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Interventions on the Gothic Roof Structure of the Nave at the Lutheran Church in Bistriţa (Romania)

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Abstract The roof structure of the Lutheran Church in Bistriţa is one of the historic roof structures with the widest span in Europe. With a volume of over 9,500 cubic metres, the span of the trusses is 22.60 m. The roof structure – built between 1557 and 1561 – underwent several consolidation interventions. It was seriously damaged in the fire of June 11, 2008, which entirely destroyed the tower's roof structure and extended to the nave as well, in particular in the area next to the tower. The interventions treated those deficiencies of the nave roof structure resulting from the fire, or from defective maintenance and usage throughout time – missing parts, degraded joints, etc. – or from previous interventions, which altered the static model (by introducing straining devices on intermediary supports that were created subsequently). Made of 39 trusses (out of which 20 main and 19 secondary), the consolidated roof structure was restored as follows: at the first 8 trusses – where the fire destroyed over 70% of the parts – the initial structure was restored; at the consolidated trusses from 1897 (from truss #9 to truss #23), the static model resulting from consolidation was kept in the restoration process; whereas from truss #24 to truss #39 – consolidated in secondary trusses in 1926 – the initial static model was also restored.

Keywords: Lutheran Church in Bistriţa, Gothic roof structure, restoration works

Introduction

The fire of June 11, 2008 affected the Lutheran Church in Bistriţa, destroying a considerable part of the nave's Gothic roof structure, respectively the Eclectic roof structure of the tower and compelling the initiation of an emergency intervention, so as to (i) eliminate the timber structure that was irremediably altered by the fire, (ii) protect the church against weather, (iii) elaborate the concept of an intervention aiming at restoring – reconstructing the roof structures.

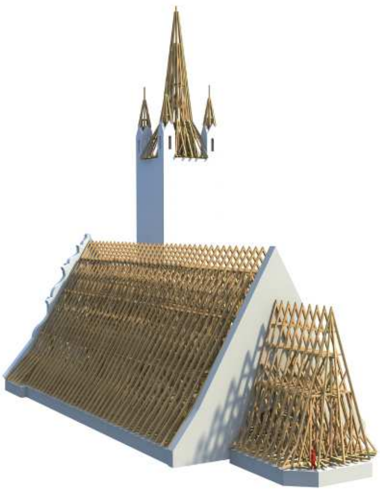

Figure 1: General view of the church

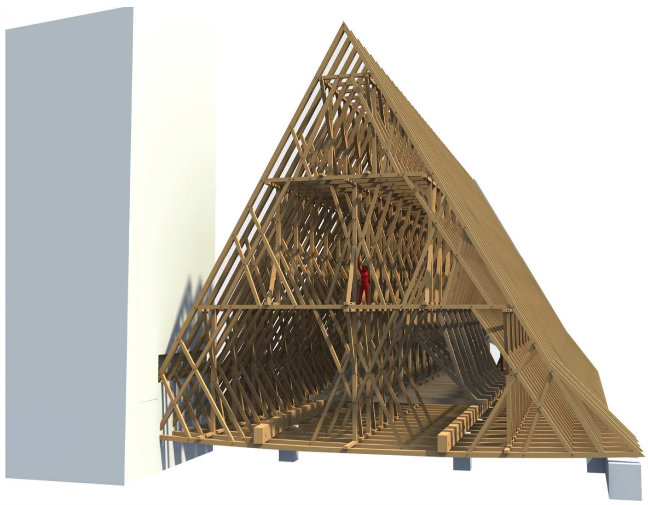

Figure 2: The nave roof structure – axonometric view

Built between 1560 and 1561, the roof structure of the church nave is among the roof structures having the widest span, of no less than 22 m, without intermediary supports. Similarly to the church building, the roof structure has experienced many interventions along the centuries, which have "altered" considerably even the structural scheme of the load-bearing structural sub-unit. As a consequence of the fire, emergency interventions were aimed at strengthening the entire unit, and at the same time, a full assessment of the entire roof structure was also carried out.

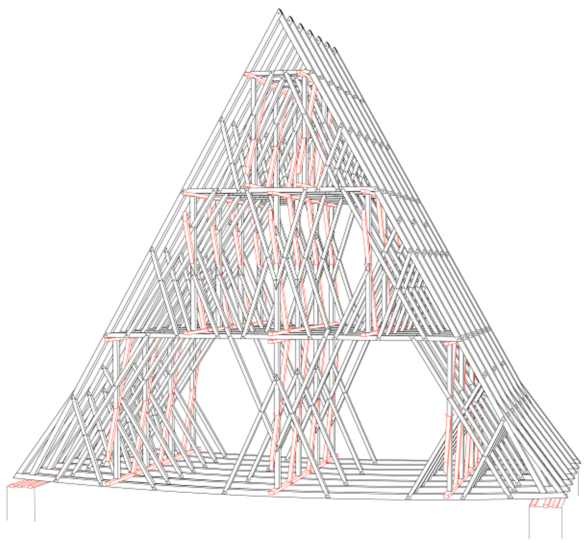

Figure 3: The original roof structure – axonometric view

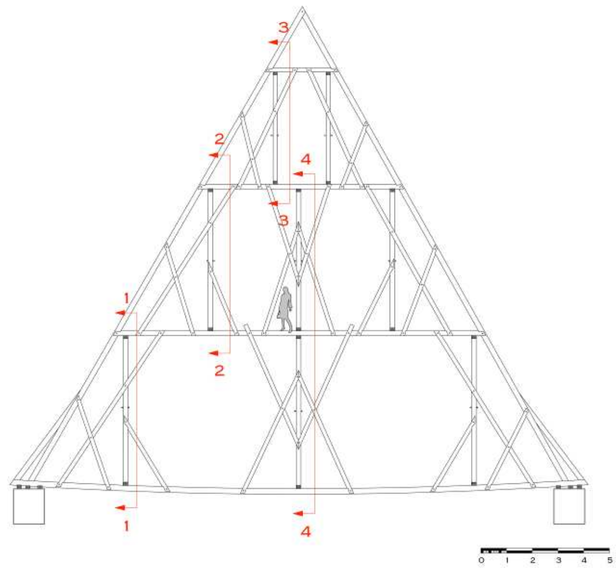

Figure 4: The main truss from the original roof structure

In line with the dissemination of calculation techniques over the past 20 years, respectively the improvement of structural analysis, what is noteworthy is a remarkable change in specialists' attitude towards historic timber load-bearing structures, including the possibility of elaborating a 3D model of the load-bearing structure subunits made of thousands of bars. Thus, besides the appreciation of the material, respectively technological value of this heritage, the specialists managed to identify the historic mechanical concept – this time perfectly – based on intuition and a long experience.

The strengthening (of the Gothic nave and choir roof structure), respectively reconstruction (of the tower roof structure, which was completely destroyed by the fire) concept was carried out in parallel with the implementation process (this being an emergency intervention), the permanent presence of the engineers in all the implementation phases facilitating a broader understanding of all the details. Access was ensured to all the levels, respectively to all the joints of the roof structure.

Description of the Roof Structure

The church nave roof structure has a Gothic character and is made of 20 main trusses and 19 secondary trusses, interlaced, respectively of 8 longitudinal bracing frames (3 per each of levels I and II, respectively 2 on level III). It can be dated between 1559 and 1563, according to the general contractor agreement signed in December 16, 1559, the inscription recently discovered in the nave and the dendrochronological research carried out in 2009 (Rus 2010). The span of the trusses is approximately 22.60 m.

The trusses located next to the tower have missing parts, as there is no joint connection between the tie beam and rafter, since the tower wall located in the prolongation of the nave's longitudinal diaphragm does not allow the two truss elements to cross each another. There have been at least two major interventions on the nave's roof structure, which altered the roof structure's structural behaviour: in 1897 (when two longitudinal compound beams were mounted, resting upon the heightened intermediary columns, as well as the straining devices in the main trusses up to truss no.

23) and in 1926 (when straining systems were mounted in some of the secondary trusses, starting with truss no. 26).

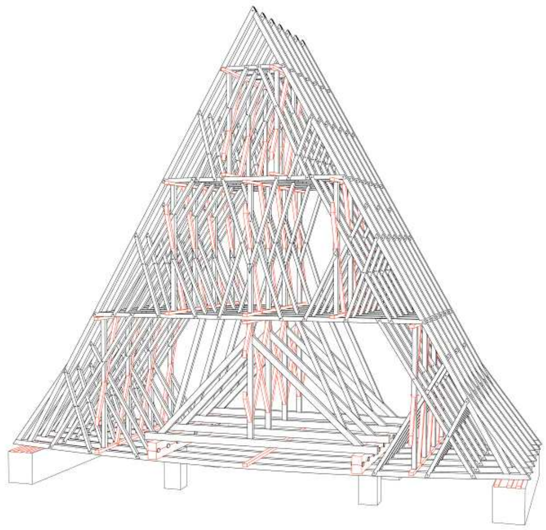

Figure 5: The roof structure – axonometric view and the intervention in 1897

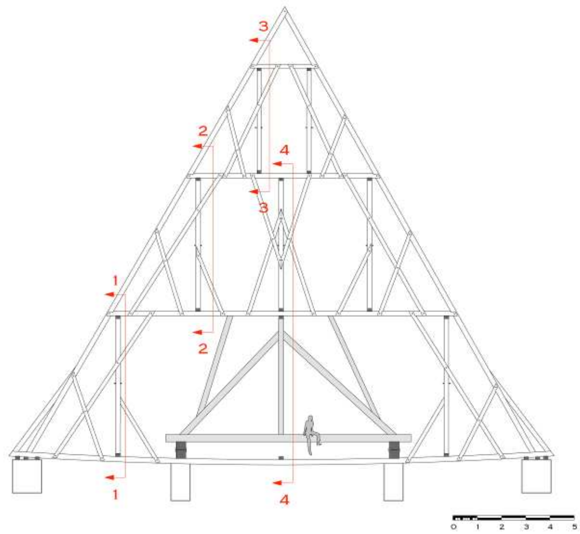

Figure 6: The main truss – with the straining device (built in 1897)

The Gothic roof structure above the nave is a type I roof structure and has a hanging-device in the vertical symmetry axis (Szabó 2005).

The actions of the roof structure sub-units are conveyed to the supporting sub-unit in the load-bearing structure by means of three wall plates, located on the peripheral longitudinal walls. The wall plates are not embedded into the walls' masonry structure, the contact between the wall plates and the load-bearing wall being ensured only by friction.

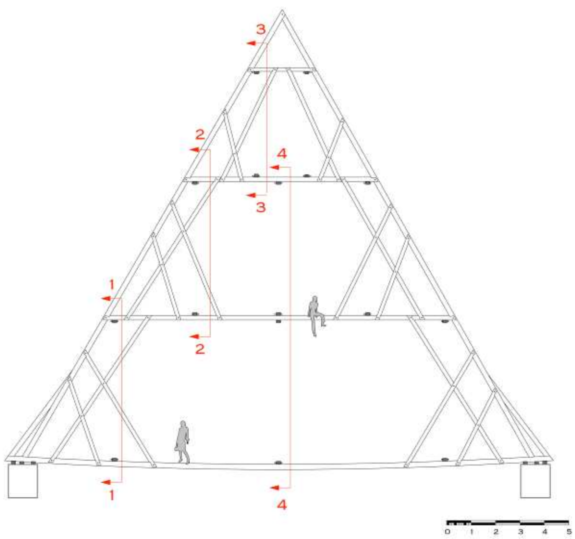

Figure 7: The original secondary truss

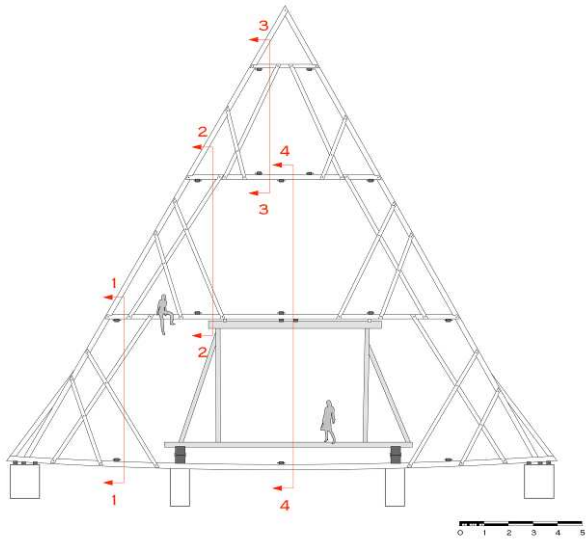

Figure 8: The secondary truss with the intervention from 1926

The nave roof structure is a spatial network of linear load-bearing elements, arranged (sequenced) in cross frames (placed 0.80–1.45m apart) and longitudinal bracing systems. Because of the spatial load-bearing structure, they can achieve three-dimensional mechanical behaviour.

The cross frames (main and secondary trusses) are simply supported sub-units connected by notches to the wall plates. The notches – located at the two ends of the tie-beams – make the wall plates and trusses work together facing horizontal movements.

The longitudinal bracing system rests upon the supporting sub-units of the load-bearing structure, attached through the gable masonry.

Dead-loads are carried (and conveyed to the supporting sub-units in the load-bearing structure) exclusively by the cross frames: (at least in the case of type I) main and secondary trusses (in most cases, symmetric to the vertical symmetry axis, which goes through the ridge).

Usually, these frames are load-bearing structures with thrusts, made of bars placed along triangular outlines (rafter – tie-beam – rafter), whose dead-loads are divided into compression slanted components – according to the rafters' direction – balanced by the tie-beam tensile strain and by the vertical reaction of the wall plates. [Except for the trusses by the tower (in the direction of the tower, there is no joint connection between the tie-beam and rafter); in this case, the wall plates take over some of the horizontal actions].

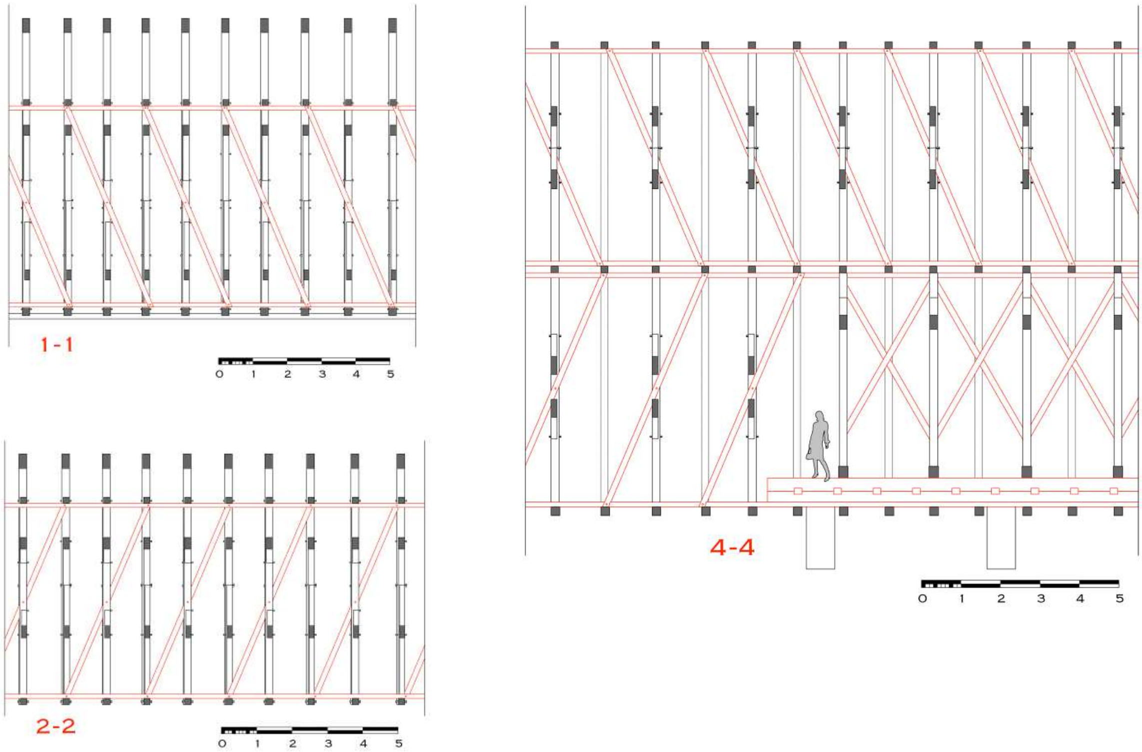

Figure 9: The longitudinal bracing plan systems – sections 1-1, 2-2, 4-4

The triangular outlines are completed by linear elements, whose role is: (i) to reduce the bending of: rafters (under the self-weight of the roof covering, acting with gravity on the rafters, respectively the loads exerted upon the roofing), collar beams and upper collars; (ii) to fix/brace the rafters, respectively the tie-beam in joints – angle braces. The angle braces are placed in a single row (in the case of main trusses), respectively two rows (in the case of secondary trusses, on two levels); (iii) the hanging of horizontal elements – vertical and slanted hanging posts. Passing braces (compound rafters) are also present, one of their roles being to hang the vertical bars.

Non-gravity actions exerted crosswise (in the plane of the trusses) are also carried by the triangular outline braced as previously described. Each of the elements has its role in carrying and conveying non-gravity actions, but the extent to which each of them takes part in the gravity or non-gravity actions differs as follows: collar beams have an important role in carrying gravity action, but are less useful in carrying non-gravity actions. Angle braces, upper collars, passing braces (compound rafters) and angled hanging posts have an important role in carrying non-gravity actions.

Non-gravity actions exerted longitudinally are carried by the longitudinal bracing system placed vertically, symmetric to an axis going through the ridge of the roof. These frames and the main trusses have elements in common (king and queen posts in tension); there is also a connection between the main truss and the longitudinal plates, through passing braces or angle braces, even though the joint between the truss and the longitudinal frame is made by means of notched longitudinal plates. The outcome of the spatial model reflects a correct empiric-intuitive concept: there is not a single element whose load-bearing capacity is exceeded.

The Interventions

The nave roof structure was divided into sections, which were restored separately.

Figure 10: Local interventions –rafters' end repair

Figure 11: Local interventions – collar end repair

The first section, made of the first 9 trusses, destroyed to an extent of around 70% by the fire, was restored respecting its initial shape, that of 1559-1563. Parts of elements preserved from the fire were lengthened with new material, identical to the existing one, i.e. hand hewn fir timber. The curtailed trusses in the area of the tower were anchored to the tower masonry with metal. The longitudinal frames were also fixed to the western gable through metal elements.

Figure 12: Reconstruction intervention at the first section, level II

Figure 13: Replacement of damaged rafter and upper collar, second section

The second section (trusses 9-23), less affected by the fire but severely damaged as a consequence of unprofessional interventions along the years, reinforced in 1897 (by introducing some Eclectic type timber straining devices at the first level of the roof structure), was restored preserving the intervention of 1897.

Many of the angle braces and compound rafters were replaced locally or completely rebuilt, because when the tie-beams had been previously replaced, the angle braces-tie beam joints and the compound rafter-tie beam joints were destroyed, cutting off the ends of the angled elements, without dovetail halved joint in the newly introduced tie beam. On this occasion, the restoration consisted in replacing the properly cut-out slanted elements and in carving slots for the tie-beams halved joint.

The third section (trusses 24-38), also strengthened in 1926 (through insertion of straining trusses at the first level of the roof structure, supported by the longitudinal compound beams), was restored according to the initial shape, that of 1559-1563, by replacing missing elements and the burnt parts,

discarding the interventions of 1926. Once more, many angle braces and compound rafters were partially replaced or completely rebuilt, as previously explained.

Degraded missing parts and shorter parts (in particular angle braces) were totally replaced, even if only locally degraded. Longer parts (i.e. common rafters, tie-beams, collar beams, compound rafters, King/Queen posts in tension, longitudinal plates, etc.) were restored by replacing the degraded parts of the respective elements, achieving connecting joints able to carry tension, as well as eccentric compression loads.

Vertical positioning of distorted trusses was also attempted, due to lack of efficiency of longitudinal bracing frames connected only by friction to the cross frames.

Figure 14: New angle brace – rafter dovetail joints

Figure 15: Rafter, compound rafter extension joints

Conclusions

The nave roof structure was restored at different stages, on sections. Where the fire destroyed most part of the elements (the first 8 trusses), and where previous interventions did not imply major changes of original elements (between trusses #24 and #39), the initial model (that existed between 1557 and 1563) was restored, this decision being entirely sustained by the results of mechanical design simulations. In the area between trusses #9 and #23 the restoration went back to the shape that resulted from the interventions back in 1897 (which in their turn, implied essential changes to the static model, finalized by major changes to the first level of roof structure), the presentation of the subsequent intervention being considered useful.

Restoration was possible because the original design – empirical and intuitive – was perfect, each of the 1,506 struts forming the nave roof structure have enough load-bearing capacity, resulting even in a strain that is compatible with current provisions.

Discrepancies – referring to those trusses with missing parts near the tower, as well as to the anchoring of the gable to the longitudinal bracing frames – were solved through connecting metal parts, as restoration of historical details was not enough.

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