Baroque roof structures in Transylvania – Research and analyses

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ABSTRACT: Baroque roof structures encompass important and unique historic values, within: (a) their structural conformation (trusses and longitudinal bracing systems); (b) the craftsmanship of framing and jointing (carpenter marks, joints); (c) the authentic, historic timber material that has been preserved for centuries.

Given the high level of safety characterising Baroque roof structures, a relatively significant number of these survive in Transylvania, though there is no thorough inventory, yet.

The lecture presents the typology of Transylvanian Baroque roof structures, the PhD research programme carried out in order to analyse these structures, and through two case studies the level of safety, durability and the unique character of these structures.

Though professional interest has increased towards historic (roof) structures, Baroque roofs in Transylvania face a double threat. Scientific research needs to result in a guideline to be used in order to correctly conserve/reinforce Baroque roof structures throughout Transylvania.

1 INTRODUCTION

Baroque roof structures developed in Continental Europe (France, Austria, Germany, Czech Republic) at the turn of the 16th–17th centuries became widely used in Transylvania in the 18th century. Transylvania is the easternmost territory where this type of continental historic roof structure can be found. In other parts of Romania (Moldova, Walachia, etc) this type of roof structure cannot be found.

As concerns their development in time, a number of transitory structures can be identified between the previously used Gothic roof structures and the Baroque ones. Later, pure Baroque structures became widely constructed, which persisted into the first half of the 19th century, when Eclectic roof structures came to replace them.

Given their high level of safety, a relatively significant number of Baroque roofs can be found in Transylvania, though there does not exist a thorough inventory, for the moment.

2 DEFINITION

Historic roof structures are structures constructed by carpenters following empirical-intuitive conceptions based on knowledge accumulated empirically, and passed on from generation to generation in carpenter’s guilds. Researching, understanding, scientifically describing these types of structures present a special interest, as they incorporate historic and technological values worth preserving for future generations.

Historic roof structures with Baroque character include roof structures of buildings constructed in Baroque architectural style, as well as roof structures of ensembles built in other architectural styles:

– earlier buildings, with the roof rebuilt in the Baroque period, or
– later buildings, with Baroque carpentry still surviving within carpenter’s guilds (in Transylvania most early 19th century buildings still have roof structures with Baroque character).

Roof structures with Baroque character are made up of two plane systems of linear bars, laid out in two orthogonal directions: transversal load-bearing plane systems (main and secondary trusses), and longitudinal bracing systems, placed primarily in the rafters’ plane. The component elements (bars with rectangular or pentagonal sections) are predominantly realised of soft wood – pine or other resinous timber.

In order to illustrate the structural conformation of roof structures with Baroque character, a typical Baroque roof has been developed, using the data of over 50 such roofs surveyed. This is given below, to
provide a synthesis of structural sub-ensembles and the names of various elements:

The Figures illustrate the typical Baroque roof structure of a construction with characteristic dimensions: 10 m span, 28 m length, 50.2° inclination angle (6/5 height/half-span ratio). The main truss (Fig. 1) includes the Baroque straining system made up of: the tie-beam (1), pair of compound rafters (3); straining beam (4) and counterbraces (5), including also a king strut/double suspension bar. The following figures give the conformation of the typical secondary truss (Fig. 3), as well as a bay of the longitudinal bracing system (Fig. 4).

2.1 Terminology

The Anglo-Saxon (coastal) roof structures differ both in structural conformation and elements from the continental historic roof structures. Therefore the English terminology of historic continental roof structures generally, and the one related to the Baroque roof structures especially is a significant issue. The present lecture uses the terms mainly as given in Bálint SZABÓ’s Illustrated Dictionary of Historic Load-Bearing Structures.

The following aspects need to be highlighted:

– The Romanian/Hungarian terminology derives from the German one, due to the coexistence within the Habsburg Empire (Monarchy). The 20th century terminology used by craftsmen/builders has its origin in the German 19th encyclopaedic books on carpentry (which actually focused on the description of 19th century, eclectic/early engineered structures, not on Baroque ones).
Concerning Romanian (and Hungarian) terminology, we need to mention that for almost half a century (during the Communist Era) both timber structures and historic buildings were neglected, therefore their terminology has been forgotten.

The above mentioned dictionary is trying to reflect the structural behaviour/role of the various elements within the structure.

In order to promote international cooperation and exchange of information, it would be necessary to elaborate an internationally accepted English terminology for non Anglo-Saxon historic roof structures. The present lecture could present a starting point in order to discuss the proposed terminology for roof structures with Baroque character.

In order to clearly define roof structures with Baroque character, contrasted to medieval (Gothic) roof structures, the innovative elements and structural conformation need to be shown.

2.2 Innovations of Baroque roof structures

Baroque architecture changed the volumes and ratios of buildings, therefore in many cases it was necessary to place the eaves height below the keystone of the vault.

(a) This has determined one of the innovations generalised within Baroque roof structures, that in most cases secondary trusses do not possess tie beams (various solutions within typology, criterion: 4 – see Fig. 8).

From the point of view of structural conformation, secondary trusses without their own tie-beams are not self-supporting systems (contrary to the secondary trusses of Gothic or Romanesque structures, where secondary trusses do not transfer gravitational loads to main trusses).

(b) The invention of the Baroque straining system (see Fig. 1) – which is actually a “false” or “partial” straining system. It is working properly as a straining system only in the cases of secondary trusses without individual tie-beams and without collar beams. In the other cases the straining systems have determinant role in stiffening the structure for horizontal loads. (The number of Baroque straining systems is the 2 criterion of the typology). Secondary trusses without individual collar beams are rare. (The roof structure of the Reformed church, Cluj, secondary truss type II, Fig. 12, has no individual collar beam).

(c) Mansard roofs – were developed in France, within the Baroque architectural period, and mean roofs (rafters) with broken, uneven line (plane). This represents the 1st criterion of the typology.

(d) The only (continental) historic roof structure in Central-Eastern Europe containing elements with pentagonal cross section, is the one with Baroque character. The special elements are: the eaves pentagonal purlin and the upper (or middle) pentagonal purlin (Fig. 5).

There exists a debate concerning the correct designation of these elements as “purlins”. Both in eclectic and Anglo-Saxon roof structures purlins transfer gravitational loads from rafters in secondary axes (trusses) to main trusses. But in Baroque roof structures generally secondary trusses possess either or both tie beams and collar beams, which actually minimise the transfer of efforts from secondary trusses to main trusses. Therefore the lower/upper pentagonal plate is also a term frequently used for these elements.

In less important roof structures or where the craftsmanship of the carpenters failed, either or both pentagonal purlins can have simple, rectangular shape.

(e) The middle suspension bar/king strut (7) in Baroque roof structures can be made up of a compound section (double bars), representing the 3rd criterion of the typology.

(f) The typical Baroque longitudinal bracing system (Fig. 4) is one of the most innovative and most determinant sub-ensembles of a Baroque roof structure. It represents an efficient way of providing longitudinal stiffness for the structure.

The Baroque longitudinal bracing system, like bracing in Anglo-Saxon roofs, is always placed in the plane of the rafters (Fig. 6). The various patterns of the bracing system are given within the 6th criterion of the typology.

(g) Unlike medieval roof structures based exclusively on carpenters’ knowledge passed from generation to generation within the guilds, the Baroque roof pattern was designed and drawn. There are treaties and drawings of architects preserved, such as Franz Ignaz Michael Neumann, The Construction Plan for the Vaulting and the Roof, republished by Hansmann (2000).
Baroque roofs are mostly surveyed, assessed and studied – as integrated parts of historic buildings – in order to be repaired, conserved, reinforced or converted for a new use.

These researches are objective-oriented and in many cases can hardly be used for scientific purposes. The authors promote the elaboration of a guideline for those working in the professional survey, documentation, and conservation or reinforcement planning of historic roof structures generally, and Baroque ones particularly.

3 TYPOLOGY

In order to provide a researchable data base, as well as an organised overview of the roof structures with Baroque character, a typology is a useful tool. The typology presented within this lecture is based on the measured survey of 50 Baroque roof structures, as well as on visits to Baroque roof structures in Hungary, Austria, Germany, and further roofs (not measured, just inspected) in Transylvania.

Two main principles were followed when developing the present typology:

– It refers only to pure (mature) Baroque roof structures; it does not include hybrid or transitory structures neither between Gothic and Baroque, nor between Baroque and Eclectic structures (unlike the detailed topography of roof structures in Mur-Mürz area, Steiermark, Austria, Caston).
– It analyses the structural and geometrical conformation of both structural sub-ensembles and of elements.

This typology presents a working phase of the Transylvanian Baroque Roof Structure Typology, which will embody the results of a through inventory (phase I) on a limited, but representative geographical area (Cluj county), to be carried out in 2008. The typology will also be open for completion by an eventual through Transylvanian inventory.

The typology, Figure 8 has been developed using 6 criteria in order to identify the specific characters of a given Baroque roof structure, as follows:

1. continuity / plane of common rafters;
2. number and type of Baroque straining systems;
3. type / existence of a suspension bar;
4. horizontal force transmission system;
5. main / compound rafter;
6. pattern of the longitudinal bracing system.

Using this classification, all Baroque roof structures can be identified by a code made up of 6 letters combined into three groups: 1 + 2 + 3 – general + main truss characteristics – 4 – identifying the load transmission from secondary to main trusses – 5 + 6 – describing the longitudinal bracing system.

Using the typology, the typical roof presenting elements of the Baroque roof (chapter 2) has the following code: A.1.2(c)-b(3)-I. A(1).

3.1 Classification by the continuity/plane of rafters

All Baroque roof structures fit into one of the two basic groups: (A) – Continuous/linear common rafters (plane); (B) – Interrupted common rafters (mansard roofs).

3.2 Classification by the number and type of Baroque straining systems

Up to a 10.00 m span, in many cases Baroque straining systems placed in main trusses are not combined with other straining systems on upper levels (eventually just with an upper collar beam). This represents the basic...
Figure 8. Transylvanian Baroque roof structure typology, working phase 2007.
type of the classification (1), designated by the second character of the code in the typology.

The most general type though is (2), where the Baroque straining system on the first level is combined with other straining systems on one or more upper levels.

The third version included in the typology (3), is rare within Transylvania, being used for large spans and in important buildings. This subcategory includes roofs with two Baroque straining systems placed one above the other, combined or not with further straining systems on upper levels.

In Austria, Germany these types are more usual than in Transylvania/Hungary, connected to the economic power of the area/time. Even more there can also be identified Baroque straining systems on three levels. This version was not included in the present typology, as none was identified in Transylvania, yet.

In a number of special cases: large spans, or use of the attic space as granary, or deposit functions, the Baroque straining systems are additionally strengthened. These special cases are included in the typology marked with *, at criterion 2*.

3.3 Classification by the existence and type of (compound) suspension bar

Reduced spans in a high number of cases are coupled with the lack of suspension bars, a version identified by the third character (1).

Suspension bars have a decisive role in limiting the long term creeping of tie beams; therefore they are present in all structures with a span over 10.00 m – version identified by note (2).

Two structural solutions were identified:

(s) – hanging bar made up of one element. In this case the joints between the tie-beam and the suspension bar are solved using wrought iron bends;
(c) – hanging bar made up of a compound element (two bars) – joint solution: pegged/treenailed half lap.

3.4 Classification by the transmission mechanism of loads from secondary trusses to main ones

The second group of letters describes the secondary trusses, which belong to three main groups (particular solutions identified are not included):

(a) Secondary trusses with tie-beams – used frequently in early Baroque roofs and buildings without vaults above the upper level. Secondary trusses are self-supporting, load transfer being minimal, mainly from horizontal loads.
(b) Secondary trusses with trimmers and header beams, the most general solution, both in buildings with and without vaults above the upper level.

(c) Secondary trusses with shoes of eaves purlin, with maximum load transfer from secondary to main trusses (compared to the other two solutions).

Between two main trusses there are 2–5 secondary trusses, usually 3.

In later structures, a frequently adopted solution is alternating different types of secondary trusses.

3.5 Classification by the solution of compound rafter and elements of the longitudinal bracing system

The more common solution is that the compound rafter of the Baroque straining system is made of a timber with large cross section, 17 × 30, having a double role in the structure.
The main role of the compound rafter in the Baroque straining system is working for axial forces (compression from gravitational loads, compression/tension from wind loads). Due to the jointing between the compound rafter and tie-beam, as well as counterbrace and straining beam, transfer of bending moment is also possible (chapter 4).

Its secondary role is serving as the inclined post of the longitudinal bracing system, placed parallel to the plane of rafters. This solution is marked by the character – I – within the third group of characters.

A less used (cheaper and more rudimental) solution is having two different bars with smaller sections placed one on the other (II).

3.6 Classification by the pattern of the longitudinal bracing system

It refers only to the Baroque longitudinal bracing system. The common solution with knee braces on different levels is not considered a defining criterion in classifying Baroque roof structures.

Within the analysed structures five patterns were identified in Transylvania, which does not exclude the existence of further patterns. The shape is marked with a symbol showing the pattern made by the diagonals. The number of levels on which these are placed within the structure is given in brackets. In the great majority of the studied Transylvanian cases, Baroque longitudinal bracing systems are placed on one level (unlike examples known from abroad – Figure 6, two levels).

The patterns are the following:

- \( \Lambda \) – the most common solution in Transylvania, made up of a pair of ascending and a descending diagonals, fixed in the eaves and the middle pentagonal purlin, also strengthened by a longitudinal element placed at the middle of their height.
- \( Y \) – is a similar pattern, the only difference being that the lower end of the diagonals is fixed to the compound rafters.
- \( / \) or \( \backslash \) – a very rare pattern, with only one of the diagonals present (Fig. 1).
- \( X \) – Saint Andrew’s cross pattern, used for more elaborate constructions, and rare in the analysed structures, in Transylvania.
- \( XX \) – double Saint Andrew’s cross, even more rare (a single case in more than 50 roofs analysed).

A through survey and the statistical data gathered will serve as the basis of qualitative assessment of various structures (rarity, structural conformation, craftsmanship of jointing, span, age all will be basic criteria in rating the value of a structure).

The authors represent the Doctoral School of the Technical University of Cluj-N. The PhD thesis of structural engineer Dorottya Makay, supervised by Professor Bálint Szabó, *The Transylvanian Baroque Roof Structures*, aims at elaborating the rating of these structures, as well as creating a guidelines for the calculation of Baroque roof structures.

4 MODELLING BAROQUE ROOF STRUCTURES – CASE STUDY: REFORMED CHURCH, KOGALNICEANU STREET, CLUJ

In the following we shall formulate the main points and questions raised by the modelling and calculus of Baroque roof structures, exemplified on the 15.70 m span, 56° angle roof structure of the Reformed church in Cluj.

The safety of roof structures with Baroque character (being at least 150–200 years old) is proven by their very existence, having survived extreme conditions while possessing (in many cases a high number of) dysfunctional joints and / or biologically decayed or missing elements.
A perfectly behaving structure (no distortions, deflections, or any other signs of incorrect structural behavior) is an ideal tool to develop a fair static/mathematic model, and in the same time to countercheck data deriving from technical legislation.

The following questions are formulated regarding all elements of the static model:

- **Loads** – especially wind loads, when a recent update of the Romanian wind-load standard results for the studied roof in a load 2.5–3 times greater than the one deriving from the former standards. (Even with the increased loads the safety factors of various elements are over 1.00).
- **Material characteristics** – as new timber is characterized by decreasing resistance, due to changed technologies both in growth and processing, standards are also giving diminishing values. A database with characteristics of 150–200 year-old timber would be useful.

### 4.1 2D modeling versus 3D models

As soft- and hardware possibilities have developed spectacularly during the last decades, interest in 3D modeling has also increased.

2D models raised their own set of questions in their time, concerning the correct appreciation of load transfer from secondary to main trusses, which will actually receive correct answers when 3D models will properly function.

Within 3D modeling, the eccentric jointing of elements is creating one of the most complicated problems, especially in Axis 8 VM, where eccentric jointing cannot be created, unlike with the software Robot. Figure 14 shows the jointing of element-axes within the lower main truss joint (cf. Fig. 5).

A useful tool in 3D modeling is limiting the full-structure model to a characteristic section (minimum two bays), that is describing the behavior of regular elements (Fig. 13).

### 4.2 Bar-end conditions

One of the most debated questions concerns the inner joints of the model.

The safest modeling, and clearly closely describing the truss behavior, is using pin joints. Structures with pin joints are more flexible, so if a structural checking gives correct results with pin joints, it will surely resist with partially fixed joints, too.

Though this approach is correct in the structural expertise of a particular roof, the scientific approach is the one identifying the extra safety within a Baroque roof structure, introduced through joints (double pegs combined with mortice and tenon and notches) with a capable bending moment: Figure 15.

A mathematical model of the rotational moment capacity of the joints has also been developed. The next step of the PhD research program is in situ testing in order to control the mathematical model through on site measurements.

Though calculation and modeling are important steps in conserving Baroque roof structures, neither scientific research nor the guidelines should end at this point.

Even in the case of the studied roof structure, calculation has demonstrated that the structure is working properly, as can be red on the structure as well, which means that conservation should be reduced to local repairs of the biologically damaged elements.
5 THE PRINCIPLE OF MINIMUM INTERVENTIONS – CONCLUSIONS

Baroque roof structures are safe and durable. The roof of the Boys’ Dorm of the Bethlen College, Aiud, had by 1999 more than 50% of its trusses decayed (one or more joints dysfunctional or one or more elements missing). Nevertheless, the ensemble was still standing.

The British practice of minimum intervention was introduced to Romanian practitioners first through the ACTT 2000 project. This training programme was jointly organised by the Transylvania Trust and the British Institute of Historic Building Conservation. (Since 2001 they run the Built Heritage Conservation Training Centre within the Bánffy castle in Bontida, Romania).

In the framework of carpentry workshops, in situ repairs based on the minimum intervention principle was carried out. (Fig. 16)

A continuity joint assures 50–70% of the capacity of the element's full cross section. Therefore the hand-out of Baroque roof conservation needs to discuss the estimation of the overall change in stiffness and resistance of the structure through the introduction of a high number of repair joints.

Baroque roof structures represent exceptional historic values which need to be conserved for future generations. Therefore their inventory and perfect structural understanding is indispensable in order to assure their protection, conservation and consolidation, without destroying the historic fabric and values they carry. So is expertise and craftsmanship, from consultant to craftsmen.

REFERENCES


