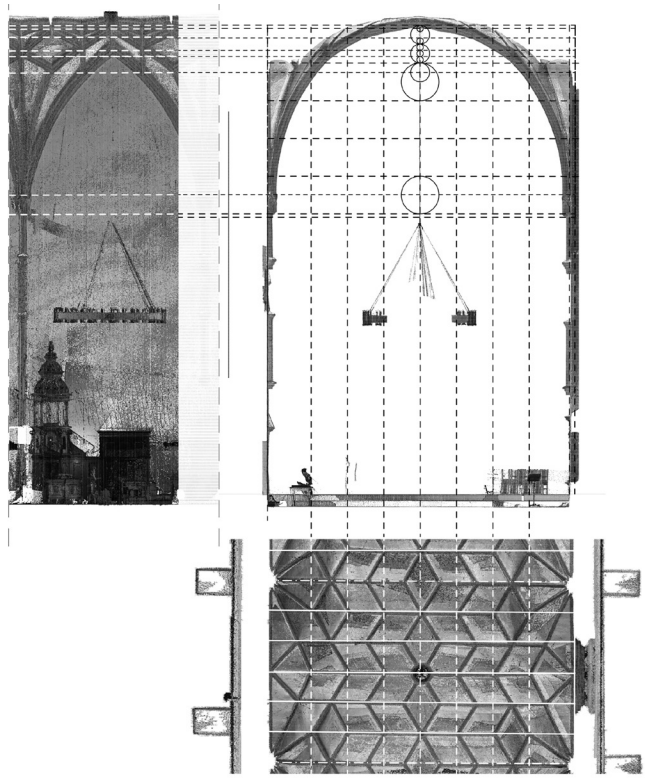


Figure 19. Reconstructed quadrate-net for the construction of the rib junction's positions of the nave of the Reformed Church of Nyírbátor

Measuring the radius of the curvature of the individual ribs,[74] we found that they not only can be accepted as uniform (thus the "Prinzipalbogen" principle applies), but the average value of the radius of the measured ribs (7.02 m) approximates the distance between the neighbouring imposts. (With the uncertainties of these measurements detailed above.)

All things considered, we found that in the case of the Reformed Church of Nyírbátor numerous underlying geometric design principles apply, on the plan layout, in regards to the junctions' heights and on the plan of the vault's rib system as well. Thus, the church indeed shows features of buildings constructed along uniform principles, presumably in one building period.

3.4. Theoretic reconstruction of the building process of the vault of the Reformed Church of Nyírbátor

In the case of the Reformed Church of Nyírbátor, we attempted to reconstruct a plausible building process as well *(Fig. 20)*.

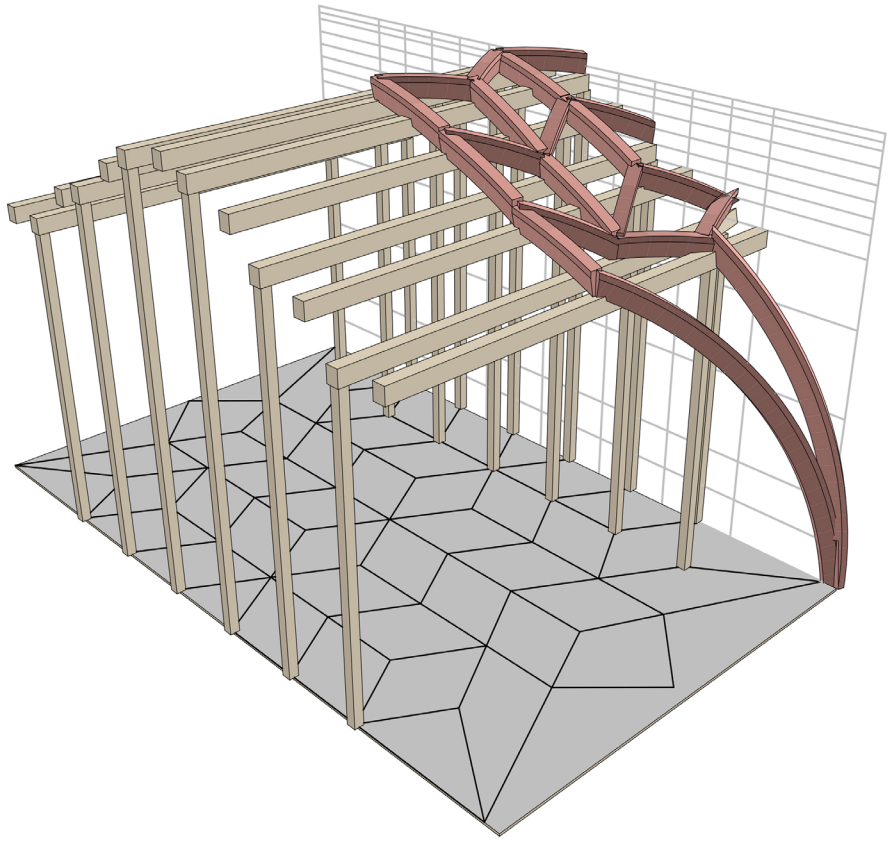


Figure 20. Theoretic reconstruction of the vault of the Reformed Church of Nyírbátor's building process

[74] The measurements were carried out on a third of all the individual ribs, in even distribution along the vault.

- As a first step, the temporary supporting structure was erected. In this case, the application of linear elements is likely as the vault's geometry is also describable by lines and neither the ribs nor the webbing follows even surfaces. (Using an elevated working level is probable due to practical considerations.)
- On this supporting structure and centrings, the rib system was built.
- Then, as the mapping of the vault suggests, the webs were built freehand (as the span to be covered by an individual web is suitably small for this method).
- Finally, the temporary supporting structure was taken down.

4. DISCUSSION

As the results of the two point clouds' analysis showed, several significant differences occur between the two vault structures.

The mapping of the vaults revealed that while the nave vault of Szeged-Alsóváros shows features characteristic to pseudo-ribbed vaults and webs built on formworks, the webbing's section lines in the case of the vault of Nyírbátor are rather dependent on the ribs' positions and have significant curvature, thus render a real net vault with webs built freehand likely.

Although the rib system of both vaults was likely constructed, a significant difference is clear. As multiple researchers have pointed out,[75] the rib system of the nave vault in Szeged-Alsóváros contains ribs parallel to the longitudinal walls. Although as our survey showed, they are indeed not straight but slightly arched – thus capable of being self-supporting or even load-bearing elements (to an extent) in the system – visually, their not tectonic aspect is undeniable. In the case of Nyírbátor, no such elements appear in the rib system.

Another important difference between the two rib systems is the idea of constructing the height values of the ribs' junction points. In the case of Szeged-Alsóváros, the circle segment determining the overall shape of the rib system naturally gives these values as well. Whereas in the case of Nyírbátor, there is no such surface which describes the whole system. The height values can be constructed in strong connection with the other distances characteristic of the building, based on a vertical cross-direction quadrate net.

The application of the "Prinzipalbogen" theory can be accepted to be true in both cases.

All in all, the fundamental difference between the two structures lies in the fact that one of them (Szeged-Alsóváros) is describable with a surface, while the other (Nyírbátor) is not. In effect, both result in the explicit geometric description of the junction point's spatial positions, but in Szeged it is done by two coordinates (construction of the plan) and projection to a surface, while in Nyírbátor by three coordinates (two on the plan plus the height) *(Fig. 21)*.

We attempted to reconstruct a plausible building process in the case of both vaults based on our geometric findings. The two methods (presented above) significantly differ from each other. Although these reconstructions can by no means be considered confirmed, they take into account the fundamental geometric dissimilarity of the two structures. Thus, even though the exact methods are only theoretic reconstructions, we stand by the statement, that finding such a building technique, which can be applied to both vaults effectively, is highly problematic.

[75] Császár 2002. 155; Szőke 2005. 879; Szőke 2009. 449.

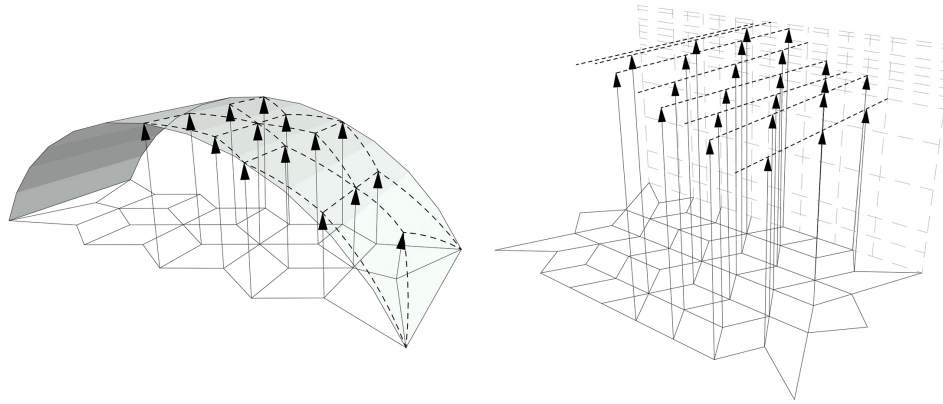


Figure 21. Theoretic difference of the construction principles of the two vaults; left: the nave vault of the Franciscan Church of Szeged-Alsóváros; right: vault of the Reformed Church of Nyírbátor

Based on the results presented in this article, we think it is worth revisiting the question of the formerly suggested strong connection between the two vaults. We found that the two structures fundamentally differ from each other regarding the connection of the rib system to the webbing. Furthermore, the underlying principles for positioning the rib systems' junction points in the space are also quite dissimilar, as in the case of Szeged-Alsóváros, a surface derivable from a circle segment describes the system, whereas in the case of Nyírbátor, the coordinates of the junctions points were constructed in three directions (parallel to the church's main axis, parallel to the church's cross-direction and the vertical height). On the whole, no significant similarity was found between the two vaults' geometric systems, thus no basis for reconstructing similar building methods was present. All in all, we think that the presumed strong connection between the two buildings, especially the work of the same guild or building master cannot be proven based on the underlying geometric construction design or the probable building techniques of the vaults. Naturally, it is not inconceivable that the same builders used different methods on different buildings. However, even though their rib pattern may seem similar at first glance, the two vault structures are not a strong enough basis to prove this former statement.

5. CONCLUSION

In the present article, we analysed the exact geometry of two vaults, which in the former literature on the topic were considered strongly related to each other. Based on our analysis we on the one hand carried out the geometric comparison of the two vaults, and on the other hand, proposed plausible theoretic reconstructions for the original building techniques of the structures.

Regarding the vaults' geometric analysis, we found that the nave vault of the Franciscan Church of Szeged-Alsóváros has features characteristic of pseudo-ribbed net vaults and net vaults with webbing built with formwork regarding the connection between the rib system and the webbing. The plan of the rib system was presumably constructed. According to our analysis, the vault's rib system can be described by a surface derivable from a circle segment, thus the spatial positions of the ribs' junction points can be derived by projecting the rib system's plan to this surface.

Analysing the vault of the Reformed Church of Nyírbátor, we found that the connection between the rib system and the webbing has features characteristic of real net vaults with webbing built freehand. The rib system of this vault cannot be described by an even surface. The plan of the vault was likely constructed. Based on our examinations, the heights of the rib junctions can be constructed based on a vertical quadrate net in the vault's cross direction. Thus, the rib junctions' spatial positions can be determined by three coordinates (parallel to the church's main axis, parallel to the church's cross-direction and the vertical height). We found that most dimensions characteristic of the vault system are strongly connected to the whole church's dimensions. Based on these findings, the church can be considered a self-contained geometric system.

Regarding the comparison of the two vaults, we found that as there are very few similarities between the measured geometric features and reconstructed underlying construction ideas, our findings do not support the formerly presumed strong building connections, although may not give enough basis to reject them either.

As for the original building techniques of the vaults, in the case of Szeged-Alsóváros, we re-evaluated the existing theory and described a technique consistent with each of our geometric observations. In the case of the vault of the church of Nyírbátor, we gave a theoretic reconstruction for the building process as well. The two techniques significantly differ from each other, in accordance with the great dissimilarities found in the geometric systems.

It is to be noted that our analyses and conclusions are based strictly on geometric observations and deductions made from those. We do not attempt to decide questions related to the building dates of the vaults at this point of our research. However, collecting data with similar methods as we used in this research regarding the plausible building techniques of individual case studies, with time, may provide enough information about construction methods characteristic of certain periods. This would make it worthwhile to revisit the question of the building date of the nave vault of Szeged-Alsóváros.

Aside from the concrete results of our hereby presented research, we find it important to accentuate the significance of revisiting the formerly accepted statements of the architectural-historical research, building connections and genealogies, as with the ever more accurate survey methods new, never before evaluated data can be collected about the buildings. The analysis of this data may provide new information, which either supports or weakens the former considerations of these topics.

6. ACKNOWLEDGEMENTS

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Conflict of interest

The 2nd author, János Krähling is a member of the Editorial Board of the journal. Therefore, the submission was handled by a different member of the editorial board, and he did not take part in the review process in any capacity.

REFERENCES

Bálint, Sándor: *A Szeged-alsóvárosi templom*. Pannonia Kiadó, Budapest 1966.

Choisy, Auguste: *L'art de batir chez les byzantins.* Librairie de la Société anonyme de publications périodiques, Paris 1883.

Császár, László: Későgótikus boltozattípusok Európában I. *Építés- Építészettudomány* 19 (1987–1988) 1–2. 93–168.

Entz, Géza: *Nyírbátor. Református templom*. TKM Egyesület, Budapest 1994.

Entz, Géza – Szalontai, Barnabás: *Nyírbátor.* Budapest 1959.

Fehér, Krisztina: Tas-de-charge – An essential part of Gothic vault. *Periodica Polytechnica Architecture* 52 (2021) 1. 21–31.

Fehér, Krisztina – Halmos, Balázs: *Problems of Surveying Profile Shapes of Gothic Architectural Fragments*. Pollack Periodica 13 (2017) 1. 217–224.

Fehér, Krisztina – Halmos, Balázs: Remarks on the Proportions and Dimensions Used in the Design of the Medieval Church of Zsámbék. *Periodica Polytechnica Architecture* 50 (2019) 2. 97–114.

Harsányi, István: A szeged-alsóvárosi ferences templom gótikus szentélye csillagboltozatának helyreállítása. *Műemlékvédelem* 45 (2001) 5. 294–304.

Harsányi, István: *Szeged Alsóvárosi ferences templom hajó-boltozatának és falfelületeinek kutatása, építészettörténeti vonatkozások föltárása. II. kötet. A hajóboltozat felújítási munkáinak tervezését megelőző építészeti-műemléki kutatás.* (2005) Available at: https://docplayer.hu/16384222-Dr-lukacs-zsuzsa-emlekere.html (Accessed 20 April 2023).

Heyman, Jacques: *The Stone Skeleton. Structural Engineering of Masonry Architecture*. Cambridge University Press, Cambridge 1995.

Hoffstadt, Friedrich: *Gothisches ABC-Buch. Vorlegeblätter zum gothischen A-B-C-Buche…* Siegmund Schmerber, Frankfurt a. M. 1840.

Huerta, Santiago: Technical Challenges in the Construction of Gothic Vaults: The Gothic Theory of Structural Design. In U. Hassler – C. Rauhut (eds): *Bautechnik des Historismus. Von den Theorien über gotische Konstruktionen bis zu den Baustellen des 19. Jahrhunderts.* Hirmer, München 2012. 163–195.

Jobbik, Eszter – Krähling, János: Late Mediaeval Net Vault Construction Method Rediscovered by Geometric Analysis. A Case Study of the Fortified Church of Băgaciu (Bogeschdorf). *Brukenthal. Acta Musei* 17 (2022) 2. 179–202.

Krähling, János – Fehér, Krisztina: A szászbogácsi evangélikus templom műemlékfelmérésének és dokumentálásának módszertana. *Műemlékvédelem* 63 (2019) 3–4. 140–163.

Lengyel, G. – Bagi, K.: Numerical Analysis of the Mechanical Role of the Ribs in Groin Vaults. *Computers and Structures* 125 (2015) 42–60.

Levárdy, Ferenc: *Szeged Alsóvárosi templom*. TKM Egyesület, Budapest 1980.

Lukács, Zsuzsa: *Szeged. Alsóvárosi ferences templom és kolostor.* TKM Egyesület, Budapest 1999.

Lukács, Zsuzsa: A Szeged-alsóvárosi középkori ferences kolostoregyüttes. In Kollár Tibor (ed.): *A középkori Dél-Alföld és Szer*. Csongrád Megyei Levéltár, Szeged 2000. 143–192.

Meckel, Carl Anton: Figurierte Gewölbe der deutschen Spätgotik. *Architectura: Jahrbuch für Geschichte der Baukunst* 1 (1933). 107–121.

Müller, Werner: *Grundlagen gotischer Bautechnik. Ars sine sciencia nihil*. Deutscher Kunstverlag, München 1990.

Nagy, Zoltán: A ferencesek Szeged-alsóvárosi temploma. *Magyar Építőművészet* (1944) 89–93.

Papp, Szilárd: *A királyi udvar építkezései Magyarországon 1480–1515*. Balassi, Budapest 2005.

Ranisch, Bartel: *Beschreibung aller Kirchengebäude der Stadt Dantzig…* Raths und Gymnasii Buchdruckern, Dantzig 1695.

Szőke, Balázs: A Szeged-Alsóvárosi ferences templom hajóboltozata. In Őze Sándor – Medgyesy-Schmikli Norbert (eds): *A ferences lelkiség hatása az újkori Közép-Európa történetére és kultúrájára* 2. PPKE BTK–METEM, Piliscsaba – Budapest 2005. 875–890.

Szőke, Balázs: Boltozat-rekonstrukciók és boltozatok számítógépes elemzése. In: Buzás, Gergely – Rezi Kató, Gábor – Vasáros, Zsolt (eds): *Reneszánsz látványtár. Virtuális utazás a múltba*. Budapest, 2009. 443–462.

Tomlow, Jos: Versuch einer (zeichnerischen) Rekonstruktion des Gewölbes im spätgotischen Kreutzgang des Klosters Hirschau. In Schreiner, K. (ed.): *Hirsau St. Peter und Paul 1091–1991.*

Ungewitter, Georg Gottlob: *Lehrbuch der gotischen Konstruktionen. Neue bearbeitet von K. Mohrmann*. Chr. Herm. Tauchnitz, Leipzig 1901.

Voigts, Clemens: Spätgotische figurierte Gewölbe in Bayern: Konstruktion und Herstellungsweise. In *Koldewey-Gesellschaft Veereinigung für Baugeschichte Forschung e.v. Bericht über die 48. Tagung für Ausgrabungswissenschaft und Bauforschung vom 28. Mai bis 1. Juni 2014 in Erfurt*. Thelem, Dresden 2014. 245–252.

Warth, Otto: Die Konstruktionen in Stein. Band I. In Breymann, A. G. (ed.): *Allgemeine Baukonstruktionslehre mit besonderer Beziehung auf das Hochbauwesen…* J. M. Gebhardt, Leipzig 1896.

Wendland, David: Traditional Vault Construction Without Formwork: Masonry Pattern and Vault Shape in the Historical Technical Literature and in Experimental Studies. *International Journal of Architectural Heritage: Conservation, Analysis, and Restauration* 1 (2007) 4. 311–365.

Valódi hálóboltozat vagy bordákkal díszített donga?

A nyírbátori ferences templom hajóboltozatának és a nyírbátori református templom boltozatának geometriája, szerkesztés- és építéstechnikája

ÖSSZEFOGLALÓ

Jelen tanulmányban a magyar késő gótikus hálóboltozat építészet két jelentős példájának, a szeged-alsóvárosi ferences templom hajóboltozatának és a nyírbátori református templom boltozatának, szerkezeti kérdéseit és építésmódját vitatjuk meg, a lézer szkenneres felméréseinkkel gyűjtött új geometriai adatok alapján. A kutatás során arra jutottunk, hogy a korábban elfogadott elméletekkel ellentétben a két boltozatszerkezet jelentősen különbözik egymástól. Míg a szeged-alsóvárosi hajóboltozat bordahálójának és süvegfelületének egymással való kapcsolata geometriai értelemben a dongaszerkezetű ál-hálóboltozatok, illetve a zsaluzott süvegekkel épült hálóboltozatok tulajdonságait mutatja, addig a nyírbátori boltozat a szabad kézből falazott süvegekkel épült hálóboltozatok csoportjába sorolható. Továbbá a szeged-alsóvárosi boltozat bordarendszere egy szegmens-körívből származtatható, egyszergörbült felülettel írható le, míg a nyírbátori bordaháló bordacsatlakozási pontjainak térbeli pozíciója csak a tér három irányában megadott koordinátákkal írható le, szabályos felülettel nem. A boltozatok geometriai tulajdonságai, és az azokból levezethető feltételezett szerkesztési alapelvek segítségével mindkét esetben elkészítettük az építési folyamatok elméleti rekonstrukcióját is. Végezetül a geometriai elemzés és a felismert szerkesztési elvek alapján értékeltük a korábbi kutatásokban felmerülő érveket a két szerkezet és épület szoros műhelykapcsolata és az építőmester személyének azonossága tekintetében.

KULCSSZAVAK

késő gótikus hálóboltozat, ál-hálóboltozat, gótikus szerkesztési elvek, gótikus boltozatépítési módszerek, gótikus építési módszerek, geometriai boltozatelemzés, épületkutatás, nyírbátori református templom, szeged-alsóvárosi ferences templom, épületszkennelés