“BUILDING ARCHAEOLOGY” WITH LASER SCANNING: GEOMETRY-BASED ARCHITECTURAL ANALYSIS OF THE FRANCISCAN CHURCH OF SZEGED-ALSÓVÁROS

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Introduction

Nowadays, the terrestrial laser scanning of historic monuments provides vital geometric data for non-destructive building archaeology. This method may help to unveil hidden construction logic on a purely geometric basis, allowing researchers to gain deeper insight into original building techniques and the relationships between structures.

This article demonstrates the potential of terrestrial laser scanning through an examination of the Late-Gothic Franciscan Church of Szeged-Alsóváros (HU). The debated periodisation of the church and the visible plan alterations, particularly the hexagonal-to-octagonal transition in the apse, offer a unique case for exploration. By comparing construction methods and the dimensions of the building, geometric considerations may uncover new insights. Based on the diverse rib patterns of the net vaults (nave, apse, sacristy; Figs. 1 and 2a, b, c), attempts to reconstruct their building order were formerly made. Furthermore, some propose that the ground floor vault of the tower was originally ribbed but the ribs were destroyed during the Ottoman occupation of Szeged (Fig. 3). One author of this article carried out preliminary research and drew conclusions about the structural solutions for the nave vault.[1] However, the other vaults in the building have not yet been compared with these conclusions.

We assert that precise geometric data can provide fresh insight into ongoing debates. While definitive answers may be elusive through non-destructive methods, geometry-based investigations offer significant potential to advance scientific understanding, especially when destructive examinations are not possible.

1.1. *Building history*

The Franciscan church of Szeged-Alsóváros has a one-aisle nave, a polygonal apse with a choir, and a tower – connecting the apse and the sacristy. This church connects to the cloister, which is nowadays mainly in its eighteenth-century form.

On the site of the monastery, a former church consecrated to Saint Peter existed (last mentioned in 1497).[2] The present church was presumably built in the second half of the fifteenth century – although

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[1] Eszter Jobbik and János Krähling, “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,” *Építés-Építészettudomány* 51, no. 3-4 (Sep., 2023): 229-256, https://doi.org/10.1556/096.2023.00100.

[2] Zsuzsa Lukács, *Szeged. Alsóvárosi ferences templom és kolostor* [Szeged. The Alsóváros Franciscan church and cloister] (TKM Egyesület, 1999), 3; However, its position is not yet clear, as its remnants may be included in the present nave walls (Sándor Bálint, *A Szeged-alsóvárosi templom* [The Szeged-Alsóváros church] (Budapest: Pannonia Kiadó, 1966), 26), or could be under the present apse (István Harsányi, “A szeged-alsóvárosi ferences templom gótikus szentélye csillagboltozatának helyreállítása” [Restoration of the stellar vault above the Gothic apse of the Franciscan church of Szeged-Alsóváros], *Műemlékvédelem* 45, no. 5 (2001): 294-304, 303), east of the apse (Lukács, *Szeged*, 3), or somewhere in the vicinity of the church (Zsuzsa Lukács, “A Szeged-

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the exact dates are debated in literature.[3] According to an inscription on the wall, 1503 could be the date of the works on the church (the date of consecration)[4]; however, certain researchers claim that the monastery ensemble was only finished by 1543 – the year of the Ottoman occupation of Szeged.[5]

The church exhibits multiple building periods, with diverse brickwork attributed to the Franciscan order's mendication of materials.[6] Zsuzsa Lukács noted larger bricks in the apse compared to the nave, indicating a period border.[7] István Harsányi identified a detachment line at the full height of the space.[8] He also proposed that the nave and apse walls were completed by 1503, followed by the addition of the sacristy.[9] Vaulting works then progressed in reverse order from 1503 to 1543,[10] with the sacristy completed first, followed by the apse and lastly the nave.[11] Harsányi suggests the different structure of the nave vault was driven by the urgency to complete the church before the Ottoman arrival.[12]

According to Harsányi, the – supposed – inexperience of the masters working on the church shows in the plan alteration of the apse,[13] although others attribute it to the change in the planned vault type.[14] Some mention a presumed 30-year-long pause in the building works, making the two parts of different building periods.[15]

Formerets above the nave vault, initially identified as remnants of a prior vault,[16] suggest another plan alteration.[17] The controversy centres on the building history of the nave vault. While now widely recognised as a sixteenth-century structure,[18] it was previously considered a seventeenth-century "Gothic"

alsóvárosi középkori ferences kolostoregyüttes" [The Szeged-Alsóváros Franciscan cloister-ensemble], in *A középkori Dél-Alföld és Szer*, ed. Tibor Kollár (Csongrád Megyei Levéltár, 2000), 143-192, 144).

[3] Zoltán Nagy, "A ferencesek Szeged-alsóvárosi temploma" [The Church of the Franciscans in Szeged-Alsóváros], *Magyar Építőművészet* (1944): 89-93, 92; Ferenc Levárdy, *Szeged, Alsóvárosi templom* [Szeged, Alsóváros church] (TKM Egyesület, 1980), 7; Lukács, *Szeged*, 3; Harsányi, "A szeged-alsóvárosi," 297.

[4] Levárdy, *Szeged*, 7.

[5] Lukács, *Szeged*, 3.

[6] Zsuzsa Lukács, "Előzetes beszámoló a Szeged-alsóvárosi ferences kolostor kutatásáról" [Preliminary report about the research in the Szeged-Alsóváros Franciscan cloister], in *Koldulórendi építészet a középkori Magyarországon. Tanulmányok.*, ed. Andrea Haris (Országos Műemlékvédelmi Hivatal, 1994), 437-490, 453; Harsányi, "A szeged-alsóvárosi," 297.

[7] Lukács, "Előzetes," 453.

[8] Harsányi, "A szeged-alsóvárosi," 303.

[9] Harsányi, "A szeged-alsóvárosi," 297.

[10] Harsányi, "A szeged-alsóvárosi," 297.

[11] István Harsányi, *Szeged Alsóvárosi ferences templom hajó-boltozatának és falfelületeinek kutatása, építészettörténeti vonatkozások föltárása. II. kötet. A hajóboltozat felújítási munkáinak tervezését megelőző építészeti-műemléki kutatás* [Research of the nave vault and walls of the Szeged-Alsóváros Franciscan church, exploration of the architectural historic connections. Tome II. Architectural research prior to the nave's restauration works] (Budapest, 2006), https://docplayer.hu/16384222-Dr-lukacs-zsuzsa-emlekere.html, 27.

[12] Harsányi, "A szeged-alsóvárosi," 301; Harsányi described the nave vault as a barrel vault subsequently decorated with ribs (see below).

[13] "Supposedly they realised that for the planned stellar vault, the latter, modified polygon is more suitable." Harsányi, *Szeged Alsóvárosi ferences*, 25.

[14] Lukács, *Szeged*, 12.

[15] Levárdy, *Szeged*, 7-8.

[16] Levárdy, *Szeged*, 7

[17] Lukács, *Szeged*, 14.

[18] Balázs Szőke, "A Szeged-Alsóvárosi ferences templom hajóboltozata" [Nave vault of the Szeged-Alsóváros Franciscan church], in *A ferences lelkiség hatása az újkori Közép-Európa történetére és kultúrájára* 2, eds. Sándor Őze and Norbert Medgyesy-Schmikli (PPKE BTK-METEM, 2005), 875-890, 889; Harsányi, "A szeged-alsóvárosi," 297.

example on the basis of unclear documents[19] from the Catholic congregation of Szeged and the Ottomans.[20] Some argue that these documents likely refer to the ground floor vault of the tower, with "destruction" indicating the removal of vault ribs, rather than the nave vault.[21]

Dating the nave vault is inevitably tied to its structure.[22] Initially viewed as a barrel vault subsequently decorated with masonry ribs,[23] this interpretation has faced scepticism, with Balázs Szőke rejecting the theory.[24] Recent research proposes a different construction method indicating that while the rib system precedes the webbing, the masonry technique in the lower webbing region aligns more with barrel vaults.[25]

In 1749, the roofs of the monastery and the church were ruined in a conflagration.[26] In 1870 and 1937 minor preservation works were carried out on the church, without considerable research.[27]

2. *Methodology*

This article relies on precise, point cloud-based geometry obtained through a Leica BLK360 laser scanner and processed in Leica 360 Cyclone Register, with subsequent analysis in AutoCAD. The nominal accuracy of the scanner (4mm in 10m distance) surpasses the supposed accuracy of Late Gothic or seventeenth-century construction works in a structure of this scale. We contend that potential inaccuracies in point cloud measurements are negligible when considering the inherent (un)evenness of the structure, affirming the adequacy of the precision of our scanner for this research.

After collecting raw geometric data, the next step involves its systematic analysis. In our analysis we focus on the geometry of the inner spaces, since it is mainly these dimensions and ratios of a church that were aesthetically important as the places of liturgy. The thickness of walls might have been determined with geometric methods; however, this served primarily for structural purposes rather than aesthetic, as this dimension is not perceivable. For the floor layout, we extract a narrow horizontal slice from the point cloud near the floor – thus revealing the intentions of the builders more explicitly before mistakes in wall construction become prominent. A similar method is applied to study the exact shape of structures on different sections of the building.

While many researchers have explored geometric constructions,[28] their findings typically focus on architectural details rather than plan layouts or internal space ratios. Surviving examples of plan drawings

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[19] Two permissions for the destruction of the "vaults" and "roofs" were granted (1624 and 1625), but the permission for the "repair of the church" was rejected (1626) (Lukács, "A szeged-alsóvárosi," 145).
[20] Bálint, *A Szeged*, 17.
[21] Lukács, "A szeged-alsóvárosi," 145; Szőke, "A szeged-alsóvárosi," 876.
[22] 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.
[23] Nagy, "A ferencesek," 93; Bálint *A Szeged*, 26; Levárdy, *Szeged*, 8; Lukács, *Szeged*, 14; Harsányi, "A szeged-alsóvárosi," 302; Harsányi, *Szeged Alsóvárosi ferences*, 14.
[24] Szőke, "A szeged-alsóvárosi," 890; Balázs Szőke, "Boltozat-rekonstrukciók és boltozatok számítógépes elemzése" [Vault-reconstructions and computer analysis of vaults], in *Reneszánsz látványtár. Virtuális utazás a múltba*, eds. Gergely Buzás et al. (Magyar Nemzeti Múzeum, 2009), 443-462, 449.
[25] Jobbik and Krähling, "Real".
[26] Lukács, "A szeged-alsóvárosi," 147.
[27] Levárdy, *Szeged*, 10.
[28] Since the nineteenth century, numerous scholars, including Eugène Viollet-le-Duc, have sought to elucidate the logic of Gothic constructions. However, ongoing debate surrounds much of the initial research, as the drawings from that era are frequently contrived and diverge significantly from the actual buildings.

from the medieval era are rare, but large-scale markings found in some churches[29] suggest that plans were often drawn on-site at a 1:1 scale using common ratios.[30]

The analysis of plans and sections is initiated by comparing notable measurements to identify correlations. Gothic construction processes can potentially be reconstructed using various approaches. Plans are often thought to have been designed using grids of 45-, 60-, or 90-degree patterns, influenced by construction methods such as ad triangulum and ad quadratum, both presented, for example, in the thirteenth century by Villard de Honnecourt.[31] The first step involves testing if a plan or section aligns with these methods. It is essential to seek internal logic within the building, as suggested by Robert Bork,[32] as multiple approaches can yield similar results considering the inherent inaccuracies of medieval constructions.

The analysis of vaults involves three key steps derived from past research and case studies. The first step establishes the connection between ribs and webbing, achieved by "mapping"[33] the vault through the "slicing" of its point cloud with horizontal planes and projecting these sections into one plane (Fig. 4). The geometric relationship between ribs and webbing can be categorised into three structural connection types: When the section lines of the webbing are straight without changing at the ribs and parallel to the longitudinal walls, the webbing is likely a barrel vault and the ribs are structurally independent decoration (pseudo-ribbed net vault).[34] When the section lines of the webbing are only slightly curved[35] (or occasionally introflexed[36]), and change their directions by the ribs, the structure is likely a real net vault with webs built with formwork. When the section lines are curved and change directions by the ribs, the vault is presumably a real net vault, with webs built without formwork (possibly using a centre[37] – or

[29] E.g. at Wells Cathedral and York Minster (J. H. Harvey, "The Tracing Floor of York Minster," in *Studies in the History of Civil Engineering Volume 1: The Engineering of Medieval Cathedrals*, ed. L. T. Courtenay (Ashgate Publishing, 1997), 81-86; David Wendland and Frédéric Degenève, "How to order fitting components for looping ribs: Design procedures for the stone members of complex late gothic vaults," in *Building Histories: The Proceedings of the Fourth Conference of the Construction History Society,* eds. J.W.P. Campbell et al. (Queens' College, 2017), 159-170, 164.

[30] Arnold Pacey, *Medieval architectural drawing, English craftsmen's methods and their later persistence (c.1200 - 1700)* (Tempus Publishing, 2007), 62.

[31] Carl F. Barnes, *The Portfolio of Villard de Honnecourt. A New Critical Edition and Color Facsimile* (Routledge, 2009), folio 20.

[32] Robert Bork, *The Geometry of Creation, Architectural Drawing and the Dynamics of Gothic Design* (Ashgate, 2011)

[33] This empiric visualisation method was used by among others e.g. Rave in 1955, as quoted by David Wendland, "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, no. 4 (2007): 311-365, 345, https://doi.org/10.1080/15583050701373803; Clemens Voigts, "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, 2014): 245-252, 247; Clemens Voigts, "Vaults, centring, and formwork of the late gothic period in Southern Germany," in *History of Construction Cultures*, eds. João Mascarenhas-Mateus and Ana Paula Pires (CRC Press, 2021), 78-83, 81.

[34] This nature was generally accepted in the case of the nave vault of the church (as mentioned above), and in the case of the masonry ribbed vaults of South-Transylvania. E.g. Victor Roth, *Geschichte der deutschen Baukunst in Siebenbürgen* (Heitz&Mündel, 1905), 36.

[35] Wendland, "Traditional," 342.

[36] Manfred Schuller, "Bautechnik," in *Der Dom zu Regensburg* 7/3, eds. Achim Hubel and Manfred Schuller (Pustet, 2016), 434-503, 474.

[37] Eugene Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française de XIe au XVIe siècle* (Bance-Morel, 1854-68), fig. 58; Georg Gottlob Ungewitter, *Lehrbuch der gotischen Konstruktionen. Neue bearbeitet von K. Mohrmann* (Chr. Herm. Tauchnitz, 1901), 117.

without that[38]) (Fig. 5). (Clemens Voigts drew conclusions about the use of formworks by a very similar method.[39]).

The second step is the global geometry analysis of the rib system, examining the spatial positioning of junction points in a Cartesian coordinate system along the longitudinal, cross and vertical directions of the vault (Fig. 6). (Although literature on the topic treats the idea that the construction of a rib system starts with its plan as an axiom,[40] our former research supports our claim that exceptions exist.[41] Thus, in identifying the two coordinates describing the plane during our analysis, where the projected picture of the vault was first constructed is of crucial importance). This step explores the plan, cross- and longitudinal section of the rib system, searching for underlying construction ideas.[42] The four possible outcomes include highly regular vaults where all three projections can be constructed independently and cases where the primacy of one projection (and two coordinates) can be assumed while the third coordinate depends on the initial two constructed.[43] During our previous works, we identified cases when the primacy of the plan view or the cross-section could be supposed;[44] however, the primacy of the longitudinal section is only a theoretical possibility so far. It is important to note that the significance of ratios and orderly construction methods in Gothic architecture may not universally characterise every detail, as modern survey methods reveal deviations at times.[45]

The last step of the vault analysis is the examination of the geometry of individual ribs. Here, the "Prinzipalbogen" principle, which most researchers formerly relied on to describe net vaults,[46] is the main focus of our considerations. This principle, which asserts that in a given net or stellar vault each rib has the same curvature, has been rejected by some researchers since the nineteenth century.[47] However,

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[38] Johann Claudius von Lassaulx, "Beschreibung des Verfahrens bei Anfertigung leichter Gewölbe über Kirchen und änliche Räumen," *Journal für die Baukunst* 1 (1829): 317-30, 325.

[39] Voigts, "Spätgotische," 248; It is to be noted that Voigts proved that the combination of these methods in the same vault occasionally occurred as well (Voigts, "Spätgotische," 250; Voigts, "Vaults," 80-81).

[40] Bartel Ranisch, *Beschreibung aller Kirchengebäude der Stadt Dantzig…* (Raths und Gymnasii Buchdruckern, 1695); Friedrich Hoffstadt, *Gothisches ABC-Buch: Vorlegeblätter zum gothischen A-B-C-Buche…* (Siegmund Schmerber, 1840); Otto Warth, "Die Konstruktionen in Stein. Band I," in *Allgemeine Baukonstruktionslehre mit besonderer Beziehung auf das Hochbauwesen…*, ed. A. G. Breymann (J. M. Gebhardt, 1896); Ungewitter, "*Lehrbuch".*

[41] Eszter Jobbik and János Krähling, "Late Mediaeval Net Vault Construction Method Rediscovered by Geometric Analysis. A Case Study of the Fortified Church of Băgaciu (Bogeschdorf)," *Brukenthal. Acta Musei* 17, no. 2 (2022): 179-202; Eszter Jobbik and János Krähling, "The Geometric System of the Nave Vault of the Church on the Hill of Sighișoara," *Studia Universitatis Babeș-Bolyai. Historia Artium,* 68 (2023): 7-43, https://doi.org/10.24193/subbhistart.2023.01.

[42] Taking into account the building time of these systems, we look for construction methods, which require steps that are quite simple to mark out in real scale (parallel or perpendicular lines, circles, divisions into halves or thirds etc.) (see above).

[43] E.g. the vertical dimension (height) of the junctions depends on their position on the plan view, if the latter is projected to a cylindrical surface – as presumed in the nineteenth-century literature (see above). However, the dimensions are independent if an underlying construction idea (e.g. construction in a quadrate net) can be identified both on the plan and the cross-section of the vault, as we have found in the case of the church of Nyírbátor (Jobbik and Krähling, "Real").

[44] Jobbik and Krähling, "Late"; Jobbik and Krähling, "The Geometric".

[45] Krisztina Fehér and Balázs Halmos, "Remarks on the Proportions and Dimensions Used in the Design of the Medieval Church of Zsámbék," *Periodica Polytechnica Architecture* 50, no. 2 (2019): 110.

[46] Ranisch, *Beschreibung*; Hoffstadt, *Gotisches*; Carl Anton Meckel, "Figurierte Gewölbe der deutschen Spätgotik," *Architectura: Jahrbuch für Geschichte der Baukunst* 1 (1933): 107-121; Werner Müller, *Grundlagen gotischer Bautechnik. Ars sine sciencia nihil* (Deutscher Kunstverlag, 1990); Jos Tomlow, "Versuch einer (zeichnerischen) Rekonstruktion des Gewölbes im spätgotischen Kreutzgang des Klosters Hirschau," in *Hirsau St. Peter und Paul 1091-1991,* ed. K. Schreiner (Kommissionsverlag Konrad Theiss, 1991).

[47] E.g. Lassaulx in 1835, as quoted by David Wendland, Johann Claudius von Lassaulx, "Gewölbe >aus freier Hand< - Die Wiedererfindung der gotischen Architektur und die Entwicklung der technischen Literatur," in *Bautechnik des Historismus. Von*

recent research has identified examples of the application of the principle.[48] Multiple theories exist in literature to construct the value for the radius of the curvature if the principle applies. A simple solution is to set the radius as half of the diagonal of the vault plan.[49] Another widespread method is the principle of the longest route. This idea, that the radius of the curvature is the longest continuous rib-route from the impost to the crown point, originated in a sixteenth-century sketchbook from Dresden,[50] and has been published in numerous works.[51] Thus, a thorough geometric analysis reveals not only the application of the Prinzipalbogen but also the details of its implementation.

Based on our above-detailed geometric observations we were able to compare the vaults of the church on a level which was hitherto not possible. Our examinations also allowed us to reconstruct plausible building methods.

3. *Results*

3.1. *Analysis of the church plan*

The analysis of the plan of the Franciscan Church of Szeged-Alsóváros started with the examination of the apse polygon. The apse stood as the starting point of the construction and building works in many cases. This appears to hold true for Szeged as well. It can therefore be assumed that the underlying geometrical logic of the church was also born here.

When testing feasible construction methods, we considered the limitations and possibilities of the period. All approaches described could be constructed on site using set-squares and drawing compasses and by setting up cords, stakes and pegs.

Measured at approximately 6TF in width and 10.5TF in length (excluding the polygonal part),[52] the apse initially suggested a logical construction method using a 90-degree grid of 0.5TF-sized squares (method one), which also marks out the thickness of the walls. However, the polygonal part proves incompatible with this system, eliminating it as a possibility (Fig. 7).

Then, two alternative approaches matching the mentioned measurements were identified. For method two we considered the diagonal of a square with sides equal to the width of the apse. By rotating the diagonal to align with the square and connecting its endpoint to the opposite corner of the original square (Fig. 8), and repeating this process, we obtained a length close to that of the apse. While this method does not explain the shape of the polygonal part, it does not contradict it. For method three, triangulation or a 60-degree grid was involved (Fig. 9), utilising the width of the apse as the diameter for construction circles. The hexafoil arrangement of these circles determined the nodes for our grid, including the corners of the polygon.

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den Theorien über gotische Konstruktionen bis zu den Baustellen des 19. Jahrhunderts, eds. Hassler Uta and Rauhut Christoph (Hirmer, 2012), 93-117, 106; David Wendland, "*Zum Bau figurierte Gewölbe - eine Anleitung im Werkmeisterbuch des Rodrigo Gil de Hontagñon*," in *Werkmeister der Spätgotik: Personen, Amt und Image*, eds. Stefan Bürger et al. (Wissenschaftliche Buchgesellschaft, 2010), 244-272.

[48] Jobbik and Krähling, "Late"; It is to be noted that measuring rib curvatures, especially in the case of shorter ribs, is a difficult task, as a small change in the arch 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.

[49] Ranisch, *Beschreibung*; Elena Pliego, "The germ of the Prinzipalbogen concept in Bartel Ranisch," *Nexus Network Journal* 19 (2017): 405-25, 407.

[50] François Bucher, "Medieval architectural design methods, 800-1560," *Gesta* 11, no.2 (1972): 37-51, 47.

[51] Hoffstadt *Gothisches*, XIV.A/5; Ungewitter *Lehrbuch*, 67-68; Meckel, "Figurierte," 108.

[52] The church, according to Harsányi, was built using Transylvanian Fathoms (TF). 1 TF equals 1.752m according to him (Harsányi, "Szeged Alsóvárosi," 13). We use this unit to describe the building; however, other units are also possible to have been used.

Upon examining the nave layout, the more probable approach becomes apparent. Repeating the process of method two on the nave plan (Fig. 10) does not result in the length of this space. However, the grid of method three (Fig. 11) aligns well with the nave. The sides of the equilateral triangles (or the radius of the circles constructing them) are x=5.33m (approximately 3TF), and their height is h=4.57m (approximately 2.6TF). The width of the apse in this system is 2x, and the width of the nave is 2.5x. The length of the apse is 4h, plus 1h for the polygonal part, and the length of the nave is 8h. The widths, lengths and heights of the nave and apse correlate: the height multiplied by 2.5 equals the nave length and multiplied by 1.5 equals the apse length.[53]

3.2. *Analysis of the apse vault*

Examining the vault of the apse, the first observation is that the ribs have highly irregular lower surfaces and their elements do not connect smoothly to each other (Fig. 12). This feature, visible to bare eyes, has been formerly described: István Harsányi explains it with the toppling of the centrings by the time the webbing was built.[54]

Applying the above-described vault analysis method, the first step is the "mapping" of the vault (Fig. 13). We found that the horizontal section lines of the webbing are close to straight, and getting closer to the crown line they have a slight curvature[55] and change direction each time they cross a rib. Based on these characteristics, we concluded that this vault is likely a real net vault, probably with webbing built with formwork.

Next, we examined the plan layout of the rib system. We found that despite the slight irregularities within a given rib, this view does not reflect the disorderly appearance of the general view. Regarding the plan, we observed that the rib junction points of the highest position do not fit on a straight line. Thus, the crown line of the vault is not straight. However, the other junction points of the same types fit on straight lines that run parallel to the longitudinal walls on the southern and northern sides respectively. The distribution of these lines along the western wall of the apse can be constructed using a length value equal to an eighth of the height of the apse (from the floor to the lower surface of the crown-junction elements – see above) and the third of this latter (as shown on Fig. 14a).

In the cross-direction of the vault, in plan, the junctions mostly fall on the lines between the imposts facing each other and the lines between the middle of the bays. These lines are all parallel to each other (Fig. 14a). Constructing the plan view of this rib system is conceivable using circles as well. In this case, the diameters of these circles also seem to relate to the height of the apse (as described above) (Fig. 14b). As part of the analysis of the plan, we measured the projected lengths of the ribs on the plan view. These values proved to be very even within the rib-type groups.

Based on our observations, we concluded that the plan of the rib system in the apse is sufficiently orderly to allow for multiple construction methods. In these, values otherwise characteristic of the geometric system of the church appear, and thus these regularities are most probably not accidental. Since the plan of the rib system proved to be regular enough that multiple plausible construction methods can result in it, we think that finding the underlying construction idea used by the original builders is not possible. Nonetheless, we see it proved that the plan of the rib system was indeed constructed.

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[53] Jobbik and Krähling, "Real".

[54] Harsányi, "A szeged-alsóvárosi," 296.

[55] It is worth mentioning that closer to the crown – where the section lines show a more visible curvature – the tangent of the vault surface gets closer to the horizontal direction. Thus, the newly built courses are less supported by the previous ones than in the case of those closer to the imposts. Having a more significant curvature means that the rows work as individual arches regarding the load-bearing characteristics. We find this a probable explanation for the phenomenon described.

However, several deviations occur. These likely relate to the visible irregularities of the rib elements. Regarding these, as the walls of the apse do not show signs of significant posterior-to-building movements, we accept Harsányi's explanation.

Regarding the cross- and longitudinal sections of the rib system, we found that the distance between the apse floor and the lower surfaces of the crown line junctions is the same as in the nave (Fig. 15). It must be noted that the lower surfaces of the junction points do not fit on an even surface. Nonetheless, on the longitudinal sections the lower surface of the junction points of the same type fit on straight lines. These are parallel to each other on the southern as well as on the northern sides. The ribs do not start from the same height on the southern and northern sides – although all the other corresponding junctions are at the same height on the two sides (Fig. 15).

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 an orderly height construction seems to exist on the southern side. The northern side follows this system as well, except for the height of the imposts. The construction may be deduced from the same values as in the case of the plan (Fig. 15).

Thus, our conclusion regarding the apse vault is that all three dimensions of the positions of junction points can be constructed individually. Measuring the curvature of the radius of each rib, we concluded that the Prinzipalbogen does not apply to the system.[56]

3.3. *Analysis of the sacristy vault*

In the case of the vault of the sacristy, we found that the horizontal section lines of the webbing are approximately straight (occasionally slightly concave) and change direction each time they cross a rib (Fig. 16). Similarly to the apse vault, closer to the crown line they have a slight curvature, the explanation of which is likely the same as there. Thus, we concluded that likely this is a real net vault with ribs built with formwork as well.

Regarding the plan layout of the rib system of the sacristy, we observed that it is highly regular. It is symmetric to the (straight) crown line, and the positions of the imposts are equally distributed along the walls. The plan views of the junction points of the same type fall on straight lines both in the longitudinal (east-west) and cross (north-south) directions on each side. The longitudinal lines are all parallel and are determined by the third and the ninth of the width of the sacristy (Fig. 17a).

Given the observed regular features, we concluded that the plan view of the rib system was likely constructed. It must be noted that in the case of this level of orderliness, the original construction method cannot be stated with certainty as multiple construction methods may result in the same plan.

Analysing the cross- and longitudinal sections of the rib system, we found that on the longitudinal sections the lower surface of the junction points of the same type fit on straight lines. These are parallel to each other on the southern as well as on the northern sides (Fig. 17b). The height positions of the junction points of the same kind on the two sides of the vault (south and north) slightly differ from each other. However, the height differences of the corresponding junctions on the two sides are equal (thus,

[56] Interpreting the measurements, it must be kept in mind that measuring the rib curvatures is a difficult task, as a small change in the arch height results in a great change in 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 experiences of our formal works (Eszter Jobbik and János Krähling, "A Self-contained Stellar Vault Construction Method. The Vault of the Matthias Oratorio in the Inner City Parish Church of Budapest," *Periodica Polytechnica Architecture* 54, no. 1 (2023): 73–85. https://doi.org/10.3311/PPar.21454; Jobbik and Krähling, "Real"), and even the sacristy of the present church (see below), we found that even with these uncertainties, the 'Prinzipalbogen' can be detected. However, in this case, the lower surfaces of the ribs proved to be quite irregular, making the judgement of the builders' original intentions even more difficult.

the junction positions on the two sides are "vertically shifted" by approximately 9.5cm). On the northern side a construction method using the values identified on the plan view could be detected. (This can be interpreted as a construction based on a quadrate net).

We found that the lower surfaces of the junction points do not fit on a surface. The height of the vault (from the point where the rib curvatures start to the lower surface of the crown junctions) is half the width of the room. The other height values come from dividing the height of the vault with simple ratios (halves, thirds) (Fig. 17c).

Overall, the global geometry of the ribs shows characteristics of a system whereby all three dimensions of the spatial positions of the junctions can be individually constructed. We found that the vertical shift between the two sides may come from a mistake made during the original construction works, as no sign of later damage to the system shows, and except for the vertical distance of imposts every characteristic vertical distance matches on the two sides.

Regarding the individual analysis of the ribs, we concluded that the Prinzipalbogen may have been applied to this vault. The average of the measured values is 4.63m, which can be regarded as a value derived from the geometric system of the ribs: five times the elemental length on which the plan geometry of the vault is based. However, this value differs from the one calculated based on the "longest route" method (see above).

We also noted that there are some anomalies in the system regarding the radius of rib curvatures, which in some cases are not even (Fig. 18a). These examples are on the southern side (with one exception – which is a formeret). There are some ribs the curvature of which deviate significantly from the average (Fig. 18b). These appear in the system where most of the uneven curvatures are. These remarks may indicate that the error was indeed made on the southern side and establishing the geometric system on the northern side is well founded.

3.4. *Analysis of the vault of the ground floor of the tower*

Although the vault of the ground floor of the tower presently lacks ribs, some researchers think that it might have been ribbed before the Ottoman occupation (see above). Thus, we think it is necessary to carry out our analysis on this vault as well. However, it must be kept in mind that during our analysis we primarily focus on the lower surface of the junctions since during the construction works, the elements are supported by a temporary structure from underneath; thus, that is the height the builders can calculate with. In this case, we can only regard the groins as the basis of our analysis – virtually the upper surface of the ribs.

Regarding the "mapping" of the vault, the horizontal section lines of the webbing are nearly perfect straight lines. In their case, no difference appears between the lower and upper regions. The lines distinctly change directions at the groins (Fig. 19).

The vault, being quite small and of a simple pattern, has a very regular plan view. The plan of the groin system can be constructed using a uniform value. Two and a half times this value equals the diameter of the circumscribable circle of the vault (Fig. 20a). (As the plan is small and regular, the exact construction method for it is hard to reconstruct). One slight anomaly can be seen in the position of the upper junction point of the northern lunette.

The height of the apex of the formeret from the floor is double the value determining the plan. As in the case of the formerets, ribs do not always appear, even if the vault is ribbed. This observation does not lead to further considerations – so much the more since the vaults of the sacristy and apse of the present church differ from each other in this characteristic. We also found that the upper junctions of the lunettes are approximately at the same height, while the crown point is around 24cm above this height.

Considering our former statement about the positioning of the lower surface of the rib, if this was indeed a rib vault, we must calculate with a rib height while reconstructing the original construction method. The rib height of the sacristy and the apse is around 24.5cm, and that of the nave is around 30cm. However, even though the rib heights in the apse and sacristy seemingly fit the system, the vault being originally ribbed is far from proven. The hypothesis can only be proved via a wall excavation.

The junction points of the groins and the groins crossing at the crown of the vault may fit on a sphere surface, the radius of which is three times the value determining the plan and the height of the formeret (Fig. 20b). This observation supports the idea that the vault originally did not have ribs.

Considering our observations, we found that the vault and the space of the ground floor of the tower seem constructed – but whether ribs were involved or not cannot be ascertained.

Measuring the curvatures of the groins, we found that in the case of the formerets and the lunettes, they are close to being uniform. The average (3.95m) is approximately equal to the calculated "longest route" for this vault. However, it must be noted that this was measured on the upper surface of the assumed ribs, which means that if there were indeed ribs, the curvature values measured on their lower surface would have been slightly lower – although, the difference on an approximately 4-meter-long chord length is likely smaller than the inaccuracy of our measurements and the presumed inaccuracy of the building methods (see above). In the case of the groins crossing at the crown, we measured a more significant curvature than in the case of the latter two types. The groins connecting the formerets and the lunettes are straight and horizontal.

4. *Discussion*

4.1. *The geometry of the plan*

As discussed in section 3.1, it is likely that the plan of the church was constructed using triangulation, given the conformity of the nave and apse to this method (Fig. 11).

On Figure 21, corners A1-A6 in the apse and N1-N4 in the nave are marked. Table 1 displays discrepancies between these corners and their corresponding grid points. Notably, corners A5 (28.99cm) and A6 (23.47cm) in the apse exhibit errors an order of magnitude larger than others. However, measuring their distance from the constructing circle around the polygonal part yields a more accurate alignment (discrepancy: 3.03cm and 2.64cm, respectively). This suggests that the grid might not have been a highly rigid organizing tool, with the focus potentially being on constructing circles.

The apse and nave share a uniform grid of triangles and circles, indicating that the builders of the nave were likely familiar with the construction system and measurements of the apse. Despite the potential non-simultaneous construction of the two parts, as discussed in section 1.1, the builders of the nave were either identical to or closely linked with those of the apse. The triumphal arch, however, is not part of the grid of either the apse or nave, as it is visually evident on the plan.

While the church plan is initially defined by the reconstructed grid system up to a height of 4.7m, the nearly perfect hexagonal shape starts to distort, reaching an "octagonal" layout at around 5.7m, as mentioned in multiple sources (Fig. 22). This new layout, shown in Figure 23, lacks a connection to the grid system; the "octagon" appears to have been constructed in a purely functional way, ensuring optimal support for the upper parts of the walls despite the change in angles.

The apse polygon was likely to have been modified to accommodate the current style of vault, which the hexagonal layout would not allow for. While the plan alteration does not necessarily imply a halt in building construction, it is one possible explanation. Alternatively, the concept might have changed, possibly due to client demands, the marking out of the new plan in such a high elevation proving to be challenging for the builders.

4.2. *Geometric connections between the apse, sacristy and nave vaults*

Based on the detailed geometric description, the apse and sacristy vaults are worth discussing in relation to each other and to the nave vault. In the case of both the vaults of the apse and the sacristy, we concluded that they are likely real net vaults with webbing built with formwork. However, in the case of the nave, former research showed[57] that the lower part of the webbing was built as a barrel vault – even though the rib system was built prior to the webbing. Then, the upper part of the webbing was built on the rib system, with formwork. Thus, regarding the connection between the ribs and the webbing, the techniques in the apse and the sacristy match, but the one in the nave is unique.

Regarding the rib system of the vaults analysed in the present article, we found that both in the case of the apse and the sacristy the three coordinates of the spatial positions of the rib junctions can be constructed independently. However, in the case of the nave the lower surfaces of the junctions fit on a cylindrical surface (a circle-segment–arched barrel vault). Thus, in this case, the longitudinal and cross-direction coordinates (the plan of the rib system) must be constructed primarily, which determines the vertical position by projecting it to the surface.[58] Therefore, the construction principle likely applied in the case of the nave vault significantly differs from that of the apse and sacristy.

Former researchers examined the pattern of the rib systems to find connections. Some claim that the pattern in the nave is deducible from that in the sacristy by adding extra elements to it.[59] Others accentuate the feature of the nave vault that it has ribs parallel to the longitudinal axis,[60] which distinguishes it from the others, along with its pattern, often named as a “densely ribbed net vault”.[61] Even though these obvious differences exist, we identified some details which connect the geometry of the vaults of the nave and apse to each other: the underlying values determining the geometry of the two rib systems are in accordance with each other. The eighth of the height of the apse and nave (as defined above) is equal to the length of the ribs of the nave projected to the plan view. This value also determined the details of the construction in the case of the apse.

In the case of the vaults of the sacristy and the nave, the Prinzipalbogen may have been applied during the building works. However, in the case of the apse, this cannot be shown – either because it was not applied, or because the ribs got too distorted.

Overall, the underlying construction principles of the apse and the sacristy are mostly in accord with each other. The nave vault differs significantly from these both in the connection of ribs and webbing and the global geometry of the rib system. However, the underlying values of the construction in the case of the nave and apse vaults are alike. The same is not true in the case of the sacristy.[62]

4.3. *Theoretic reconstruction of the building techniques*

Based on the descriptions we gave about the vaults in section 3, we attempt to reconstruct the original building methods of the vaults of the apse and the sacristy. In the case of these vaults, the primacy of the

[57] The detailed geometric description of the nave vault and the deductive reasoning for the reconstructed building methods are given in the article Jobbik and Krähling, “Real”. In this article we only cite the details necessary for understanding.

[58] The detailed proof for this hypothesis can be found in Jobbik and Krähling, “Real”.

[59] László Császár, “A Szeged-alsóvárosi ferences templom boltozatairól” [About the vaults of the Szeged-Alsóváros Franciscan church], in *Détshy Mihály nyolcvanadik születésnapjára*. Tanulmányok, eds. István Bardoly and Andrea Haris (Kulturális Örökségvédelmi Hivatal, 2002), 155-160, 159.

[60] Szőke, “A szeged-alsóvárosi,” 879.

[61] Szőke, “A szeged-alsóvárosi,” 887.

[62] Nonetheless, this does not necessarily mean a different building period, it may have occurred due to the basic geometric differences of the outlines of the spaces that were vaulted.

rib system to the webbing can be accepted as well. Based on the results of the mapping, the webs were built with formworks.

As for building the rib system, theoretically, any two coordinates (longitudinal, cross-direction or vertical) of the spatial positions of the junctions could serve as starting points in both cases. However, the primacy of the plan view (longitudinal and cross-direction coordinates) may be supposed, as there is no reason against it (Fig. 24).[63] Using linear temporary supporting structures seems likely, as the rib junctions do not fit on a regular surface.

4.4. *On the periodisation of the vaults*

Regarding the periodisation of the vaults relative to one another, we gave the former theories in section 1.1 on the building history. Based on the exact geometry we described, we have the following remarks on the question:

The basic building method and construction idea differ radically in the case of the structures of the vaults of the apse and the nave. This could indicate a considerable concept change – especially with the never-finished formerets above the nave vault. Harsányi's idea, that the rapid completion of the nave vault was needed,[64] may provide a plausible explanation, even though according to the newest results, the structure of the vault differs from what he described.[65] (It must be noted that the different rib pattern of the nave alone does not justify the change in the method, as the vault of Nyírbátor was built with a pattern similar to the nave, with a technique similar to the apse and the sacristy.[66])

However, as we described above, the underlying values of the construction in the case of the nave and apse vaults are in accordance with each other. Bearing in mind the precision of measurements achievable for the masters of the early sixteenth (or even the seventeenth) century, we find it plausible that the two structures were built by the same masters, with not too much time difference. Therefore, the theory of the seventeenth-century building time of the nave vault seems less likely. (Though as this value can be constructed from the dimensions of the church plan, their constructions being entirely independent from each other cannot be excluded – even though we find it less likely).

Regarding the apse and the sacristy, their differences lie in their rib patterns and the orderliness of their rib systems – the latter may result from later movements of the structures. Based on our geometric observations the idea that they originate from the same period is to be supported, though their building order cannot be decided on this basis.

5. *Conclusion*

In the present article, we analysed the laser-scanned point cloud, thus the exact geometry of the church of Szeged-Alsóváros, with particular emphasis on its plan layout, and the vaults of the apse, sacristy and the ground floor of the tower.

Regarding the plan, we considered the possible geometric construction of the apse and nave and identified a system that can be applied to both parts with high accuracy. It was demonstrated that the nave and the apse were presumably constructed along the same principles – potentially by the same master or workshop. Moreover, the structurally sound solution of the "octagonal" higher parts and the accuracy of

[63] Even though during our former research we found examples, where constructing the plan view was not the starting point of building a net vault, in those cases the plan views' geometries were not orderly.
[64] Harsányi, "A szeged-alsóvárosi," 301.
[65] Jobbik and Krähling, "Real".
[66] Jobbik and Krähling, "Real".

the hexagonal lower parts of the apse walls indicate that the change was not due to the incompetence of the builders, but because of either the client’s wish or a time gap during the build.

Regarding the vaults, we first gave their minute geometric descriptions. These showed that the underlying construction ideas in the apse and sacristy are in accordance. However, these differ from the plausible construction idea of the nave vault in multiple points (the result of the “mapping”, the idea behind the global geometry of the rib system). On the other hand, certain underlying values of the geometry of the rib systems match in the case of the nave and the apse. These are derivable from the values determining the main dimensions of the church (the lengths and heights of the nave and the apse). Based on this, we claim that it is plausible that the building times of the two vaults do not differ from each other significantly, as in the Late Gothic period the builders lacked the precise means of measuring to know the corresponding values on the spatial structures.

Consistent with the results of the geometric descriptions, the hereby reconstructed building strategies and the type of the temporary supporting structures were the same in the case of the vaults of the apse and the sacristy (and these differed from those of the nave).

Regarding the vault on the base floor of the tower, the geometric description did not provide enough additional information to confidently decide the question of whether the seventeenth-century written sources referred to the destruction of its ribs. Nonetheless, regarding the spatial positions of the groin junctions, certain values detectable on the plan view may define their vertical positions as well. This can indicate that the vault was originally constructed without ribs as well.

Aside from the concrete results of our hereby presented research, we find it important to accentuate the significance of the exact geometry-based method we used. Such analyses provide new data for archaeological research, even if destructive research methods are not possible. Thus, analysing data gathered via the laser-scanning of historic monuments may provide information which either supports or weakens the former considerations of these topics.

Acknowledgements

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ANNEXES

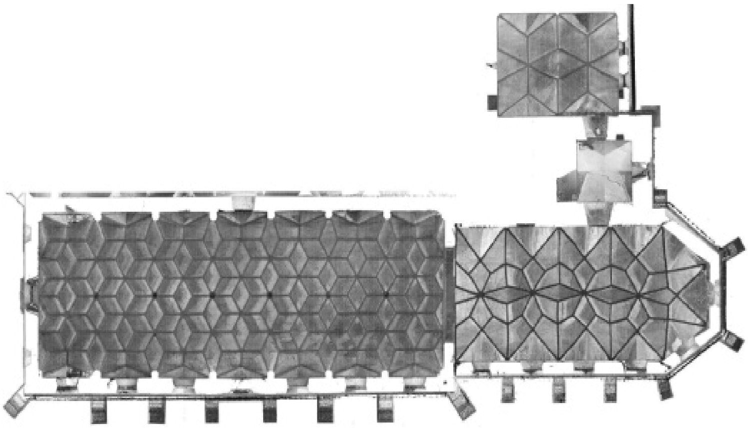

Fig. 1. The plan of the Franciscan Church of Szeged-Alsóváros. The author's work.

a b c

Fig. 2. The vaults of the nave (a), apse (b) and sacristy (c) of the Franciscan Church of Szeged-Alsóváros. The authors' photos.

Fig. 3. The vault of the tower's ground floor in the Franciscan Church of Szeged-Alsóváros. The authors' photo.

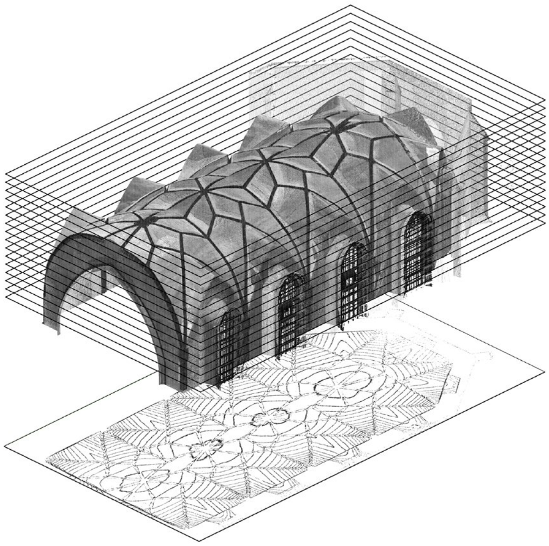

Fig. 4. Theoretic method of “mapping” a vault, presented on the example of the apse vault. The authors’ work.

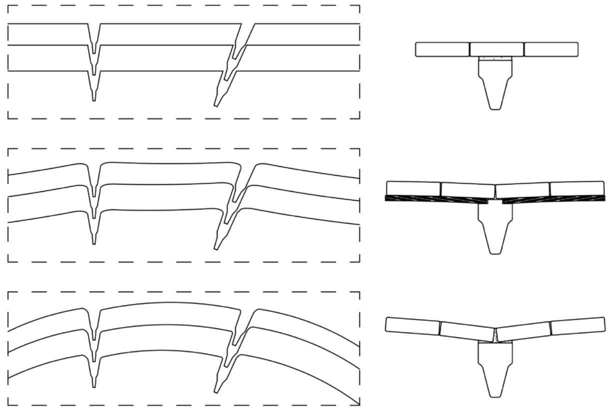

Fig. 5. Theoretic outcomes of “mapping” a vault. a. barrel vaults and decorative ribs; b. “real” net vault, webs built with formworks; c. “real” net vault, webs built without formwork. The authors’ work.

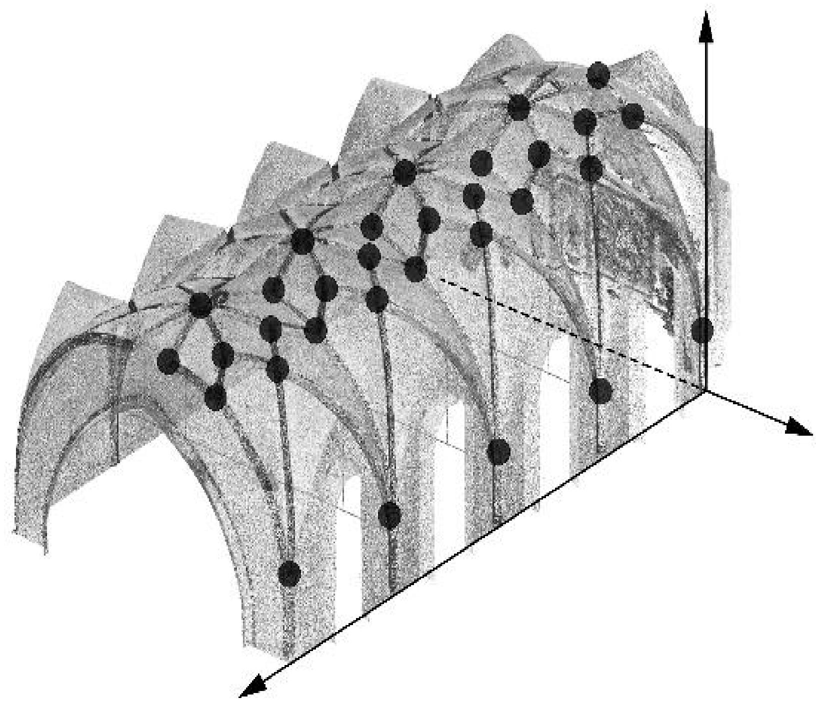

Fig. 6. Theoretic Cartesian coordinate system for the interpretation of the global geometry of the vault’s rib system, presented on the example of the apse vault. The authors’ work.

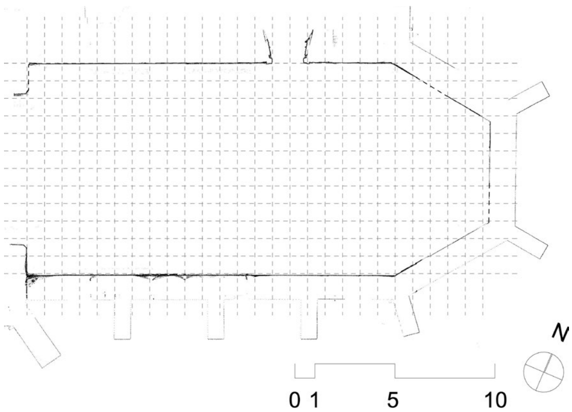

Fig. 7. Method 1: 90-degree grid applied to the plan of the apse. The grid is made of squares with side lengths of 0.5 Transylvanian Fathoms. The authors' work.

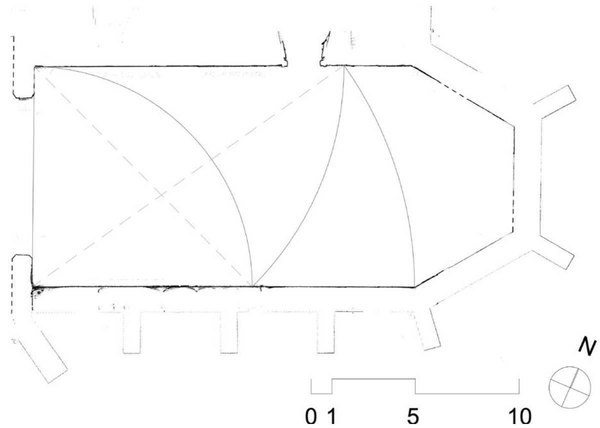

Fig. 8. Method 2: Rotating the width of the apse to the southern wall, then rotating the diagonal made this way to the northern wall, and again, the new diagonal to the southern wall. The authors' work.

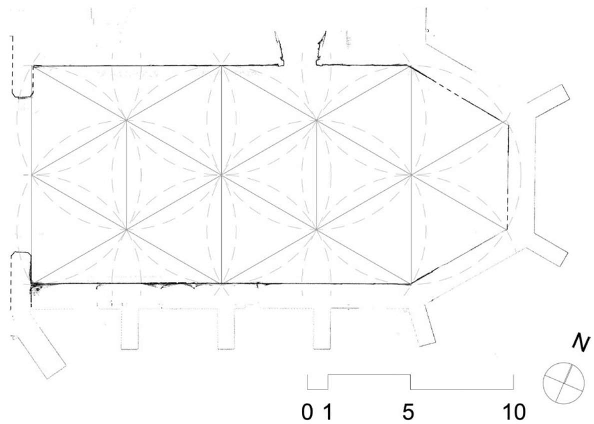

Fig. 9. Method 3: 60-degree grid applied to the plan of the apse. The grid is made of triangles with side lengths of 5.33 metres or about 3 Transylvanian Fathoms. The authors' work.

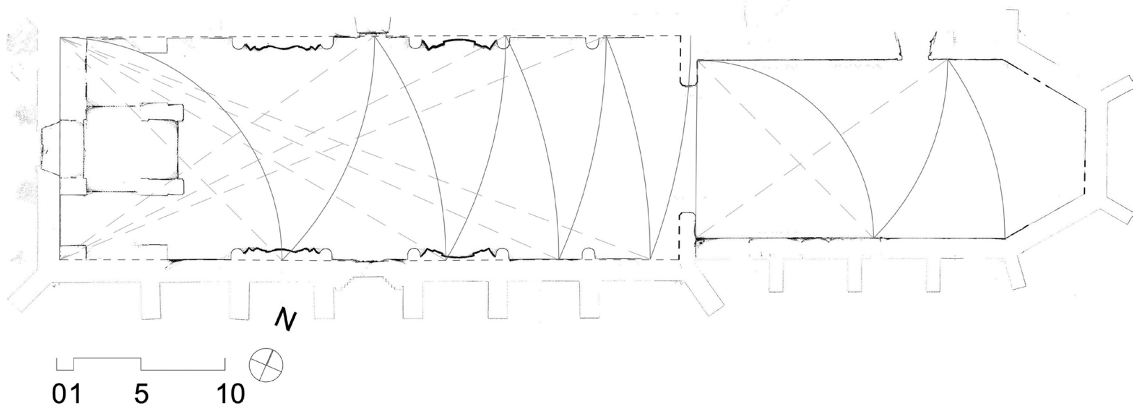

Fig. 10. Method 2 applied to the apse and nave. The authors' work.

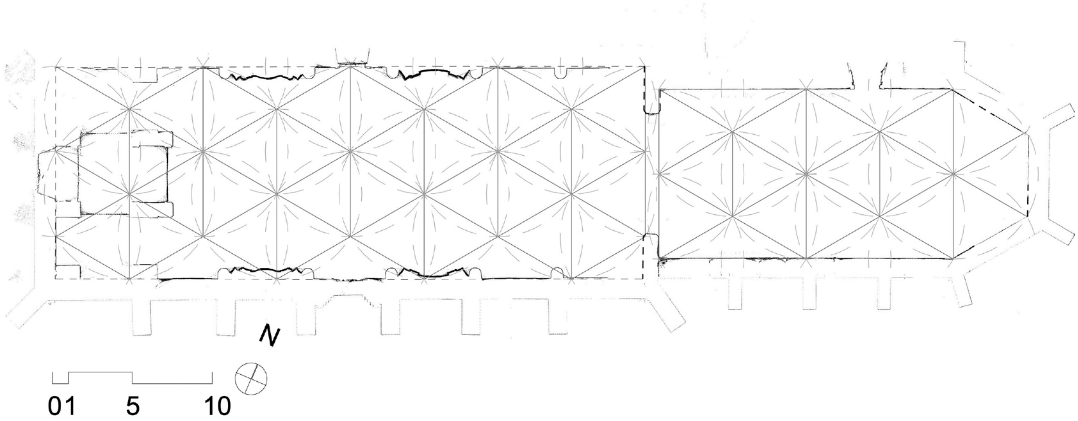

Fig. 11. Method 3 applied to the apse and nave. The authors’ work.

Fig. 12. Example of a highly distorted rib in the apse’s rib system, frontal view from the point cloud and photo. The Authors’ work.

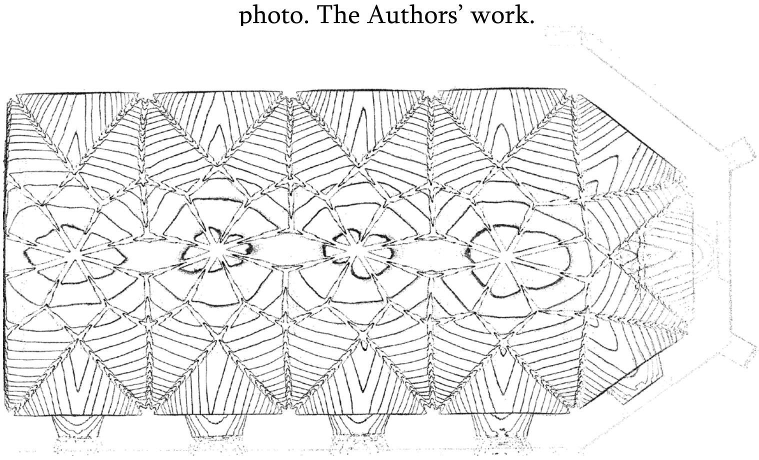

Fig. 13. “Mapping” of the apse’s vault. The authors’ work.

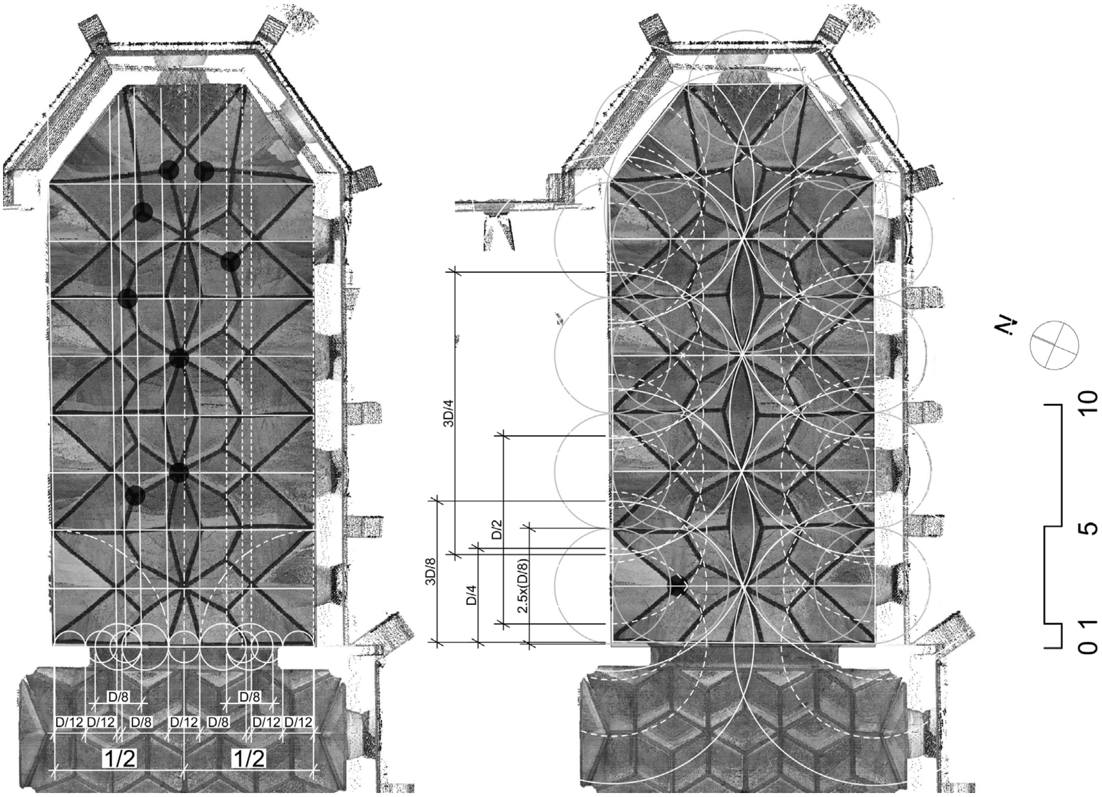

Fig. 14. Probable construction methods of the plan of the apse's rib system. a. construction with lines; b. construction with circles ("x" refers to the "x" value defined in the text). The authors' work.

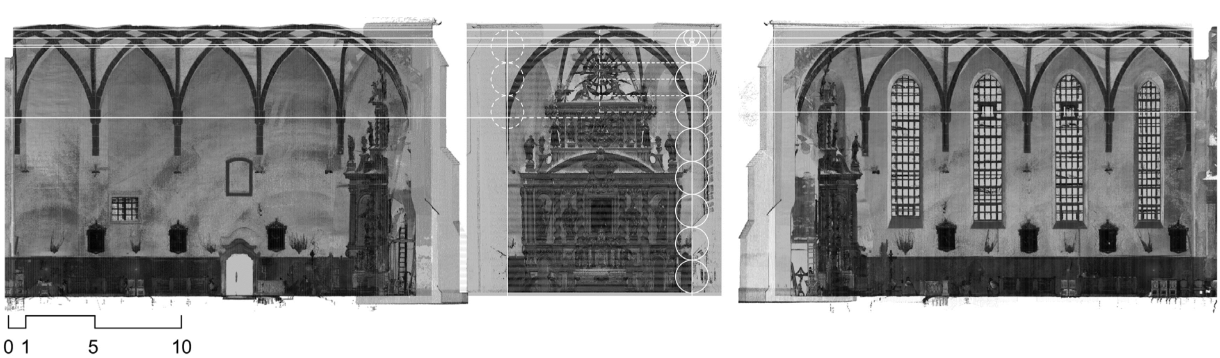

Fig. 15. Reconstructed construction principles on the longitudinal and cross-sections of the apse's rib system; a. longitudinal section looking to the north; b. cross-section looking to the east; c. longitudinal section looking to the south. The authors' work.

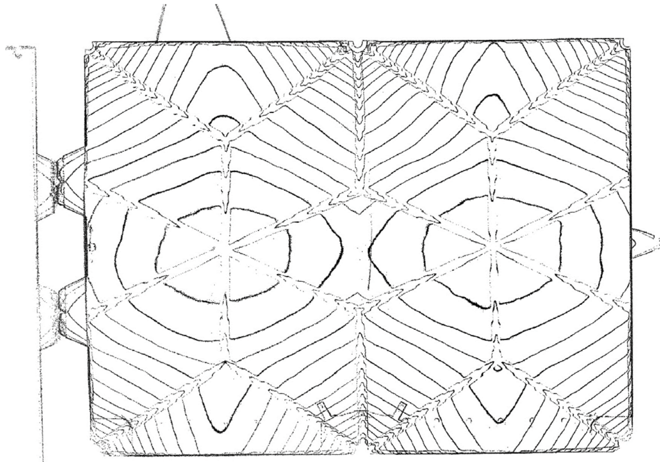

Fig. 16. "Mapping" of the sacristy's vault. The authors' work.

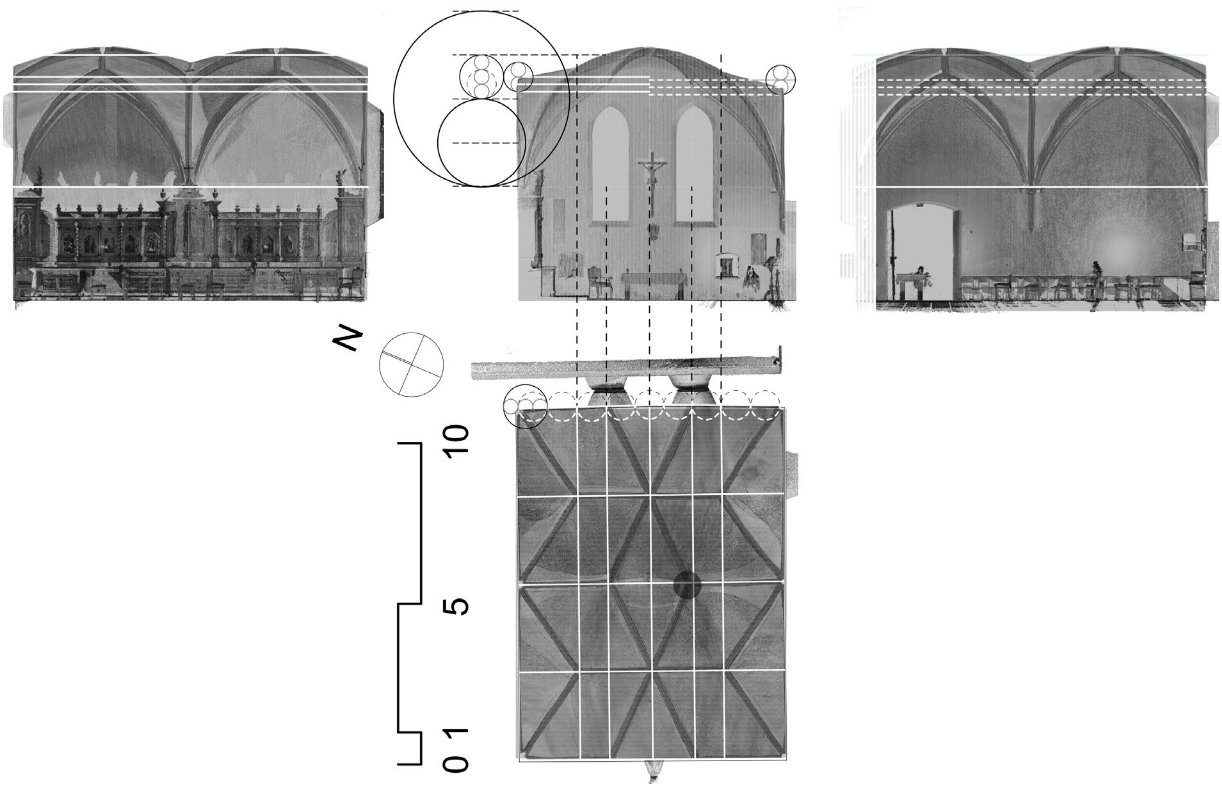

Fig. 17. Reconstructed construction principles on the plan and longitudinal and cross-sections of the sacristy's rib system. a. longitudinal section looking to the north; b. cross-section looking to the east; c. longitudinal section looking to the south; d. plan. The authors' work.

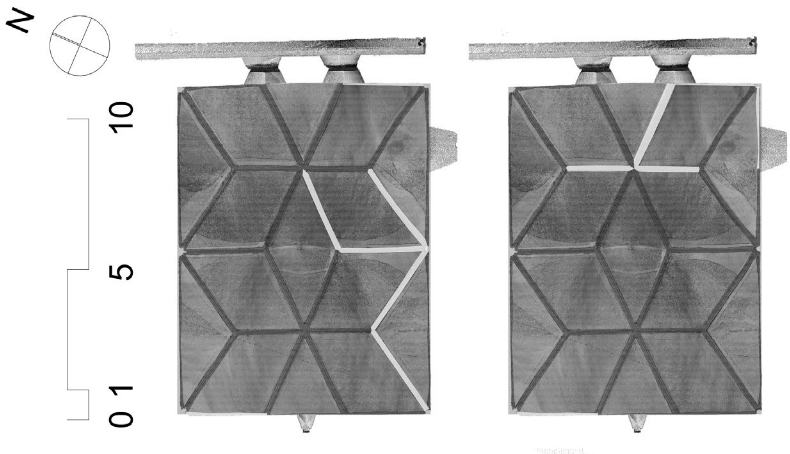

Fig. 18. a. Situation of non-uniformly curved ribs on the sacristy's plan; b. Situation of ribs with curvatures greatly deviating from the average value. The authors' work.

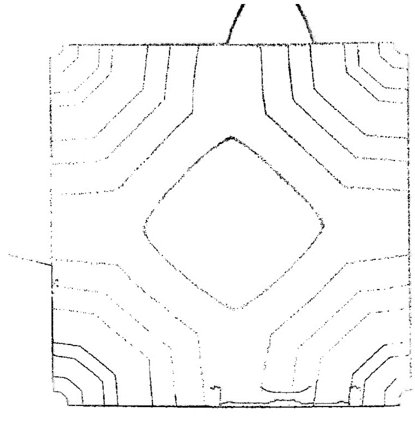

Fig. 19. "Mapping" of the vault on the tower's ground floor. The authors' work.

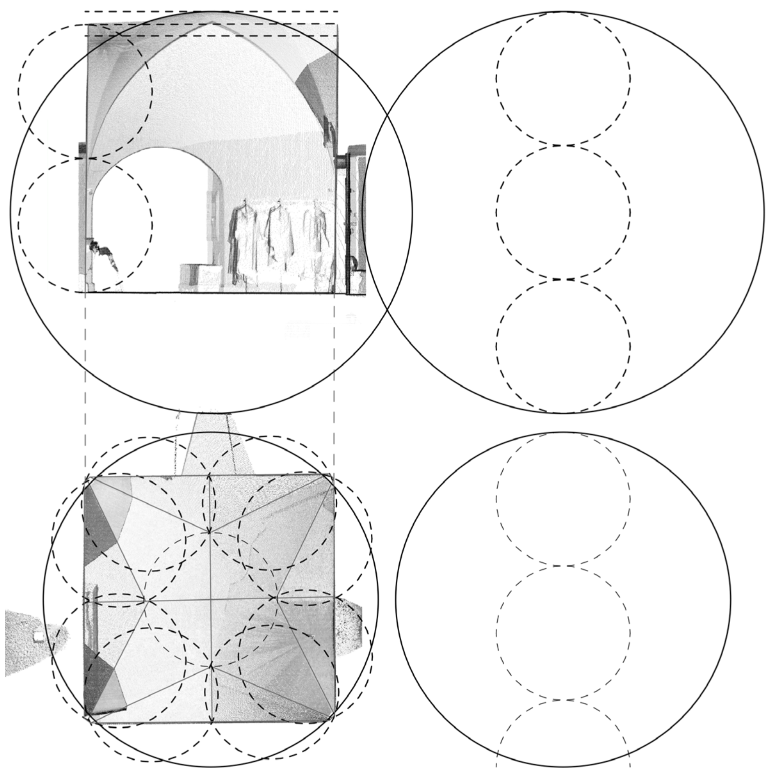

Fig. 20. Reconstructed construction principles of the groin system on the plan and cross-sections of the vault on the tower's ground floor. a. cross-section of the vault looking to the north; b. plan of the vault. The authors' work.

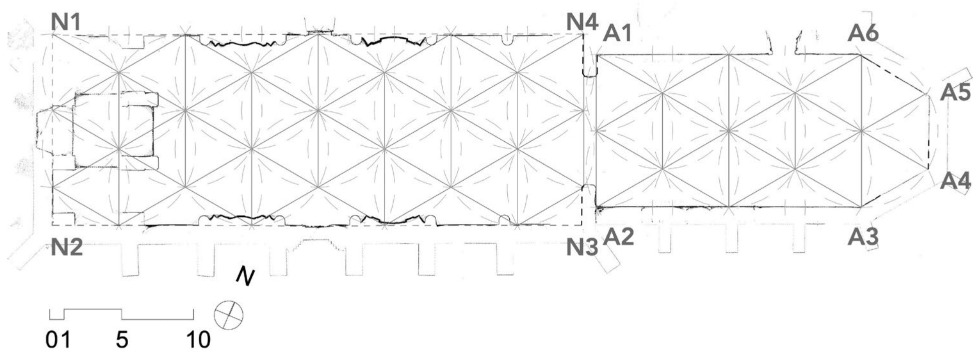

Fig. 21. 60-degree grid applied on the apse and nave, the main corners of these spaces marked. The authors’ work.

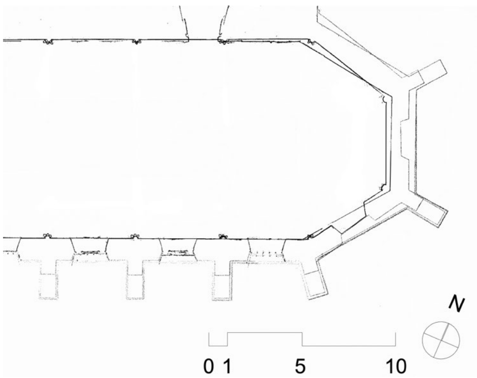

Fig. 22. The lower hexagonal and higher roughly octagonal layout projected on each other. The west endpoints of the hexagonal walls are further west, and the east endpoints are further east than those of the octagonal walls. The authors’ work.

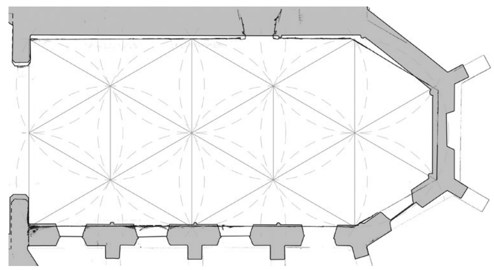

Fig. 23. The octagonal layout of the higher apse walls projected onto the grid of the lower walls. This layout shows no connection to the grid. The authors’ work.

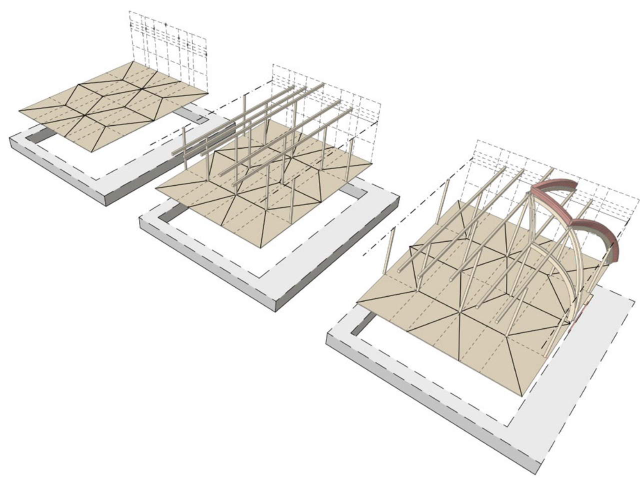

Fig. 24a, b, c. Theoretic reconstruction of the construction and building process of the apse’s and sacristy’s vaults, presented on the example of the sacristy’s vault. The authors’ work.

Corner	Error – grid (cm)	Error – circle (cm)
A1	7.69	7.59
A2	4.47	1.19
A3	3.78	2.90
A4	4.12	2.89
A5	28.99	3.03
A6	23.47	2.64
N1	8.15	4.03
N2	3.93*	2.48*
N3	15.48*	12.04
N4	5.57	4.49

Table 1. Errors of each corner from their respective grid points and from the nearest points of their constructing circles. The numbers marked with "*" are the errors if the grid was flipped along the axis of the nave. The authors' work.