

Budapesti Műszaki és Gazdaságtudományi Egyetem  
Építészmérnöki kar, Csonka Pál Doktori Iskola  
Építészettörténeti és Műemléki Tanszék

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GEOMETRIC ANALYSIS, CONSTRUCTION TECHNIQUES AND  
BUILDING METHODS OF LATE GOTHIC NET VAULTS

Thesis booklet



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Budapest, 2025

## **Subject of the doctoral research**

The primary aim of the research is the analysis of the construction and building techniques of Late Gothic net vaults based on their exact geometric descriptions, and the typologisation of these construction and building techniques based on the case studies, as well as geometric and building technological necessities. The knowledge about the original construction techniques of Late Gothic net vaults is still strongly influenced by the literature on the topic that originates mainly from the 19<sup>th</sup> century, as sources that are contemporary to the structures themselves are scarce. These written and drawn sources – independently of their date of origin – are generally characterised by a simplifying attitude: they assume that the geometric postulates of the vault construction process (the outlines of the space to be vaulted) are regular – this seems to be a necessary consequence of the expected inaccuracies of the traditional survey techniques (especially in the case of above-head structures). With my research, I aimed to make this picture more accurate based on the modern, exact survey methods that allow for analysing and interpreting the three-dimensional geometry of net vaults.

The research resulted not only in the methodology of geometric descriptions and the typologisation of the connection between the rib system and the webbing, as well as the global geometry of the rib system of Late Gothic net vaults, but also brought on new directions in research on the interconnections of these structures. The comparative analysis of two vaults on the basis of those three-dimensional geometric characteristics that were defined in this research may be an indicator of their (potential) connections that is more precise than the previous methods.

## **Questions and aims of the doctoral research**

The two bases of the research were the examination of literature on the topic, including the construction principles described and the figures representing them, and the geometric analysis of the vaults that I surveyed via terrestrial laser scanning. The aim was to review the tendencies of geometric simplification in literary sources based on exact three-dimensional data and to develop a methodology for the exact geometric descriptions of Late Gothic net vaults geared to the modern, point-cloud-based survey methods.

The questions of the research were the following: Is it possible to determine, based on the exact geometric description and the geometric and building technological necessities, the typology of the structural connection between the rib system and the webbing, as well as the construction strategy of the rib system (based on the spatial position of the rib junction points), while defining the probable building techniques? Based on the exact geometry of the individual ribs<sup>1</sup> (especially their radius of curvature), was the 'Prinzipalbogen' principle widely used among the examined cases? I also examined how the theoretical reconstructions of the original construction and building technique of a given structure, based on its exact, three-dimensional geometry, may influence the current status of science regarding the interconnections (e.g. master builder, guild or other genealogical connections) of certain buildings.

## **Sources**

Even today, the most widely used literature on Late Gothic net vaults originates from the 19-20<sup>th</sup> centuries. Sources about the construction and building techniques of net and stellar vaults that are contemporary to the original structures are scarce in number. The sources of Medieval origin that I used during my research were the following:

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<sup>1</sup> In my dissertation, 'rib' refers to the part of the rib system that runs between two junction points. The elements of the ribs are referred to as 'rib elements'.

- the vault plans of the Wiener Bauhütte
- the drawing of a curvilinear-ribbed stellar vault by Rodrigo Gil de Hontañón
- the manuscript Ms. 12686 from the Spanish National Library
- the sketchbook of Master WG

The sources originating from after the Gothic era, which are the core of the literature on the topic:

- Ranisch, Bartel. 1695. Beschreibung aller Kirchengebäude der Stadt Dantzig... Dantzig: Raths und Gymnasii Buchdruckern.
- Hoffstadt, Friedrich. 1840. Gothisches ABC-Buch: Vorlegeblätter zum gothischen A-B-C-Buche... Frankfurt a. M.: Siegmund Schmerber.
- Ungewitter, Georg Gottlob. 1901. Lehrbuch der gotischen Konstruktionen. Neue bearbeitet von K. Mohrmann. Leipzig: Chr. Herm. Tauchnitz.
- Meckel, Carl Anton. 1933. Figurierte Gewölbe der deutschen Spätgotik. Architectura: Jahrbuch für Geschichte der Baukunst 1:107-121. <https://doi.org/10.11588/diglit.19241#0011>

The dissertation's chapter on the literary framework summarises and critically evaluates these sources, based on my own aspects and those of other researchers.

Apart from the literary sources and their figures, the most important source of my research was the detailed geometric data of my case studies. For completing my case studies, further literary research was conducted to study the building history of the buildings and to examine their potential interconnections (e.g. master builder, guild or other genealogical connections).

## Methodology

The core of the research was the theoretical background of the topic and the case studies. These were developed into the typologies, based on further geometric and building technological necessities. The theoretical background comprised the critical evaluation of literature on the construction and building methods of net vaults, and the review of the literature on the individual cases. The case studies meant the survey and geometrical analysis of actual Late Gothic net vaults. When choosing the buildings to be examined, the most important considerations were the date of the vault's building, and the potential interconnections of the buildings (based on the literature). The latter was important for the comparative analysis of the vaults. Another factor was the possibility of the terrestrial laser scanning on the spot. Eventually, I analysed 15 net vaults that belong to 9 buildings:

- Szászbogács (Băgaciu, RO), fortified church, nave vault
- Segesvár (Sighișoara, RO), Church on the Hill, vaults above the southern and northern aisles and the main nave
- Medgyes (Mediaș, RO), fortified church, nave, apse and sacristy vaults
- Landshut (D), St Martin, main nave's vault
- Szeged-Alsóváros, Our Lady of the Snows Church, nave, apse and sacristy vaults
- Nyírbátor, St George Church, church vault
- Andocs, Our Lady Basilica, apse vault
- Siklós, Castle Chapel, apse vault
- Gyulafehérvár (Alba Iulia, RO), the Lázói Chapel's vault

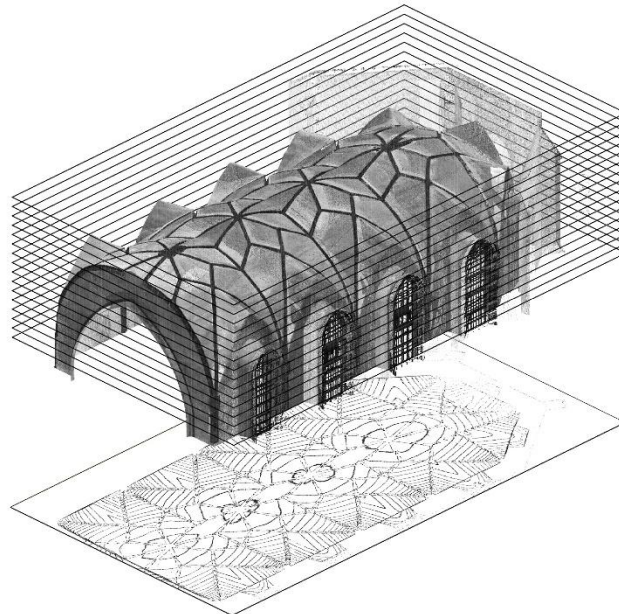
Out of these examples, in the literature, the South Transylvanian churches are mentioned as a group, and their strong connection to the Late Gothic guild of Landshut is also emphasised (especially regarding Sighișoara and Landshut). Some researchers consider the church in Szeged-Alsóváros a part of this group as well. The nave vault in Szeged-Alsóváros and the vault of the St George church in Nyírbátor are also generally known as structures that follow the same construction principles. The vaults in Andocs and Siklós represent the rare examples of the curvilinear-ribbed vaults in Hungary, therefore, they are generally mentioned together. Another layer of the presumed interconnections is the theory,

which states that the genealogy of net vaults can be derived based on the plan view of their rib systems. Based on this theory, comparing the examined sacristy vaults to the vault of the Lázói chapel may also be a valid topic.

The fundamental literature on the construction and building techniques of net vaults mostly originates from the 19-20<sup>th</sup> centuries. It is not based on the exact vault geometries but on estimated, regularised ones, probably due to the lack of accurate enough survey techniques. During my research, to analyse the case studies, I utilised the modern, point-cloud-based survey techniques. The surveys were carried out via a Leica BLK 360 scanner, and the point clouds were processed in Leica 360 Cyclon Register. As the nominal accuracy of the scanner is  $\pm 4\text{mm}$  in a 20m distance, considering the dimensions of the spaces I worked in, the inaccuracies to be expected are 0.5-1cm. The accuracy of the building techniques in the Late Gothic era is expected to be an order of magnitude larger than these values; therefore, the point clouds are adequate for the intended analyses.

The methodology of my research is based on the presumption that the geometry of a vault mirrors its original construction technique; thus, knowing the exact geometry, reverse engineering may be applied. Therefore, the irregularities that are present in a certain vault geometry may help in reconstructing the original construction technique. This is because a fully regular geometry may be achieved via multiple methods, but the 'regular irregularities' can help to exclude certain possibilities. However, to utilise this idea, it is crucial to understand the building history of the monuments and identify the distortions in geometry that may result from shifts that occurred since the construction.

During my research, the first step of the net vaults' analysis was the mapping of the vaults. This allows for examining the connection between the rib system and the webbing, as well as the building technique of the webs, and leads to primary observations about the global geometry of the rib system.



*Figure 1. Theory of mapping a vault. (Szeged-Alsóváros, apse vault)*

The second step of the analysis is the isolation of the rib system, and the examination of the spatial positions of the rib junction points in a virtual coordinate system whose axes align with the cross- and longitudinal directions of the vault and the vertical direction. As a result of this analysis step, the starting plane of the construction process (the first two coordinates of the junction points that were determined), the underlying construction principles on that plane, and the method for determining the third coordinate may be concluded.

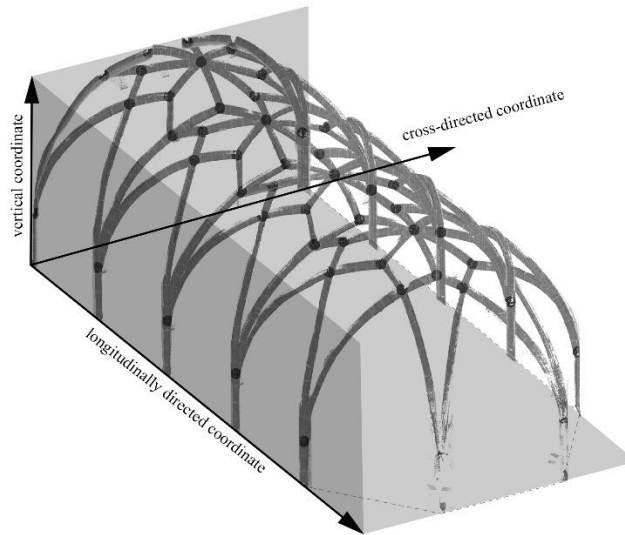


Figure 2. Virtual coordinate system fitted on a net vault (Szeged-Alsóváros, apse vault)

The next step of the analysis is the examination of the individual ribs' geometry, especially their curvature of radius, to verify whether the 'Prinzpalbogen' principle (or its variants) was used. The last step of the research was to carry out the comparative analysis of those vaults whose possible interconnections are mentioned in the literature. This resulted in comparisons that, for the first time in the research history of these structures, consider their exact, three-dimensional geometries. These results, in some cases strengthened, while in other cases may have confuted the former conclusions that were usually based on partial geometrical features (such as the pattern of the rib system, the shaping of the imposts or the profile of the ribs).

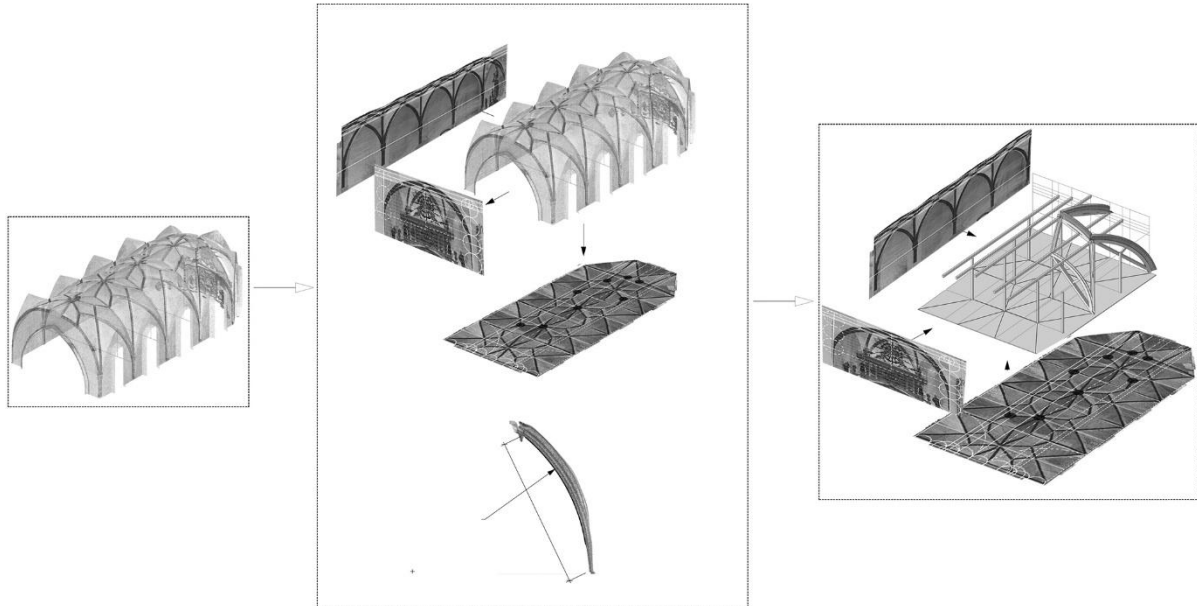


Figure 3. Methodology for the rib system's analysis: point cloud; geometric analysis of the projections and the individual ribs; interpreting the system of the regularities in the form of theoretical reconstructions of the construction and building methods

## Thesis points

1. In the case of Late Gothic net vaults, the centralising or linear characteristics are independent of the pattern of the rib system; they can be derived from its spatial geometry. Thus, these characteristics are to be considered separately from the question of whether a given vault is a 'stellar net' vault. [1] [4] [8]

In the case of real net vaults, regarding their global geometries, I defined the linear and centralising features of net vaults based on the results of my research. Linear net vaults are defined as net vaults, where the rib system and the vertical positions of the junction points do not reflect the rhythm of the bays. Centralising net vaults are defined as net vaults, where the vertical positions of the junction points, thus the global geometry of the rib system, follow the rhythm of the bays, and regarding the centre of a given bay, they adopt a centralising nature. Based on my case studies, I found that the linear or centralising characteristics are not dependent on the pattern of the rib system.

It is possible that within a given vault, both the centralising and the linear characteristics appear. Their combination is possible both along the longitudinal and vertical axes of the vault. (In the case of the fortified church of Mediaş, where the plan of the main nave's vault is regularly constructible in the eastern four bays – it is a Parleresque vault – the easternmost two bays show centralising features, while the western ones are linear. In the case of the nave vaults of the Church on the Hill in Sighișoara, the webs on the crown line are linear, while the lower webs show centralising features.)

Therefore, the question of whether a vault is linear or centralising is not equal to the question of whether it is a 'stellar net' vault. In the case of stellar net vaults, the pattern of the rib system is also restricted (stellar-like); therefore, the 'stellar net' vaults are to be considered a subcategory within the centralising net vaults.

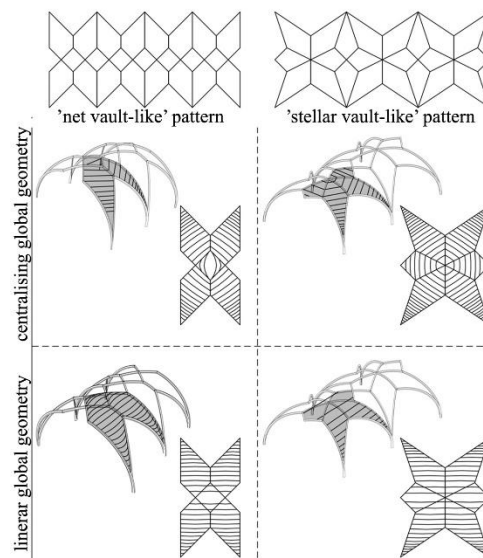


Figure 4. Type of the rib pattern and the global geometric characteristic of the rib system

2. **During my research, I developed the geometry-based typology of the construction and building methods of the Late Gothic net vaults' rib system-webbing connections. The typology differentiates between the real net vaults and pseudo net vaults, and in the cases of real net vaults, it assigns the building technique of the webs (with or without formworks) to the linear or centralising global geometry of the vault (as explained in thesis 1.) [1] [4] [8] [10]**

The basis of the typology is the exact geometry of the net vaults. For interpreting the data regarding the connection between the rib system and the webbing, I used the method of mapping. The categories of the typology are based on my own results, geometric necessities and the literature of the topic.

The net vaults, based on the connection between their rib systems and webbings, may be real net vaults – when the rib system was built before the webbing and served as perpetual centring for them –, or pseudo net vaults – when the webbing was built as a barrel vault structure, independently of the rib system.

The webbing of real net vaults could be built either with or without full-surface formworks. In the former case, following the shape of the formwork, flat webs are created, which may on occasion, if the formwork sagged during the building process result in a slightly concave surface. In the case of webs built without formworks, the individual courses have significant curvatures.

In the case of real net vaults, based on the relative vertical positions of the junction points, linear and centralising features can be differentiated (see Thesis point 1). These characteristics are independent of the building technology of the webbing and influence the direction of the individual courses of the webs in both cases (webs built with or without formworks).

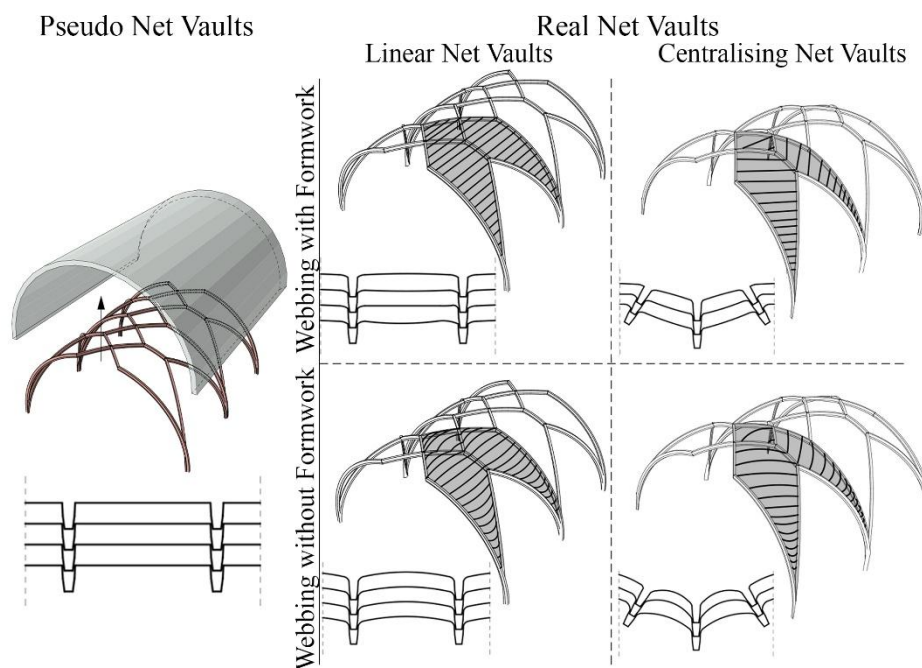


Figure 5. The global characteristics of the webbing and building method of the webs

### 3. The role of the rib system's plan in the construction of the rib system

**Regarding the Late Gothic net vaults' construction techniques, the theories that the construction of the rib system must start with the construction of its plan and that this plan view determines the whole system's geometry are the axioms of the literature. However, based on my results, these 'axioms' are not generally true regarding the Hungarian examples of these structures. [7] [3] [6] [9] [13]**

In the literature on the construction and building methods of net vaults, certain axioms appear. Such as that the vaults are always constructed above spaces with regular outlines, or that the first step of constructing a net vault must be the construction of the plan of its rib system. The latter idea is supported by practical pieces of evidence (e.g. the tracing floor in the cathedral of Wells or the treatise of Lorenz Lechler). However, based on my research, it is not the only, obligate method that was used. Examining the case studies, I identified examples of such construction methods, where the starting plane was not the plan, but a plan parallel to the cross-direction of the vault, thus the first two coordinates of the junction points that were constructed likely were the cross-directed and the vertical coordinates.

Based on the case studies, the identified construction logic and the necessities of the building technologies, I presume that the methods when the starting plane is not the plan were used when the outlines of the space to be vaulted were highly irregular, and usually it was the result of multiple building periods. In such cases, starting the construction with the plan will result in one of the following two problems: If the construction is started from the mid-line (crown line), the imposts will end up in different heights. If it is started from the walls (imposts), the ribs of the two sides will arrive at the crown line in different height positions, thus their connection to each other is problematic, and the crown line can not be horizontal. Naturally, the inaccuracies may be corrected by the walls or by the crown line (respectively); however, such significant corrections would result in a visually adverse view in the space. However, if the construction is starting from a vertical plan that is parallel to the cross-direction of the vault, the irregularities of the outline, based on the case studies, can be masked with slight corrections along the length of the vault, resulting in a visually more agreeable structure.

#### 4. Typology of the rib system of Late Gothic net vaults

During my research, I developed the geometry-based typology of the construction techniques of the Late Gothic net vaults' rib systems. The four main types that I identified are the following:

- the junction points' coordinates may be constructed independently of each other,
- construction starting from the plan view,
- construction starting from a vertical plan that is parallel to the cross-direction of the vault
- and construction starting from a vertical plan that is parallel to the longitudinal direction of the vault.

[7] [5] [6] [9] [11] [12]

The basis of the typology is the exact geometry of net vaults, and it is primarily based on geometric and building technological necessities. The case studies serve as examples of the different types. The typology is based on a coordinate system whose axes are parallel to the cross- and longitudinal directions of the vault and the vertical direction. In this coordinate system, I examine the spatial positions of the rib junction points. The analysis aims to identify the plan (the two coordinates) that were first constructed in the rib system, based on their simple and regular constructability. Based on my results and geometric and building technological necessities (e.g. the need for the stability of the structure in any given moment during the building process), the analysis may result in four theoretical outcomes. These refer to the four main types that the typology consists of.

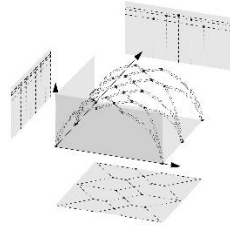
The first is the category when all three coordinates that determine the spatial positions of the junction points may be constructed independently of each other; thus, any coordinate may be constructed without knowing the other two. The examples in this category have highly regular geometries (e.g. the vault of the church in Nyírbátor; the sacristy vault in Szeged; the vault of the Lázói Chapel in Alba Iulia). This means that the original construction technique and process can not be reconstructed purely on a geometric basis.

The second category includes the net vaults, where the construction of the plan (the cross- and longitudinally directed coordinates) was carried out prior to that of the vertical coordinates. Thus, in this case, the vertical position of a given junction point is not independent of its position on the plan. (E.g. such cases when the spatial position of the junction points can be constructed via projecting their position on the plan onto a given surface – the nave vault in Szeged – or via the application of the principle of the longest route.)

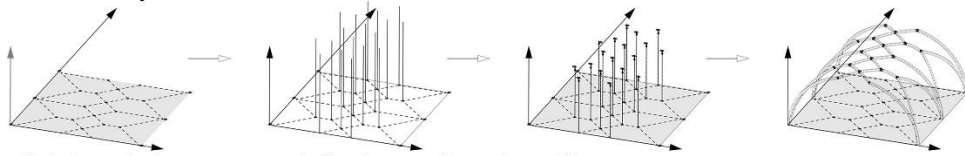
The third category consists of the vaults, where the starting plane of the construction is not the plan, but a vertical plane that is parallel to the cross-direction of the vault (cross-directed and vertical coordinates). In such cases, the junction points that have the same function in the rib system fall on straight lines along the longitudinal axis of the vault, which are parallel to each other on the longitudinal sections, but not on the plan view. On these straight lines that are defined in the space and that determine the cross-directed and vertical coordinates of the junction points, in the cases I have identified (nave vaults in Băgaciu and the Church on the Hill in Sighișoara), the third junction point coordinate was determined by using the chord length of certain rib types.

The fourth category means the vaults, where the starting plane of the construction process is a vertical plane that is parallel to the longitudinal direction of the vault (longitudinally directed and vertical coordinates). Among my case studies, no example of this category was identified; thus, it remains a theoretical possibility. I presume that the reason for the lack of examples may be that the advantages of this method would be the same as in the case of the third category; however, to carry out the geometric corrections, only the width of the vault could be used rather than its length. Therefore, this solution seems less advantageous.

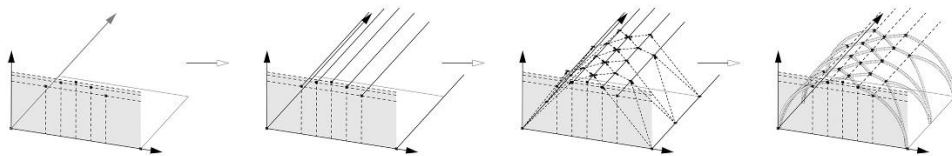
1st theoretical outcome: any coordinate may be constructed without constructing the other two



2nd theoretical outcome: plan view (longitudinal and cross-directed coordinates) constructed prior to the vertical one



3rd theoretical outcome: vertical and cross-directed coordinates constructed prior to the longitudinal one



4th theoretical outcome: vertical and longitudinally directed coordinates constructed prior to the cross-directed one

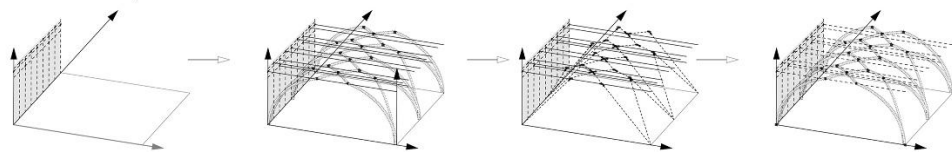


Figure 6. ábra Theoretical outcomes of the analysis of the construction method of the rib system's global geometry

5. During my research, the case studies were carried out based on the typologies and geometric considerations presented in thesis points 1, 2 and 4. In the case of certain vaults, the analyses led to significant results.

5.1. Based on the geometric analysis of the nave vault in the fortified church of Băgaciu, I theoretically reconstructed its construction and building process. This was possible due to the highly irregular geometry of the rib system, which allowed for the exact identification of the underlying regular system. [12]

The rib system of the nave vault in Băgaciu is likely an example of the construction method that starts from a vertical plane, which is parallel to the vault's cross-direction. The cross-directed coordinates of the junction points fall on well-defined straight lines on the plan (except for the southernmost junction row). However, these straight lines are only parallel on the longitudinal sections, not on the plan. On the plan, the lines on the northern and southern sides of the vault are neither parallel to each other nor to the crown line. On the plan, I found that the lines on the northern side are parallel to the eastern end of the northern wall, while those on the southern side are parallel to the eastern end of the southern wall (the nave walls are not straight at the height of the vault).

Both the cross-directed and vertical coordinates of the intersection points of these straight lines with the eastern wall proved to be regularly constructable. Thus, I claim that these lines that can be defined in the space were the basis for constructing this vault. I also presume that they appeared in a physical form during the building process, as temporary supporting structures.

Based on my results, the third, longitudinally directed coordinates of the junction points were constructed by using the chord lengths of the different rib types (those ribs that have the same function in the rib system). These chord length values proved to be very uniform within a rib type. This characteristic is the more significant, as the same regularity is not present in the case of their lengths in the plan view. Based on the standard deviation of the chord length values within the rib type groups, I derived the exact order of their construction during the building process as well.

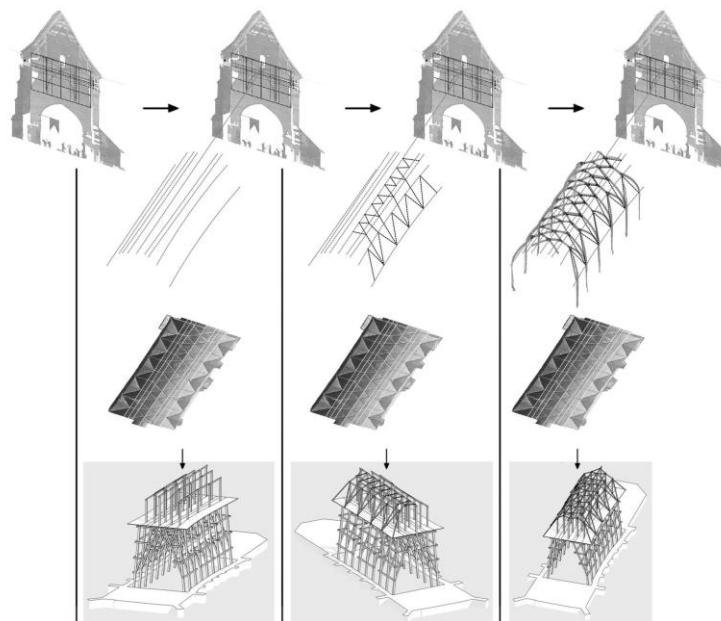


Figure 7. The reconstructed construction method and its interpretation into temporary supporting structures. Theoretical reconstruction

**5.2. In the case of the nave vault of the Our Lady of the Snows church in Szeged-  
Alsóváros, based on the geometric analysis of the webbing and the rib system, I  
theoretically reconstructed the construction and building methods. My results  
contradict the pseudo-ribbed net vault theory that often appears in the literature in  
connection with this vault structure. [10]**

During my analyses, I found that the lower surfaces of the junction points (and not the lower surface of the webbing) seem to be the set of points that have vertically defined positions. Into the cross-section of the nave, a circle can be drawn with a diameter that equals the distance between the floor level and the lower surface of the crown junctions. This circle determines the vertical position of all the other junction points as well.

On the mapping of the vault, in the lower zone (below the second row of ribs that are parallel to the longitudinal walls), the shape of the horizontal section lines of the webbing seems to be independent of the ribs' positions (except for the lower parts of the webs between the imposts and the lunettes, where the section lines are at an angle with the wall, and while getting to the apexes of the lunettes, they rotate into the position that is parallel to the wall. However, in the upper zone of the vault, the shape of the horizontal webbing section lines is not independent of the ribs' positions. The section lines in the lower zone are straight; however, in the upper zone, they occasionally turn into concavely curved lines.

On the southern side of the vault, nearly along the whole length of it, an indentation can be identified (this was formerly realised by others, too). Based on my measurements, the walls of the nave are vertical; thus, it is not their shifting that caused the deformation. The latter, and the fact that the indentation appears gradually, over multiple webs, may signify that the deformation already appeared during the building process. What is more, the webbing and the rib system are both deformed the same way, suggesting that the two parts of the net vault took the form at the same time, presumably following the deformation of the temporary supporting structure during the building process.

I think that the first step of the building process was to build the formwork for the rib system, presumably as a full-surface structure, then the rib system was built. (The indentation of the southern side may have occurred during this step.) After the rib system was finished, the webs were built. Close to the walls, they could be built without formwork; however, in the upper zone, I found the use of formwork plausible. Due to the lower zone's barrel vault-like nature, it is not impossible that here the vault was built as a barrel vault: every course consoling out a bit more. The border of the lower and upper zones of the vault falls a bit before the third of its whole width, thus to the points where flat arches first crack. The latter may support my theory as well. Above the border of the two zones, the webs could be built with formwork.

6. **The interconnections (regarding the master builders or guilds) of vaults may be judged more accurately on the basis of their three-dimensional geometric characteristics than based on the identity or similarity of the pattern of their rib systems, which is the generally used method in the literature. This is because, based on the three-dimensional geometry and the methodology that I presented in my dissertation, the original construction and building methods can likely be concluded. The application of this thesis point was presented on multiple pairs or small groups of buildings that are usually mentioned together in the literature. The comparative analysis in certain cases supported the claimed connections, while in other instances, they seem to refute them. [2] [3] [4] [7] [9] [10]**

On multiple occasions, the possibility of close interconnections between the cases that I analysed was suggested in the literature (such as the work of the same master builder or guild). However, this possibility was supported mostly not by written sources, but by the 'similarity' of the net vaults (e.g. the similarity of the rib patterns). Using the modern, exact survey techniques, it is possible to analyse the deeper geometric characteristics too.

Applying the typologies that I described in the thesis points 1-4, I found that the nave vault of Szeged-Alsóváros and the vault of Nyírbátor, although in the literature even the work of the same master builder (Brother János) is suggested, the structures of the two vaults are vastly different. In the case of the vault in Szeged, the connection between the webbing and the rib system shows on the mapping the characteristics of pseudo-ribbed net vaults or linear real net vaults built with formwork, while in the case of Nyírbátor, the characteristics are those of real net vaults built without formwork, and the centralising features are dominant. Furthermore, the global geometry of the rib system in the case of the Szeged vault suggests the construction method that starts from the plan view, as the vertical coordinates of the junctions depend on their position on the plan, while in the case of Nyírbátor, all three junction coordinates can be independently constructed. Therefore, in the case of these two vaults, both the geometric characteristics and the structural solutions that can be derived from them are different from each other, so their close interconnection, which is suggested by the literature, may be questioned.

Carrying out the comparative analysis of the nave vault in the fortified church of Băgaciu and the vault above the northern aisle of the Church on the Hill of Sighișoara, where the possible interconnection is also suggested, I found that their similarities exceed the similarities of the form, and it appears on the level of underlying construction principles and the building methods that can be reconstructed. Although the details of the geometrical construction steps slightly differ, the basic strategy of the construction is the same: it starts from a vertical plane that is parallel to the vaults' cross-directions. Therefore, in this case, the possible connections are supported by the construction and building technical analysis.

## **Summary and further directions of the research**

In my research, I carried out the construction and building technical analysis of net vaults, their typologisation based on their geometry, and, regarding the case studies, based on the above-mentioned analyses, I conducted the comparative analysis of those vaults that have possible interconnections (e.g. same master builders or guild) mentioned in the literature of the topic. I determined the factors that can be successfully used for the point-cloud-based construction and building technical analysis of net vaults, and proposed practical methods for examining them. Based on the exact geometrical descriptions, taking into account the construction and building technical necessities, I developed the geometry-based typologies of the connection between the rib system and webbing of net vaults and of the global geometry of their rib systems. Based on the results of the comparative analyses, certain examples supported the claims about the interconnections that were suggested in the literature, but others seemed to confute those.

For further directions of the research, the first possibility is to widen the circle of the case studies, and with it, to carry out more comparative analyses based on the methodology and typologies presented in the dissertation. Another possibility is to analyse the 19th-century counterparts of the Late Gothic net and stellar vaults with the same methodology. This would allow for comparing them with the 'original' Gothic vaults, or with the 19th-century theoretical works, to examine the connection between the theory and the practice of that era. (The latter direction was already started during my research that was supported by the EKÖP-24 program, where I analysed the nave vaults of the Saint Elisabeth Cathedral of Košice.)

## Publications related to thesis points

- [1] Jobbik Eszter, Halmos Balázs: Point cloud-based geometric net vault analysis and the question of ‘stellar-net vaults’, discussed apropos of the vault of the Lázói chapel in Alba Iulia. – *ACTA HISTORIAE ARTIUM* – elfogadva, megjelenés alatt
- [2] Jobbik Eszter, Daragó László: Geometry-based ‘building archaeology’ and comparative analysis of the curvilinear ribbed net vaults in Siklós and Andocs. *MATERIALI E STRUTTURE* – elfogadva, megjelenés alatt
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