

Linear and Centralised Net Vaults

Geometry-Based Building Archaeology Presented on the Net Vaults of the Fortified Church of Mediasz

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SUMMARY

This article presents an objective, point-cloud-based geometric description of the nave, apse, and sacristy vaults in the fortified church of Mediasz (RO; Medgyes, Mediasch). The description includes the global geometry of the rib systems and the connections between the webs and ribs in each vault. Based on these, we classify these structures into the geometry-based typologies for the global geometry of the rib system and the rib-web connections we established based on our previous works. Additionally, based on the vaults of Mediasz, two rib-system subtypes have been defined: centralising and linear vaults. The relationship between these subtypes and the concept of cylindric and spheric vaults, as well as their connection to the 'pattern' of the net vaults is discussed. Based on the geometric descriptions, we also discuss the possible building strategies and techniques of these vaults and consider the periodisation of the building.

KEYWORDS

building archaeology, Late Gothic net vault, geometry-based vault analysis, laser scanning, point-cloud based analysis, vaulting techniques, medieval construction methods, South-Transylvanian church

1. INTRODUCTION

1.1. General introduction

Nowadays, terrestrial laser scanning is a valuable tool for non-destructive building archaeology, providing vital geometric data for historic monuments. This method can reveal hidden construction logic based solely on geometry, enabling researchers to gain deeper insight into original building techniques and the relationships between structures. The literature's generally accepted claims about these structures mostly originate from the 19th and 20th centuries when conclusions could only be based on less accurate traditional survey methods.



Figure 1. The apse, nave and sacristy vaults (left to right) in the fortified church in Mediaș
(The Author's photos)

This article aims to present new opportunities for analysing Late Gothic net vaults based on their exact geometry. The Methodology chapter details the typologies introduced for the geometry-based classification of the rib systems and rib-web connections of the Late Gothic net vaults based on the literature on the topic and our previous results. The Results chapter presents case studies of the apse, sacristy, and nave vaults of the fortified church in Mediaș (Fig. 1). This chapter provides an objective geometric description of these vaults. In the Discussion chapter, we present our deductions based on the geometric descriptions. These deductions cover the theoretical reconstruction of the original building techniques and the discussion of a peculiar geometric phenomenon detected in the net vault of the main nave.

1.2. Building history of the fortified church in Mediaș

The building works of the present church began in the 14th century, following the demolition of the first church that was not spacious enough (first half of the 14th century).¹ During the Gothic era, the second church underwent significant modifications, including the destruction of its northern wall and the addition of a northern aisle at the end of the 14th century.² (This aisle and the main nave form a basilical space.) A new apse was built in 1440, and in the second half of the 15th century, the choir and nave were rebuilt, and a southern aisle was added to the church.³ The southern aisle of the church connects to the main nave in the manner of hall churches. However, Karl Werner explains that the structural differences between the two aisles were due to a plan alteration, rather than different building periods.⁴ According to Werner's periodisation, the apse

¹ Fabini 1999. 467.

² Fabini 1999. 468.

³ Fabini 1999. 468.

⁴ Werner 1872. 25.



and the sacristy are fitted to the altered, hall church plan, but they were concluded before the southern aisle and the main nave.⁵

The church was first mentioned in 1452 as ‘fortified’. According to Georg Soterius’ *Historia Transilvaniae*, it was completed in 1488.⁶ The net vaults of the nave and the apse date also to the end of the 15th century. The rib-crossings are adorned by blazons decorated with painted apostles and saints.⁷ Between 1550–1551, the towers were heightened.⁸

2. METHODOLOGY

2.1. Survey method

Terrestrial laser scanning was used in this study to create point clouds for the proposed net vault analysis method. Specifically, the Leica BLK 360 terrestrial laser scanner was utilised, and the point cloud data was processed using Leica 360 Cyclon Register.

It is important to consider the accuracy of the scanner when addressing the exact geometry of the vaults, as it has a precision of 8mm at a distance of 20 m.⁹ Given the dimensions of the churches’ spaces under investigation, potential inaccuracies of approximately 1–2 cm are anticipated. Consequently, considering the expected precision in the buildings’ geometry, primarily influenced by the building technologies of the Late Gothic period,¹⁰ we claim that these point clouds are well-suited for the intended analyses.¹¹

It is important to acknowledge that inaccuracies may occur during our analysis process when extracting measurements from the point cloud. However, this phenomenon is not exclusive to our measurements but is inherent in the original work of the builders of these structures. Therefore, if such variability is considered acceptable as an inaccuracy in the construction process, it should also be accepted in the measurements.

2.2. Analysis method

2.2.1. Mapping

Our analysis method is based on the concept that the geometry of the vaults is determined by the original construction and building techniques, such as the geometry of the temporary supporting structure. Therefore, the geometry of the vault can be traced back to these methods. This

⁵ Werner 1872. 26.

⁶ Fabini 1999. 468.

⁷ Oprescu 1961. 34.

⁸ Fabini 1999. 468.

⁹ <https://shop.leica-geosystems.com/leica-blk/blk360/blog/blk360-frequently-asked-questions> (Accessed 30 October 2023).

¹⁰ Fehér–Halmos (2017. 222) identifies discrepancies in the geometry of vault rib elements, attributing some to the inherent inaccuracy in the original construction. These inconsistencies are presumed to extend beyond individual elements to impact the global geometry of the vault.

¹¹ Not only our own experiences but also other research supports this claim: e.g. Vidal (2017) proved by experimental method that regardless of the deterioration, the curvature of the ribs can be found with a high probability.



also implies that the more irregular the present vault's geometry is, the more precisely the original methods can be determined. Multiple methods can be used to achieve regular geometry, but 'regular irregularities' limit the possible approaches. It is important to note that examining net vaults using this principle requires an initial assessment of whether any geometric changes have occurred in the structures since their construction.

The analysis of these vaults involves two main steps: analysing the connection between the rib system and the webbing and analysing the overall geometry of the rib system. In practice, the vaults are examined by 'mapping' them and analysing the geometry of their plan projections, cross-sections, and longitudinal sections.

By 'mapping', we mean that the vault is 'sliced' with horizontal planes. This provides information about the connection between the rib system and the webbing as well as preliminary observations about the global geometry of the rib system. Regarding the first question, the examination may result in three main theoretical outcomes.

Based on the literature, net vaults can be classified as either 'pseudo net vaults'¹² or 'real net vaults'¹³ in a structural sense. The webs of the latter may be constructed with¹⁴ or without formworks.¹⁵ Voigts¹⁶ also showed that occasionally a combination of the two main methods was used, with each web using the more suitable method. Regarding the global geometry of the rib system in real net vaults, they may be either 'linear net vaults'¹⁷ or 'centralising net vaults'¹⁸.

These various geometric and structural solutions produce mapping projections of different natures. Pseudo net vaults have straight horizontal section lines of the webbing that do not reflect the position of the ribs. Real net vaults, on the other hand, have webs and rib systems that are interdependent, which is also reflected in the mapping. If a real net vault's webs were built with formworks, the horizontal sections of the webs are close to straight and may be slightly

¹² Some researchers argue that certain net vaults are actually barrel vaults, with their rib system serving a purely decorative function and constructed after the webbing. This theory is present in the literature several times for masonry ribbed vaults (e.g. Roth 1905. 36; Fabini 1999; Harsányi 2001. 302), despite the existence of opposing viewpoints (Szőke 2012. 207–208; Pliego 2012. 220).

¹³ The more widespread theory suggests that the rib system should be built before the webbing and the webbing was built on the rib system (as described first by Saunders in 1814 and specified later by Willis in 1842 (as quoted by Wendland [2007. 342]) and mentioned by Ungewitter (1901. 37)).

¹⁴ In this case, full-surface formworks were placed on the ribs, on which the webs were built (Voigts 2021. 78) resulting in quite flat web surfaces (Voigts 2021. 78; Wendland 2007. 342) and the occasional sagging of the formwork may cause the introflexion of the webs (Schuller 2016. 474).

¹⁵ In this case, either only a centring (such device is pictured e.g. in Viollet-le-Duc (1854–1868. Fig. 58.); Ungewitter (1901. 117); Fitchen (1961. 101, Fig. 40.)) was used or not even that (e.g. Fitchen (1961. 69) – based on Lassaulx (1831) – pictures how a stone-weighted rope device can stabilize the unfinished courses), and each course of the web worked as a self-supporting arch after completion (Voigts 2021. 79).

¹⁶ Voigts 2014. 250; Voigts 2021. 80–81.

¹⁷ In this article, we define linear net vaults as net vaults where the vertical disposition of the rib system and their junction points do not reflect the boundaries of the bays. It must be accentuated that our definition does not concern the pattern of the rib system, as we found that with the same 'pattern' and in the same vault both of these characters may appear. (These geometric necessities may be seen as connected to the problem of distinguishing net vaults and stellar-net vaults. However, the difference between these two and their definitions is not unambiguous in the literature and is not independent of the pattern of the rib system.)

¹⁸ In this article, we define centralising net vaults as net vaults where the vertical disposition of the rib system and their junction points reflect the boundaries of the bays.



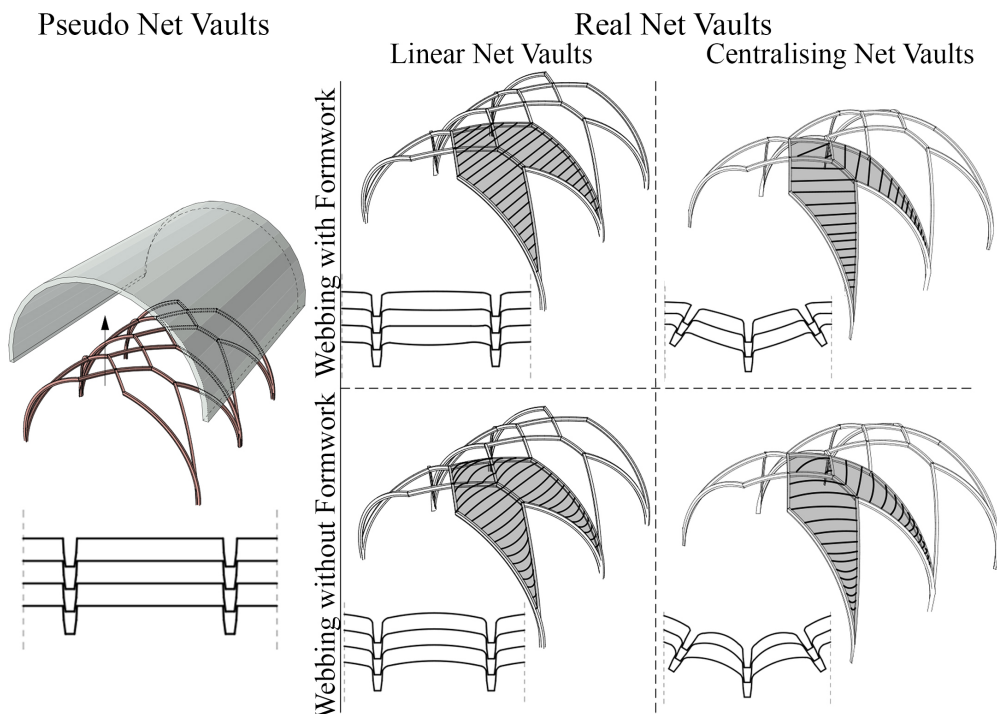


Figure 2. Theoretical outcomes of the mapping of a net vault (The Author's work)

convex or concave. However, if formworks were not used, the horizontal section lines of the webs are curved.

In the case of linear net vaults, the webs' horizontal sections (or the lines connecting the crossing points, in the case of webs built without formworks) do not change directions when crossing the ribs. In the case of centralising net vaults, they do (Fig. 2).

2.2.2. Analysing the ribs' spatial positions

After analysing the 'mapping' of the vaults, we examine the spatial positioning of junction points in a Cartesian coordinate system along the longitudinal, cross, and vertical directions of the vault (Fig. 3). While the literature on the topic assumes that the construction of a rib system starts with its plan,¹⁹ our previous research supports our claim that exceptions do exist.²⁰ Thus, during our analysis identifying the two coordinates describing the plane, where the projected picture of the vault was first constructed is of crucial importance. Based on our results and the geometric necessities in this question, this examination may result in four different theoretical outcomes.

¹⁹ Ranisch 1695; Hoffstadt 1840; Warth 1896; Ungewitter 1901.

²⁰ Jobbik-Krähling 2022; Jobbik-Krähling 2023b; Jobbik-Krähling 2024.



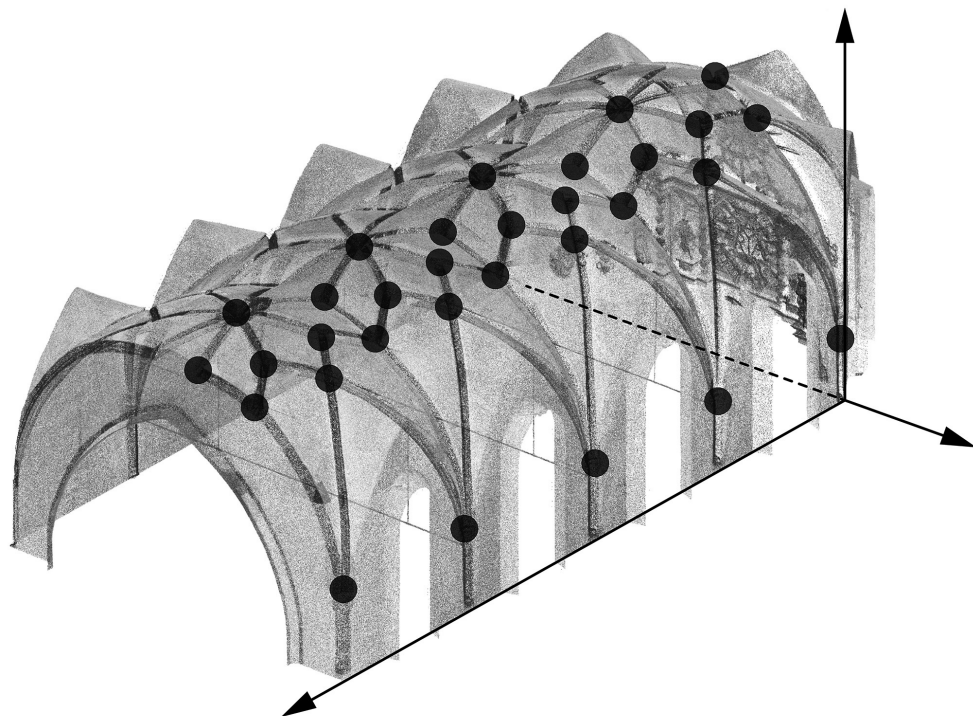


Figure 3. Theoretical Cartesian coordinate system for analysing the rib junction points' spatial positions. (Presented on the apse vault of the Franciscan church of Szeged-Alsóváros) (The Author's work)

The first theoretical outcome is when the three coordinates of the junction point's spatial positions can be independently constructed from each other. In other words, to any one of them a construction method can be reconstructed without the need to know any of the other coordinates. In these cases, the values required for the construction can be deduced from the general dimensions of the building, such as the plan layout, or height of the nave or the apse. Therefore, only vague statements can be made about these vaults. It should be noted that in these cases, although any plane of the visionary coordinate system could theoretically be the primary during construction, the primacy of the plan is the most plausible. This is because it appears to be the simplest method of execution.

The second theoretical outcome is when the rib system's geometry indicates that the plan view takes precedence over the vertical dimensions. In other words, to determine the vertical coordinate of any given rib junction point in these cases, its projected position on the plan must be known. The literature contains numerous principles that characterise the underlying construction principles of such a plan. The most fundamental of these systems include those based on quadrate nets,²¹ rotated inscribable quadrats,²² triangulation,²³ and constructions based on

²¹ E.g. Schulze's method as quoted by Müller (1975. 45).

²² Hoffstadt's XIV. A. board, as quoted in Müller (1975. 52); Guillouët 2019. 63.

²³ About constructing a Medieval building based on the principles 'ad quadratum' and 'ad triangulum' see e.g. Pacey (2007. 73-74).

circles.²⁴ To add the vertical dimension to these systems, multiple geometric descriptions appear in the literature: projection-based approaches, such as net vaults deduced from cross-vaults,²⁵ from fan vaults,²⁶ domical vault-like²⁷ (the junction points fit a spherical surface), and barrel vault-like net vaults²⁸ (the junction points fit on a cylindric surface) or ‘linear approaches’ such as the ‘principle of the longest route’.²⁹

The third theoretic outcome regarding the construction order of the different planes on the visionary Cartesian coordinate system is the primacy of the cross-section to the longitudinal-direction coordinate. This possibility had not yet been discussed in the literature, until among our former case studies we have identified such examples.³⁰ In these cases, the plan view of the vault appears disorderly, with rib junctions of the same type and on the same side of the vault falling on straight lines – with occasional exceptions. Although these lines may not be parallel on the plan view, they are parallel on the longitudinal sections. The longitudinal junction coordinates were defined using the chord lengths of the ribs in the examined case studies of this type.

The fourth theoretic outcome is the primacy of the longitudinal section to the cross-direction coordinate. So far, we do not know any real examples or descriptions in the literature of this possible case.

It is important to note that theoretical figures in the literature typically only depict rib systems (and net vaults in general) with outlines. The construction steps described in the literature result in a single point as the ‘position’ of a given rib junction element. This point must be presumed to be on the lower surface of the rib system, as that can be positioned with the help of the temporary supporting structures the most easily.³¹

2.2.3. Individual rib geometry

In the literature of Late Gothic net vaults, the ‘Prinzipalbogen’ principle is a widely accepted idea.³² The principle means that in a given net vault, each rib has the same curvature. Supposedly, the aim was to standardise the ribs to be prefabricated, which accelerates the whole building process.³³ Although some studies³⁴ have cast doubt on this theory, there are occasional results that prove its former existence.³⁵ Therefore, it must be considered when analysing net vaults.

²⁴ Pacey 2007. 77.

²⁵ Warth 1896. 254–255; Ungewitter 1901. 63.

²⁶ Warth 1897. 257; De l’Orme 1567. 108.

²⁷ Warth 1896. 258; Ungewitter 1901. 64–65; Hontañón’s sketch – as shown in Dopazo (2016).

²⁸ Warth 1896. 258–260; Ungewitter 1901. 64.

²⁹ Bucher 1972. 47; the treatise of Lorenz Lechler as quoted by Shelby and Mark (1979. 125); Hoffstadt 1840. XIV.A/5.; Ungewitter 1901. 67–68; Meckel 1933. 108.

³⁰ Jobbik–Krähling 2022; Jobbik–Krähling 2023b; Jobbik–Krähling 2024.

³¹ The drawing of Hontañón supports this idea as well.

³² It first appeared in written sources in the 16th century, in Lorenz Lechler’s treatise for his son (as quoted by Shelby and Mark [1979. 125]) and in the manuscript of Jacob von Andernach (as quoted by Müller [1974. 65–66]); then appeared in Ranisch 1695; Hoffstadt 1840; Meckel 1933; Müller 1990; Tomlow 1991, etc.

³³ Renn et al. 2014. 71; Vidal 2017. 1007.

³⁴ Lassaulx 1835, as quoted by Wendland (2012. 106).

³⁵ Voigts 2015. 56–57; Jobbik–Krähling 2023a. 81.



Overall, this point-cloud-based analysis results in a precise geometric description of the given net vault. Based on that, further deductions may be made about the original construction and building methods.

3. RESULTS

3.1. Apse vault

3.1.1. Mapping

The apse vault of the fortified church of Mediaș displays webbing with mostly straight horizontal section lines that are parallel to its main axis. This is particularly evident on the northern side, and to a lesser extent on the southern side. In some cases, slight introflexions and convex curvatures appear. Consequently, the vault can be classified as a linear net vault based on its rib system and it was likely built as a real net vault with webs built using formworks. The lunettes, however, are primarily composed of webs with horizontal section lines that are perpendicular to the vault's axis, like those found in barrel vaults (Fig. 4).

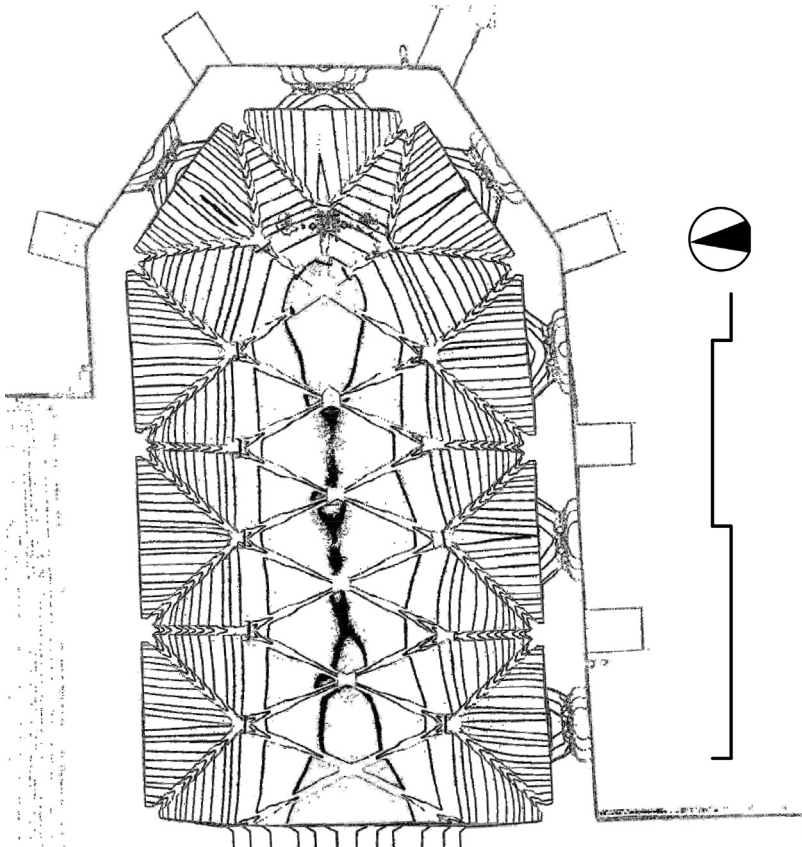


Figure 4. Mapping of the apse vault (The Author's work)

3.1.2. Analysing the ribs' spatial positions

When analysing the spatial positions of the rib junction points, we first examined the plan of the rib system. We found that in the case of the apse vault, although the outline of the apse's inner space is slightly distorted, an orderly construction method can be identified. The length of the bays and the sides of the polygonal ending can be constructed with a uniform circle that has a diameter (a) that is two-thirds of the height of the apse at the polygonal part. The cross-coordinates of the rib system's junction points are constructed using the quarter points of the apse's width, except for the lunettes of the polygon where the third-points are used. (The apse and the main nave have approximately equal widths.) For the longitudinally directed coordinates, the midpoints and endpoints of the bays' lengths are used (Fig. 5).

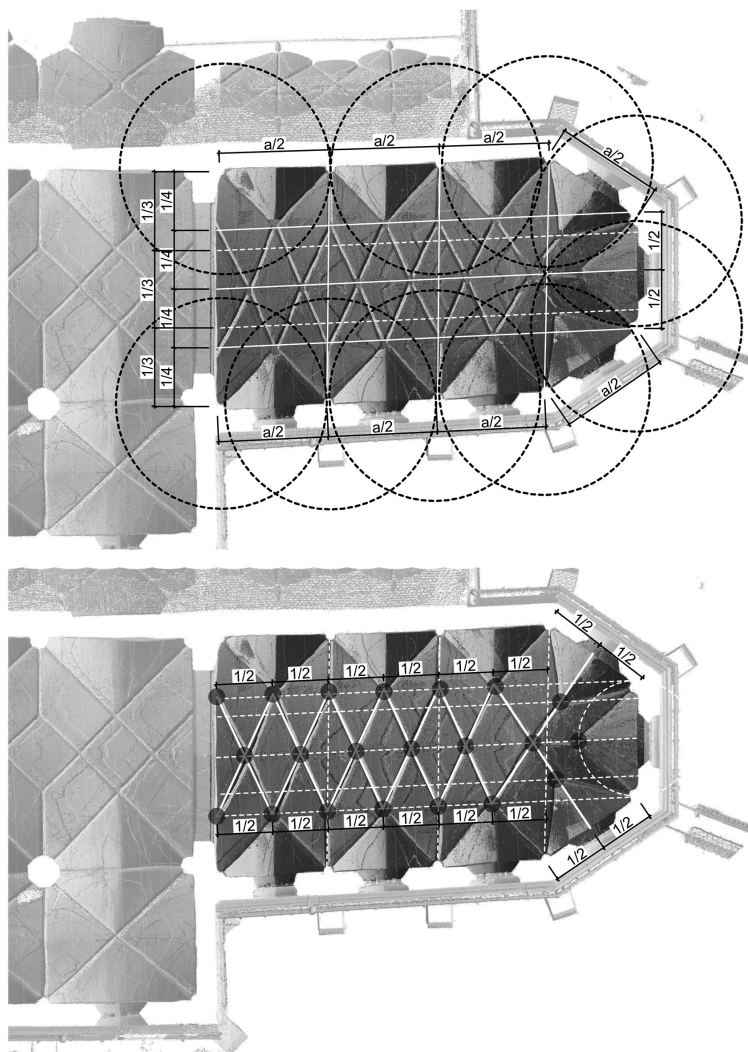


Figure 5. Theoretical construction of the apse vault's plan view (The Author's work)



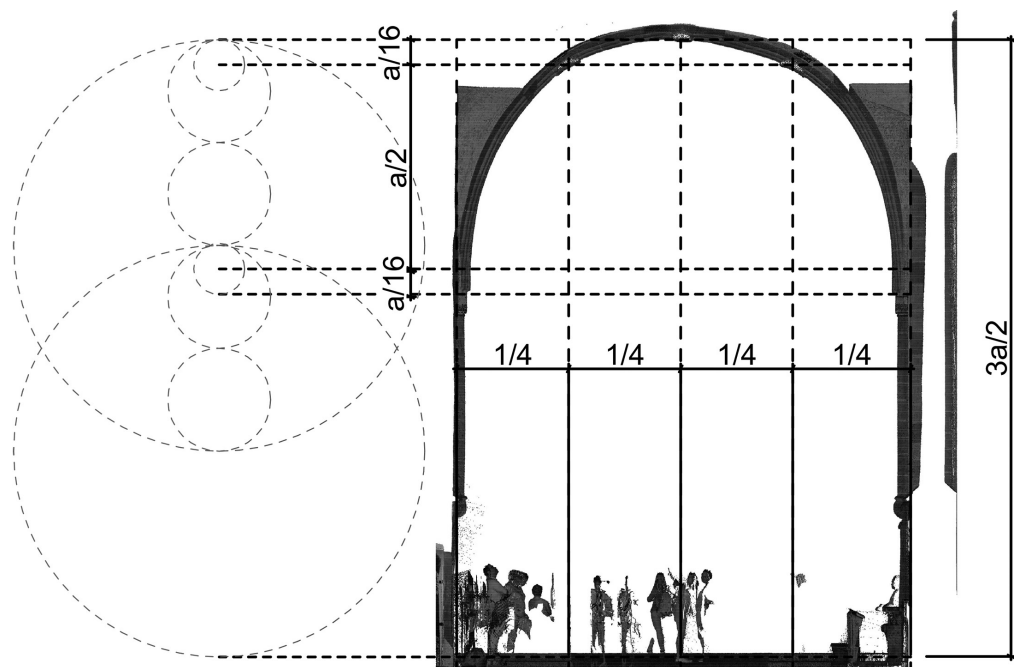


Figure 6. Theoretical construction of the apse vault's cross-section (The Author's work)

In terms of the height (vertical) coordinates of the junction points, we observed that all junction points of the same type are at the same height on longitudinal sections. On the cross-section view, an underlying construction method can be identified that uses the same values (and their simple divisions) as those used for the cross and longitudinal coordinates (Fig. 6).

As we described, the height of the apse ($1.5a$) is equal to the length of the apse without the polygonal ending (the westernmost three bays). Additionally, this value is equal to the combined length of the easternmost two bays in the nave (that adjusts to the bays in the northern – basilical – aisle) (Fig. 7). It should be noted that the second bay of the nave is longer than the others, and a significant change in the character of the vaulting system appears there, which may indicate a change in the original plans (as detailed below). Thus, this observation may be of significance.

All in all, since the spatial positions of the rib junction points proved to be highly regular, we think that finding the exact underlying construction idea that the original builders used is not possible, as there are not enough irregularities that could exclude certain possibilities. However, we see it proved that the spatial positions of the junction points were indeed constructed and that the order of the construction of the three different coordinates was not restricted.

The curvatures of individual ribs are irregular, with straight and differently curved segments occurring frequently even in the course of one given rib. We think it plausible that the exact shapes of the ribs were of secondary importance after determining the spatial positions of the rib junction points. Therefore, it is not possible to declare that the 'Prinzipalbogen' principle was used. However, it is difficult to judge the original intentions of the builders, which could have been overwritten during the structure's construction. Additionally, certain rib types – the ribs of

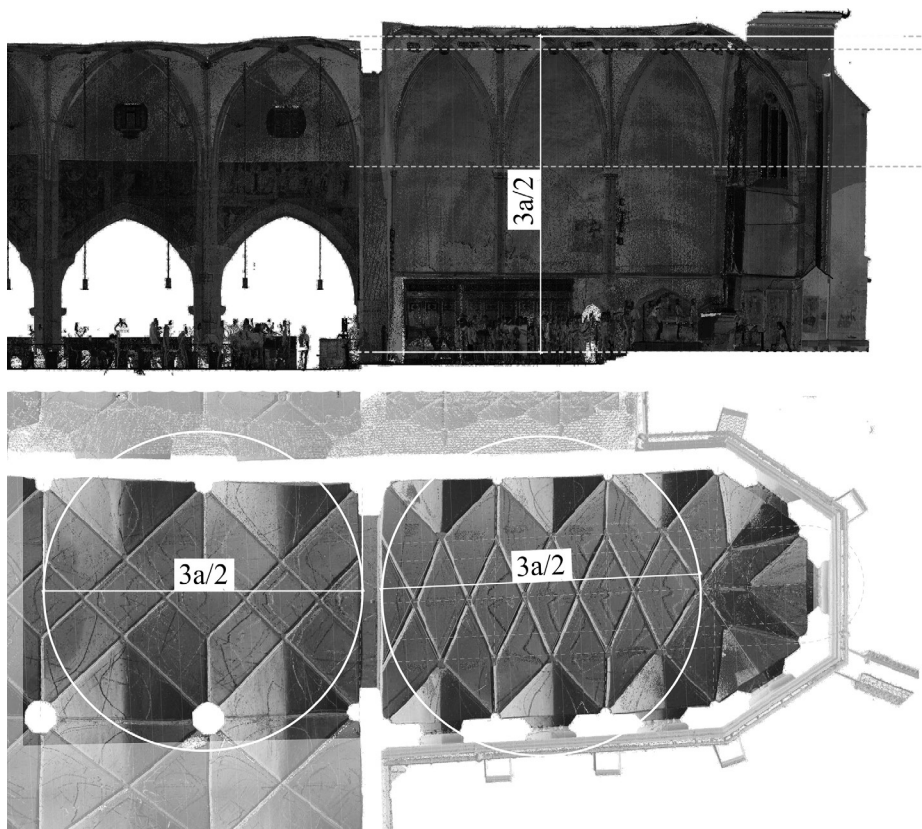


Figure 7. Geometric connection between the length and height of the apse and the plan of the nave (The Author's work)

the lunettes and the cross-directed ribs – show a more regular nature. In those cases, the curvatures are quite uniform. Besides, the average value (R , around 4.55–4.65m) of the curvatures is constructible from the construction of the cross-section view (Fig. 8).

3.2. Nave vault

3.2.1. Mapping

On the mapping, the vault of the main nave in the fortified church of Mediaș shows horizontal web sections that are mostly straight, occasionally slightly convex or concave. Therefore, we concluded that based on the mapping, the vault was built as a real net vault with webs built with formworks. However, it also presents a peculiar phenomenon. In the second bay from the east, the webbing's character changes abruptly mid-web. The easternmost bay and the eastern part of the second bay exhibit characteristics equivalent to the centralising net vaults (as defined above). However, following the mid-web change, the webs in the western part of the vault (up to the tower) have horizontal section lines that are almost parallel to the vault's axis and suggest a linear



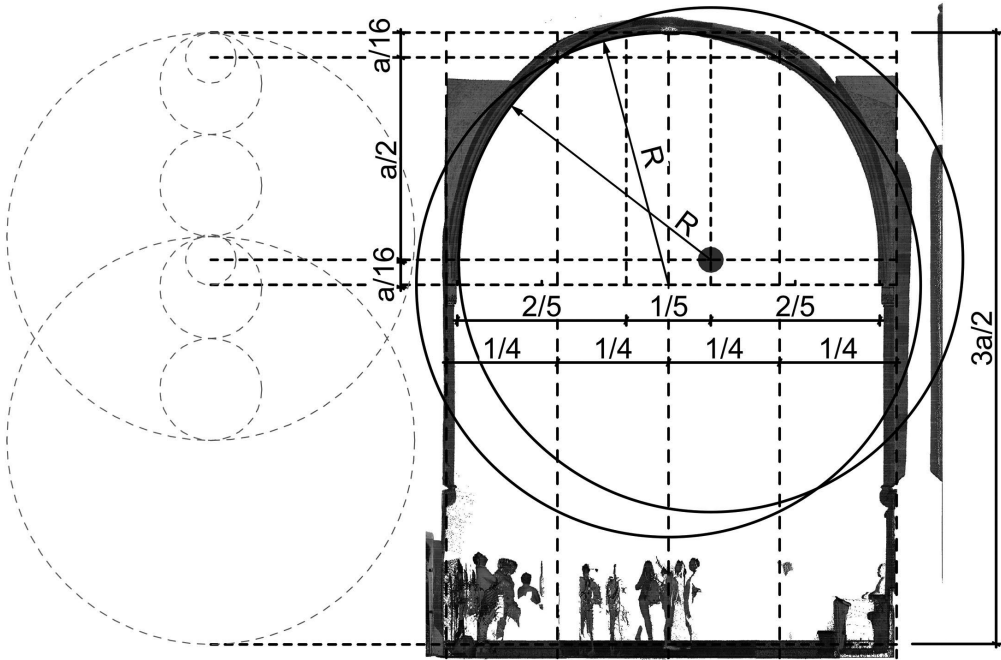


Figure 8. Geometric connection between the position of the rib junction points and the curvature of the ribs in the apse (The Author's work)

net vault. Although there are some local anomalies, the described change is unmistakable. What is even more peculiar is that the rib pattern (plan view) of the vault does not change at all (Fig. 9).

3.2.2. Analysing the ribs' spatial positions

Analysing the spatial positions of the rib junction points, we found that in the easternmost four bays (including the second, slightly longer bay), the cross-directed coordinates are determined by the third-points of the nave's width. Along the same lines, the longitudinally directed coordinates can be constructed based on the end- and mid-points of the lengths of the bays. However, the bays next to the tower are quite distorted regarding both the outlines of their plan and the plan of their rib system that seems quite haphazard (Fig. 10).

Examining the vertical coordinates of the junction points, we found that in the easternmost four bays, the crown line (the highest positioned junctions) is of an even height. This height is determined by a regular triangle's height from the lowest point of the imposts. What is more, this triangle is inscribable in the regular-length bays on the longitudinal section, thus, it adapts to the length of the bays (Fig. 11). The upper junction points of the cross-directed ribs are also of the same height in these four bays, except in the easternmost bay, which is the only such rib falling in the centralising net vault part of the vault. This junction point is positioned lower than the rest. The rest of these points can be constructed on the cross-section with the circumscribed circle of a regular triangle identical to the one previously described (Fig. 11).



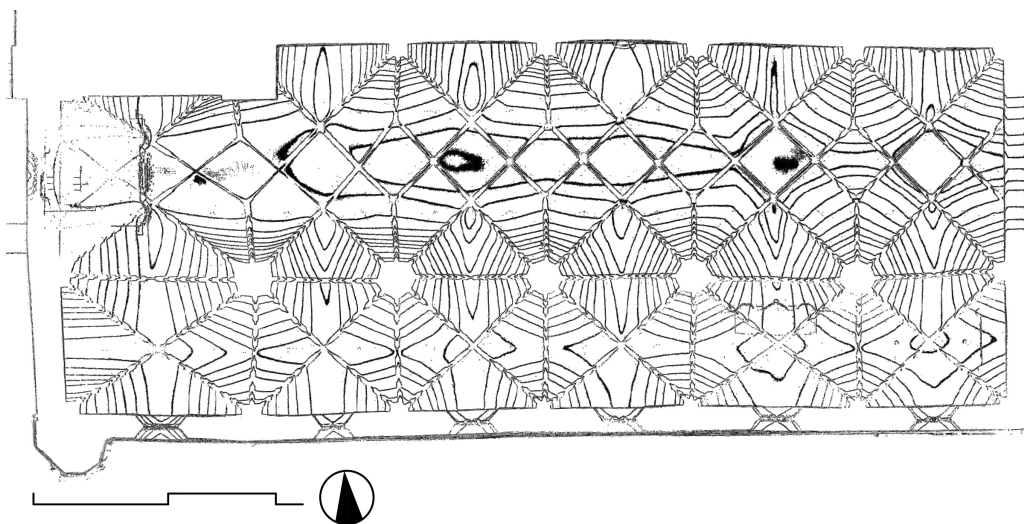


Figure 9. Mapping of the nave (The Author's work)

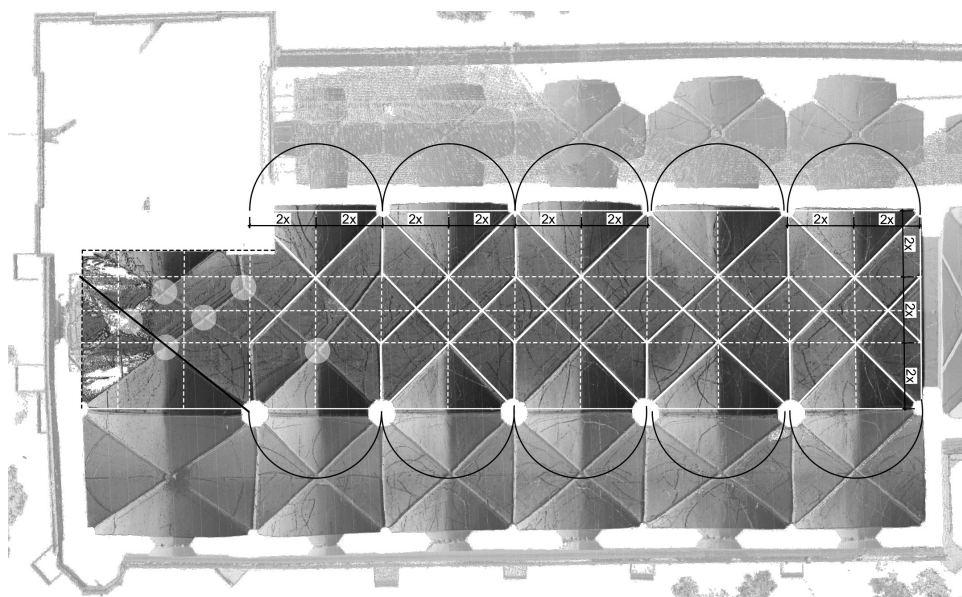


Figure 10. Theoretical construction of the nave vault's plan view (The Author's work)

However, the height of the upper junctions of the lunettes' diagonally directed ribs is not uniform. These junction points fall on a straight line that is sloping to the west. (This is the only feature that is true even in the bays next to the tower.) Examining the spaces connecting to the main nave we concluded that in the case of the easternmost bay, the sloped line's highest point corresponds to the apse's junction points of the same function. In the case of the westernmost bay, the same junction point corresponds to the crown height of the cross vault in the southern



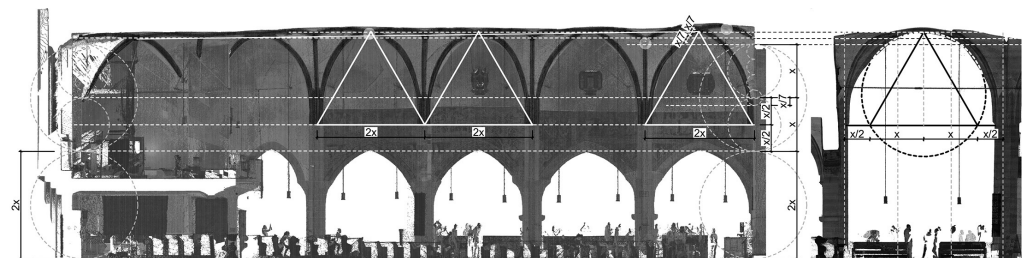


Figure 11. Theoretical construction of the nave vault's longitudinal and cross-section (The Author's work)

aisle's westernmost bay (that one cross vault is higher than the others in that aisle³⁶). However, these two limit values can also be interpreted as the vertical coordinate of the junction points on the crown line (upper) and that of the upper junction of the cross-directed ribs (lower). Overall, the exact position of the sloped line described can be determined.

The lowest point of the ribs is only interpretable in the easternmost four bays. These are determined by the same vertical coordinate that can be defined as 2.5 times the half of the regular bays' length. The vertical coordinates of the points from where the ribs have a curvature are uniformly 1.5 times the regular bays' length (Fig. 11).

Regarding the individual ribs, we found that their curvatures are very uneven, even in the course of one given rib multiple curvatures appear, thus the 'Prinzipalbogen' principle likely does not apply.

Overall, we concluded that the rib system is constructible using a uniform value regarding both its plan view and height dimensions, however, the latter is not as straightforward as the former and its logic changes throughout the vault, thus in this case, the primacy of the plan view's construction is far more plausible. It is also a significant finding that the rib system may be adjusted to the vaults of the connected spaces and act as a theoretic geometric connection between the southern aisle and the apse.

3.3. Sacristy vault

3.3.1. Mapping

The mapping of the sacristy of the fortified church of Mediaș exhibits characteristics typical of real net vaults and of centralising net vaults. The horizontal section lines of the webs are mostly slightly curved, occasionally straight. However, introflexed horizontal section lines are not typical in this case. Straight section lines do not occur near the crown. All in all, both webs built with formworks or vaulting 'from free hand' (without formwork) are conceivable in this case. The latter is likely because the straight horizontal web sections occur where the tangents of the vault are closer to the vertical than to the horizontal, the spans between the ribs of the vault are

³⁶ The easternmost four cross vaults in the southern aisle are of a uniform height that is equal to the height of the arches between the main nave and the aisle; the fifth bay is shorter than any other and its cross vault's crown point is definitely lower.



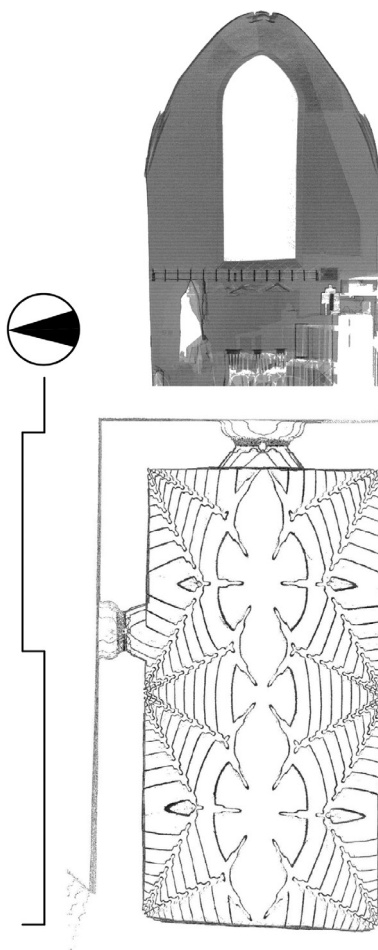


Figure 12. Mapping and cross-section of the sacristy vault (The Author's work)

not significant, and the ratio of the steep parts on the cross-section is overwhelming compared to the flat parts. The latter geometry allows the lower courses to remain stable even without significant curvature (*Fig. 12*).

3.3.2. Analysing the ribs' spatial positions

When analysing the spatial positions of the rib junction points, we found that the plan view is most likely constructed. The longitudinal coordinates of the rib junction points are based on the mid- and fifth-points of the bays' length. Regarding the cross-directed coordinates, the upper junction points of the lunettes' ribs are positioned from the walls at a distance that is equal to the half-length of the bays. The other junction points fall on straight lines that are positioned from the walls at a distance that is equal to a third of the sacristy's width (the southern side is less ex-



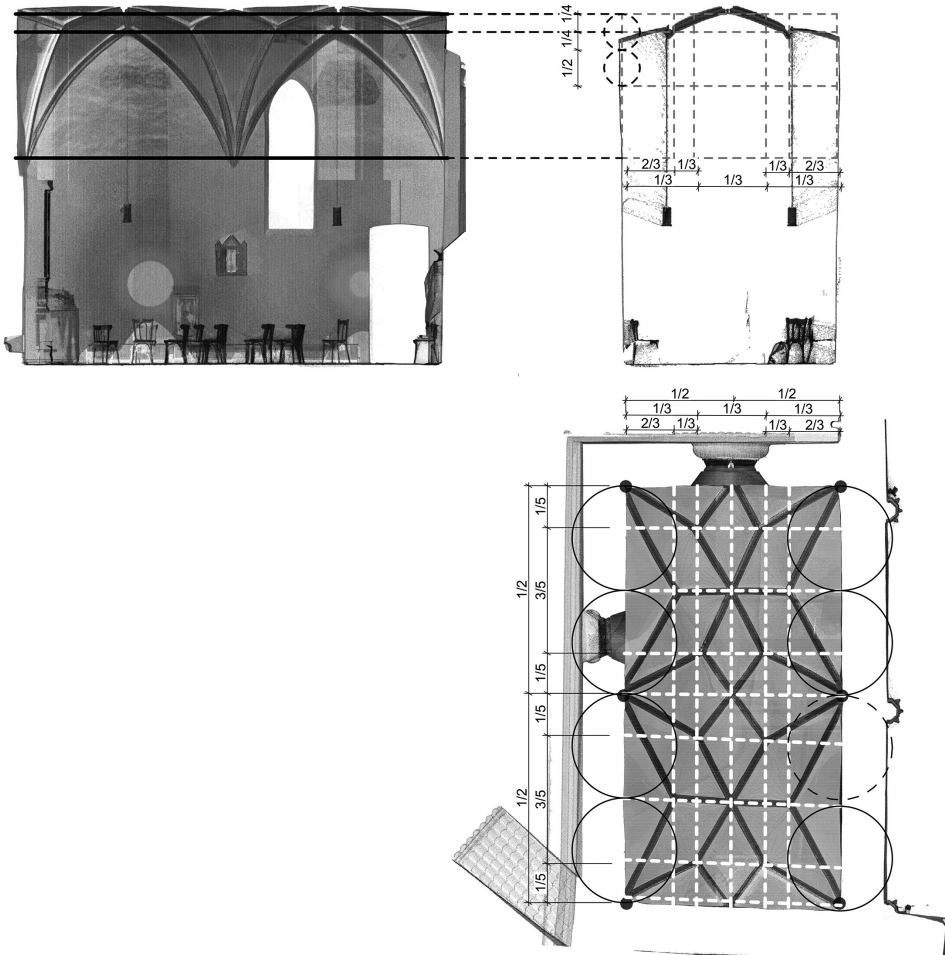


Figure 13. Theoretical construction of the sacristy vault's plan view, cross- and longitudinal sections (The Author's work)

act than the northern). This system appears clearly on the northern side, while on the southern side – due to the not parallel short walls – slight distortions occur (Fig. 13).

Regarding the vertical coordinates of the ribs' junction points, we found that they are also very regular and constructible based on a quadrate net using the third of the sacristy's width and halving and dividing it by three (Fig. 13). (The construction refers to the position of the lower surface of the ribs, as explained in Chapter 2.2.2.)

Measuring the curvature of the individual ribs showed that they are acceptable as uniform, thus, the 'Prinzipalbogen' principle may apply in this vault.

All in all, we found that all three examined coordinates of the rib junctions of this vault are highly regularly constructible. The proposed construction steps to create the rib system's geometry is a possibility, however, the same regular result can be achieved via multiple construction methods (as mentioned in Chapter 3.1.2.).

4. DISCUSSION

The net vaults in the fortified church of Mediaș display both similar and different features. The vaults of the nave and apse have the same rib pattern,³⁷ while the sacristy differs from these.

Upon evaluating the results of the mapping of the structures, it can be concluded that all three vaults are real net vaults. However, it is likely that the apse and nave vaults were built using formworks for the webs, while the sacristy vault may have been built without formworks.

Regarding the rib systems, the mappings showed that the sacristy's vault is a centralising net vault and the apse vault is a linear net vault. In the first case, the rib system's pattern can be interpreted as lined-up stellar vaults, while in the second, the features of the famous pattern best known from Parler's vault from the St Vitus in Prague appear. However, in the case of the nave where the pattern is identical to that of the apse, both centralising and linear characteristics appear, changing from one to the other mid-web. This observation is of huge importance, as neither the pattern of the rib system nor the construction technique of the pattern (on plan view) change in the nave. This shows that the rib pattern in itself does not necessarily indicate whether a net vault is of a centralising character and that centralising net vaults are not necessarily of a 'stellar' pattern. (It is also worth noting that in each bay the lunettes of the nave vault were built as webs in a centralising net vault rather than lunettes of a barrel vault – except for the easternmost one on the northern side.)

As mentioned, the nave vault changes in character rather abruptly, mid-web. This indicates that a plan alteration occurred quite suddenly. As detailed above, the webs of the nave vault were likely built with formworks. In a purely geometric sense, building a formwork on a rib system can always be carried out without such abrupt direction changes. Therefore, this geometry is hard to explain even with a plan alteration or change in the guild or master builder. It may indicate an attempt to mask a mistake during the construction process.

As we have already described in Chapter 3.2.2., in a geometric sense, the upper junction points of the lunettes' ribs in the nave follow a sloping line. This may be interpreted either as adjusted to the vertical positions of the crown line and the cross-directed ribs or adjusted to the connected spaces' vaults (apse, southern aisle). On the one hand, this indicates that the construction of the vault's vertical dimensions started from the two endpoints. On the other hand, this change in height is the geometric necessity behind the change in the centralising and linear nature of the vault. In a geometric sense, the relative spatial position of the ribs to each other 'causes' this difference. This aspect of the vault may indicate an attempt to even out the vaulting system between two given states at the two ends.

We would like to accentuate that in this case, the linear part of the nave vault and the apse vault do not fit on a cylindrical surface. Thus, although their longitudinally directed nature likely originated from a longitudinally directed (linear) temporary supporting structure, the positioning of the directing lines is not necessarily determined by a regular surface. As we have described, these vaults' rib systems are very regular and the three coordinates of the junction points could have been constructed in any order independently from each other (first theoretical outcome). However, based on practical considerations, we find it likely that the construction

³⁷ We define the complete accordance of two rib patterns as all the junction points and ribs in a given bay of one vault have their counterpart in a given bay of the other vault and vice versa.



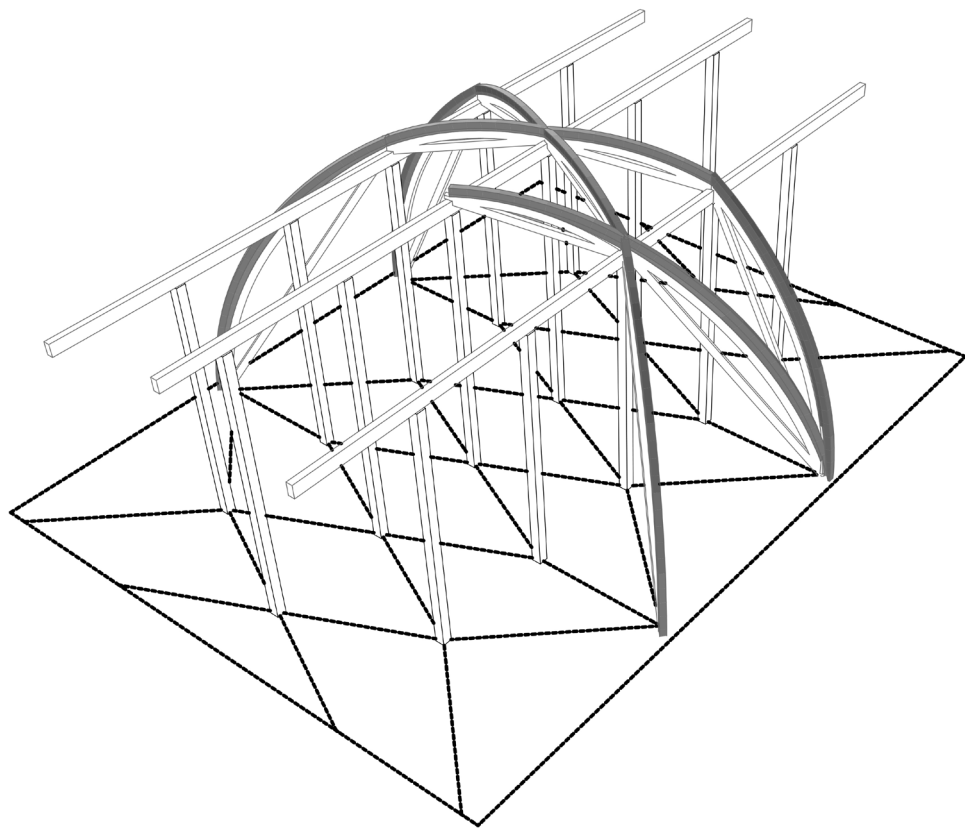


Figure 14. Theoretical reconstruction of the apse vault's building technique. The figure solely represents the logic and nature of the supporting structure and does not aim to reconstruct the exact structural solutions of the wooden structures (The Author's work)

of the rib system started with the construction of the plan (cross- and longitudinal coordinates). The theoretical reconstruction of the building technique is presented in *Fig. 14*.

The sacristy's vault – regardless of its centralising nature and 'stellar vault'-like pattern – does not fit onto spherical surfaces. This is true to its webbing, ribs and even its rib junction points (*Fig. 15*). Based on the geometric regularities detected, we think that this vault could have been built with a linear temporary supporting structure in a similar way to the net vaults of the church. A more centralised centring system also cannot be excluded among the possibilities (*Fig. 16. a–b*).

The combined length of the easternmost two bays in the nave is equal to the apse's length without the polygonal ending. However, the bays in the nave are also adjusted to the bays of both aisles. Accepting periodisation by Fabini (detailed in Chapter 1.2.), the basilical northern aisle is the most ancient part of the present building. Thus, the bays' lengths must originate from there, adopted by the main nave and the southern aisle. If this is the case, the length of the apse and consequently the construction technique of its layout was likely determined based on the nave. However, this does not necessarily indicate the building order of the vaults as those can be constructed based only on the plan layouts of the spaces they cover.



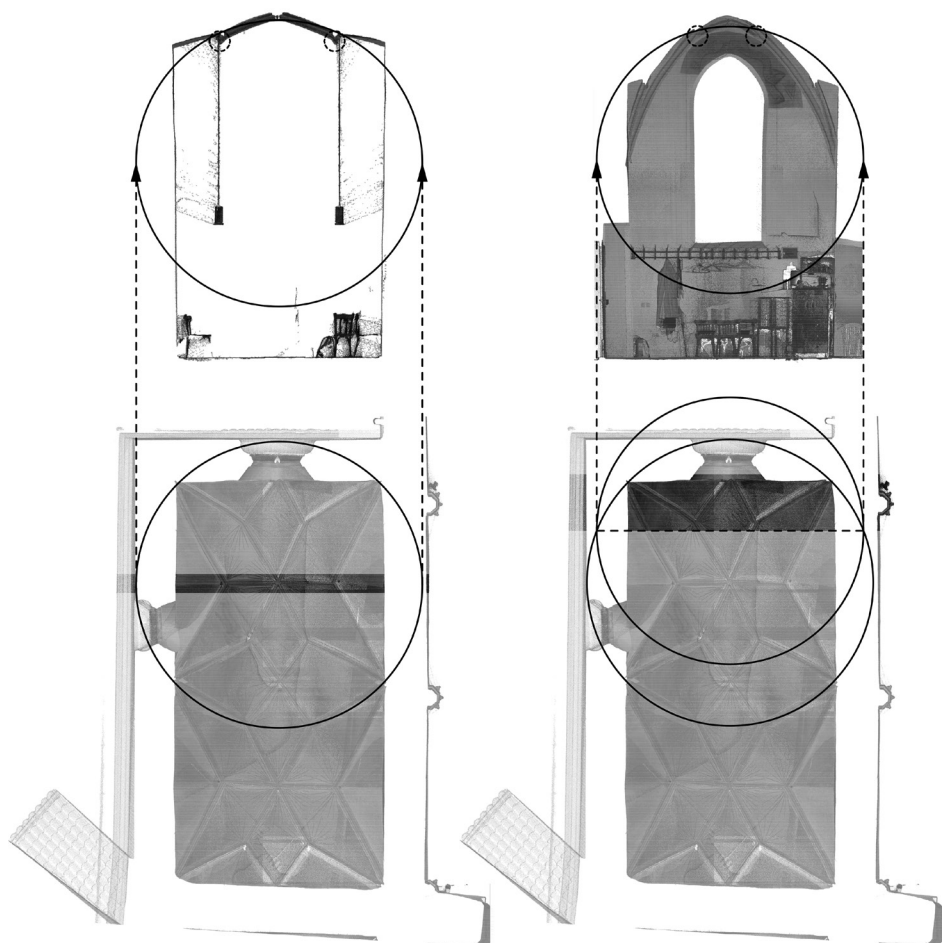


Figure 15. Plan view and cross-sections of the sacristy with the sections of the theoretical sphere that would determine a stellar vault of the same dimensions (The Author's work)

5. CONCLUSION

This article presents an objective, point-cloud-based geometric description of the nave, apse, and sacristy vaults in the fortified church of Mediaș. The description includes the global geometry of the rib systems and the connections between the webs and ribs in each vault. These geometric descriptions are fully factual and do not use any presumptions.

In the Methodology chapter, we present geometry-based typologies for the global geometry of the rib system and the rib-web connections, based on the literature of the topic and our former case studies. We then analysed the vaults in Mediaș and incorporated these structures into the typologies.

Two rib-system subtypes have been defined based on the mapping of the vaults: centralising and linear vaults. The relationship between these subtypes and the concept of cylindric and



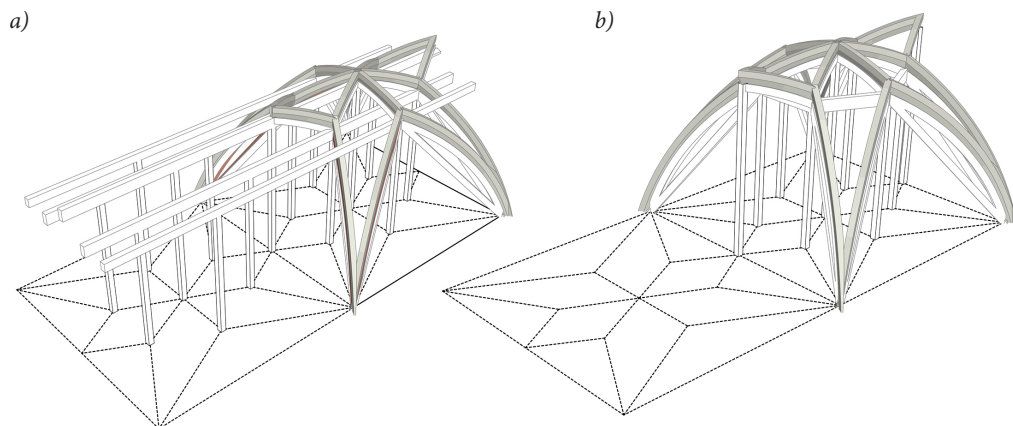


Figure 16. a–b. Theoretical reconstruction of the sacristy vault's possible building techniques.
a: linear technique; b: a possibility for centralised technique.

The figure solely represents the logic and nature of the supporting structure and does not aim to reconstruct the exact structural solutions of the wooden structures (The Author's work)

spheric vaults, as well as their connection to the 'pattern' of the net vaults, has been discussed. Additionally, the peculiar phenomenon observed in the nave vault, where these two different natures change abruptly mid-web, has been considered.

Based on the geometric descriptions of the vaults in the fortified church of Mediaș, deductions were made about their possible building strategies and techniques.

Another result based on the geometric descriptions and the presumed building techniques was the consideration of the new results about the vaults in the mirror of the periodisation of the building known from the literature.

Overall, the precise data and geometric description of the vaults of the fortified church of Mediaș provide interesting insights into the geometry and typology of net vaults. In the context of the given building, the geometric interconnections of its net vaults mean an important contribution to the present knowledge about this church that may prove useful when examining building genealogies and interconnections of the South-Transylvanian Saxon churches as well.

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Lineáris és centralizáló hálóboltozatok

Geometria alapú épületkutatás a medgyesi erődtemplom hálóboltozatainak példáján bemutatva

ÖSSZEFOGLALÓ

Cikkünkben objektív, pontfelhő alapú geometriai leírást adunk a medgyesi (RO; Mediaș, Mediasch) erődtemplom hajójának, szentélyének és sekrestyéjének hálóboltozatairól. A leírás kiterjed a bordarendszerek globális geometriájára és a borda- és süvegrendszerek egymással való geometriai kapcsolatára. Ezeket alapul véve a három vizsgált boltozatot besoroljuk a geometria-alapú osztályozási rendszerekbe, melyet korábbi kutatásaink során állítottunk fel, és melyek a hálóboltozatok bordahálójának globális geometriájára és a borda-süveg kapcsolataira vonatkoznak. Ezen felül jelen munkákban a medgyesi boltozatok geometriai elemzése alapján az osztályozási rendszerünket kiegészítettük két alkategóriával, a centralizáló és a lineáris hálóboltozatokkal. Cikkünkben kitérünk e két alkategória cilindrikus és szférikus boltozatokkal, illetve a bordarendszer alaprajzi képének „mintájával” való kapcsolatára is. A boltozatok geometriai leírása alapján megvitatjuk a szerkezetek feltételezett eredeti építés- és szerkesztéstechnikáját is.

KULCSSZAVAK

épületkutatás, későgótikus hálóboltozatok, geometria alapú boltozatelemzés, lézerszkennelés, pontfelhő alapú elemzés, boltozástechnika, középkori szerkesztéstechnika, dél-erdélyi templom

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