# Interventions on Roof Structures as Part of Conservation of Historic Buildings with Local Value

## Case Study - Vințu De Jos

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**Abstract.** Romania hosts a large number of historic buildings. Some of them are listed as historic buildings of various value, value group A for national value, value group B for local value, and some of them are even included on the World Heritage List. The historic building protection has lacked continuity and was only resumed after the 1989 Revolution. Therefore, many historic buildings are severely decayed, have been subject to unauthorized interventions, and even to interventions conducted by non-specialists. While the historic buildings on the UNESCO List or of national value are approached with big care, benefit of funds for all planning stages, the historic buildings of local value or non-listed are in real danger. The hidden parts such as roof structures are even less considered when their value is minor.

This paper analyses the interventions on a historic roof structure dendrochronologically dated back to the 1720s belonging to the church of the Bulgarian Franciscan Monastery. While applying the research principles for valuable historic roof structures, we also perform a theoretical analysis of several solutions for repairs and consolidation considering safeguarding the values, as well as of intervention implementation and efficiency based on analyses, tests, and structural modelling. This example may show how complex the reasoning when choosing a solution for repairs or intervention on 18$^{th}$ century timber roof structures.

**Keywords:** Minor Heritage · Roofs · Structural Modelling · Timber · Interventions

## 1 Introduction

The buildings considered as valuable, selected based on the age, considering their architectural, artistic, and urban values, as well as the frequency criterion and the memorial-symbolic value can be protected by law as historic buildings. Most of the buildings included in the Historic Building List are historic buildings included in the Value Group B (approximately three times more than the historic buildings included in Value Group A that includes buildings of national value) [1].


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"Minor heritage" may hide surprising values that are revealed during detailed research focused on specific interventions, such as repairs on the covering, etc. An element in this category is the example approached in this paper i.e., a 18th century church in Transylvania as part of a former Bulgarian Franciscan monastery ensemble. We use this example to illustrate how the interventions on a historic roof structure are based on a series of studies conducted by a multidisciplinary team made up of an arts historian, a conservation practitioner, an architect, an engineer, a biological assessor, especially as this type of roof structure is atypical in terms of composition and layout of certain structural elements. Each professional introduces their own assessment criteria, which are not always understood and accepted by all the persons involved.

## 2 Brief Presentation of the Structure and Its Shortcomings

The investigations presented below refer to the roof structure over the church nave as structure belonging to the category of roof structures on collar beams, where the loads are taken over from the common rafters through the collar beams. This specific type of roof structure had not been found in this area, which imposed a mandatory dendrochronological analysis.

The structure dates to 1725 [2], but it has suffered a series of interventions over time. Depending on the interventions, the evolution of the roof structure can be described in stages as follows (a presentation of the roof structure at each stage of its existence can be found in Fig. 1):

**Stage 1.** Roof structure made up of a succession of main and secondary trusses where two or three secondary trusses are intercalated between two main trusses. The distance between trusses ranges between 88 cm and 1.21 m. The truss opening is approximately 10.2 m. The pitched roof has 95%–98% slopes. The secondary trusses have pairs of common rafters connected through tie-beams at the lower end. The main trusses have double king posts (Fig. 2a). The common rafters are doubled by sprockets on the lower side. Considering the large deflection of the tie-beams (approximately 13–14 cm as found through 3D scanning of the whole building) [3], and the absence of significant displacement of the tie-beam – king post joints (Fig. 2b), it may be assumed that the king posts were added after completion of the roof structure. However, according to the dendrochronological research results, the elements are dated to close dates, which suggests the king posts were inserted at the same time or shortly after structure completion. The roof structure with tie-beams in each truss was initially supporting a painted coffered ceiling, which was the less expensive slab version in a church. The original roof structure is mainly made of spruce, with the wall plates as single oak elements [4].

**Stage 2.** Because of the large deflection of the tie-beams, which also have a role of ceiling beams, a series of king post trusses were inserted on which the main beam and, implicitly, the beams of the ceilinged slab are hung. These trusses were placed adjacent to the main trusses. When the ceiling was upgraded/modified in 1770, the planks were removed, the painted coffered elements were turned face to the attic (Fig. 3), the tie-beams were refastened on the lower side, and a stucco decoration was applied, which added load on the tie-beams and thus contributed to increasing their deflection.

The elements are all made of spruce. The tie-beams are hung on the king posts with metal elements.

**Stage 3.** Further to the changing of covering type in 1931 (from wood shingles to tiles, which translates into increased load from dead load from 30 to 65 daN/m$^2$) larger deflection occurred on the common rafters. To counter this phenomenon, two longitudinal bracing frames made up of purlins, posts and counterbraces were inserted (Fig. 4a).

Considering the written evidence of interventions for changing the church covering in 1931, when the church was taken over by the Roman Catholic bishopric, we can infer that the stages 2 and 3 of intervention on the roof structure took place at the same time. Moreover, a series of local consolidations were conducted consisting in juxtaposing tie-beams and common rafters at the cornice joints.

To confirm the study results, a structural modelling was performed (using Autodesk Robot Structural Analysis Professional 2022) and the intervention stages mentioned above were analysed (Fig. 5, Fig. 6). The modelling revealed how the various changes in the structure affected its behaviour, and showed the level of efficiency of each previous intervention.

The main damages are caused by the action of biological factors (fungi, xylophagous insects), whose development was favoured by rainwater infiltrations caused by covering decay (Fig. 4b). Moreover, the conformation of certain details contributed to the occurrence of biological agents, such as the full embedding of the wall plates in the masonry, removing any airing possibility. Also, the quality of the later interventions is questionable.

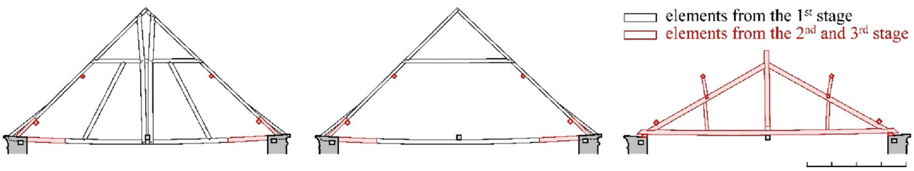



**Fig. 1.** The evolution of the roof structure. Main truss, secondary truss and king post truss.

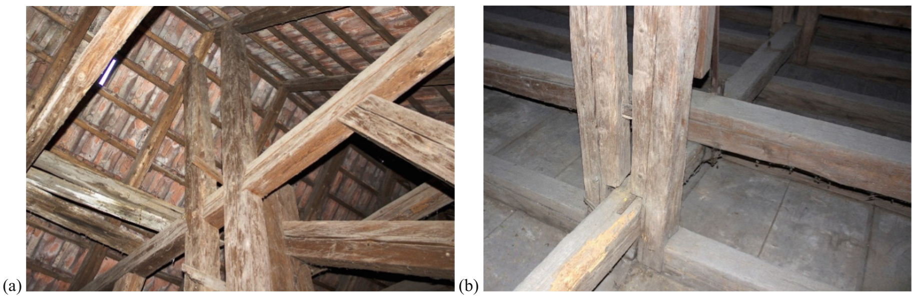
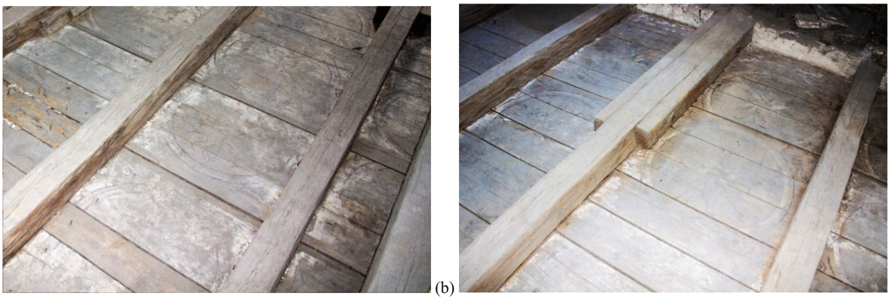



**Fig. 2.** Roof structure details: ridge joint detail (a) and king post – tie-beam joint detail (b)



(a) (b)

**Fig. 3.** Ceiling painted planks turned face to the attic

(a) (b)

**Fig. 4.** Attic interior. Later interventions - longitudinal bracing elements and king post trusses (a). Biological decay (b)

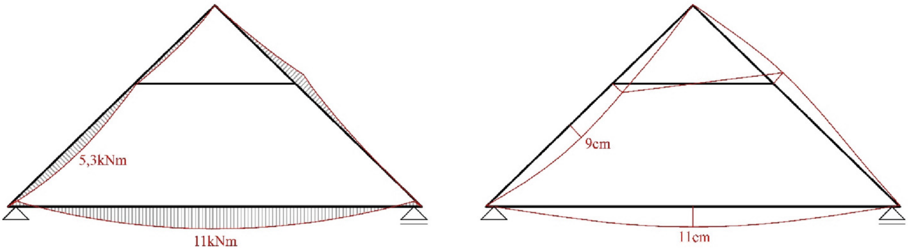



**Fig. 5.** Analysis of a simple truss, without taking into account the king-posts. The large deflection of the tie-beams are close to what we see now (one can assume that the king-posts were added after the completion of the whole structure)

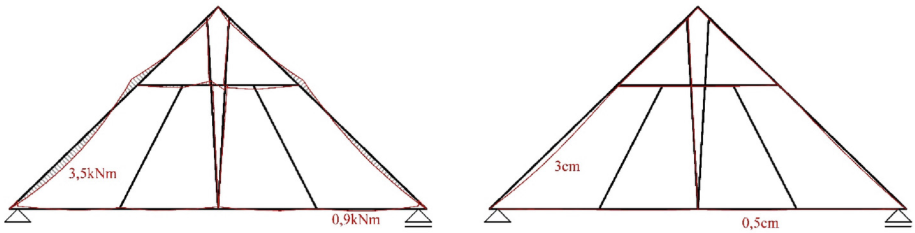



**Fig. 6.** Analysis of the main trusses, after adding the king-posts as elements for hanging the tie-beams and the purlins. The tie-beam deflection is considerably reduced. The purlins position (quite close to extremes), along with their reduced cross-sections, made them quite inefficient.

## 3 Interventions Approach

Before deciding on the type of intervention, it is very important to conduct specialised studies. All the results shall be corroborated to find the values to be protected as understood by each specialist involved. There are cases (like our example) where the solutions depend on the most valuable elements. The compliance with the conservation principles and the good practices becomes even more important. Among the criteria to be considered when conducting the analyses, we point out the following:

– intervention reversibility, which is essential to maintain the value of such a structure unaltered
– the percentage of new material inserted to the detriment of old material
– radical changes to the structure composition, with direct impact on authenticity
– material volume and quality, and amount of labour needed

Coming back to our example, the interventions are subject to a series of factors, among which the most important is the protection of the coffered ceiling. The success of the solution largely depends on the skills of the craftsmen team and on their capacity to implement the requests of the designer. A full intervention on the roof structure would involve full replacement of the wall plates and of the tie-beam/common rafter ends with reconstruction of the cornice joints. However, such works involve structure lifting, which, unless performed properly, may affect the integrity of the coffered ceiling. If we add to the above the condition to perform an emergency intervention for securing purposes, the solution should be minimum intervention with maximum effect. The intervention will have to be reversible to enable further more extensive interventions at a later stage.

A series of intervention versions were analysed in terms of structural conformation. They are described below including their respective advantages and disadvantages (Table 1):

**Table 1.** Analysed interventions.

| Intervention type and description | Advantages | Disadvantages |
|---|---|---|
| **Version 1** | | |
| - reconstruction of the longitudinal bracing frame by removing the purlins/counterbraces and replacing them with one intermediate purlin on each side<br>- introduction of angled posts (made up of element pairs) in the trusses, unloading on the tie-beams<br>- adding counterbraces in the longitudinal bracing frame | - high reversibility<br>- decrease in the number of purlins with appropriate efficiency of the longitudinal bracing | - need to pay attention to the making of the woodworking joints |
| **Version 2** | | |
| - removal of the compound rafters from the main trusses<br>- removal of the longitudinal bracing frame<br>- insertion of angle braces (element pairs) in each truss | - increased bracing in the truss plane, and decreased stress in the cornice joints | - issues related to the longitudinal bracing, with potential impacts on the gables<br>- removal of certain elements bearing historic value from the initial structure |
| **Version 3** | | |
| - replacement of the longitudinal bracing frame with a frame symmetrical to the central axis, made up of plates (lower and upper plates), vertical posts and compound rafters<br>- angle braces in each truss | - mechanical behaviour | - high consumption of material/labour<br>- low percentage of original structure preserved |

(*continued*)

**Table 1.** (*continued*)

| Intervention type and description | Advantages | Disadvantages |
|---|---|---|
| **Version 4** | | |
| - removal of queen post trusses<br>- removal of the longitudinal bracing frame<br>- introduction of intermediary purlins (one on each side)<br>- creation of a new type of main truss through modification of certain secondary trusses by adding straining-hanging trusses (made up of queen post, compound rafters and straining beam)<br>- introduction of a new longitudinal bracing frame, consisting of purlins, struts, counterbraces | - mechanical behaviour | - high consumption of material/labour<br>- need to manufacture metal parts adapted to each truss to hang the tie-beam |
| Specific interventions as recommended by the conservation practitioners | - high reversibility | - need to pay attention to the making of the woodworking joints<br>- impossibility to perform a comprehensive intervention on the roof structure |

# 4 Structural Analysis

## 4.1 Current State Analysis

This analysis was made to study the structure behaviour, namely the stress in the elements at each structure evolution stage as described above, and for the intervention versions described in the table. The modelling was focused on one fragment of the whole roof structure including three main trusses and the respective intercalated secondary trusses. Focus was put on the role of the main elements and on how they influence the structure behaviour.

For the first stage, the structural version without queen posts was first checked. The tie-beam deflections obtained from the structural calculation are comparable with the deflections that can be measured now in situ (the difference being around 2–3 cm, as it can be seen in Fig. 5). This supports the assumption that the queen posts were added subsequently. It is likely that the compound rafters were initially placed to take over the load of the timber slab (this is strange if we consider the mortise and tenon joints used). However, the fact that they are elements mainly subjected to compressive stress proves their inefficiency in the first stage of the building.

The next check referred to the change in covering type (from wood shingles to tiles). This revealed large deflections of the common rafters, with values over the allowed limit.

The results for stages 2 and 3 pointed out the inefficiency of the longitudinal bracing frame, as the posts are fragmented being made up of several elements that are not even placed on the same axis, and the counterbraces are not properly placed with respect to the angle they make with the purlins.

### 4.2 Analysis of the Intervention Versions

**Version 1** (Fig. 7, Fig. 8) consists in turning the structure into a version close to the truss with angled posts that can be found in the Transylvanian eclectic roof structures (mainly built in the second half of the 19th century). The only elements recorded with exceeded load-bearing capacity are the tie-beams, but the excess is of maximum 12%, which is acceptable for this type of structure, where the quality of the materials is different from the quality generally found in new structures. The option of removing the king post trusses was also checked, but the stresses occurred in the king post – tie-beam joint exceed the load bearing capacity of those joints.

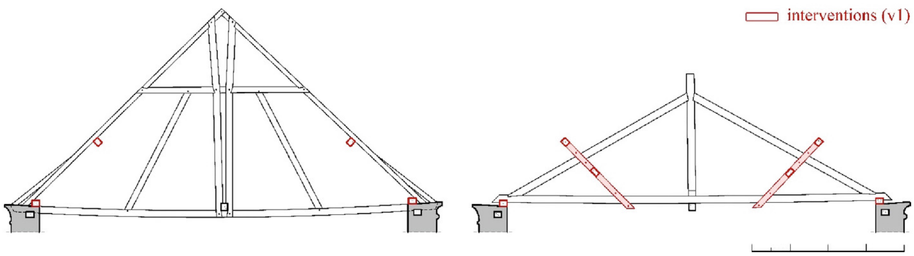



**Fig. 7.** Version 1 of interventions. Main truss and king post truss.

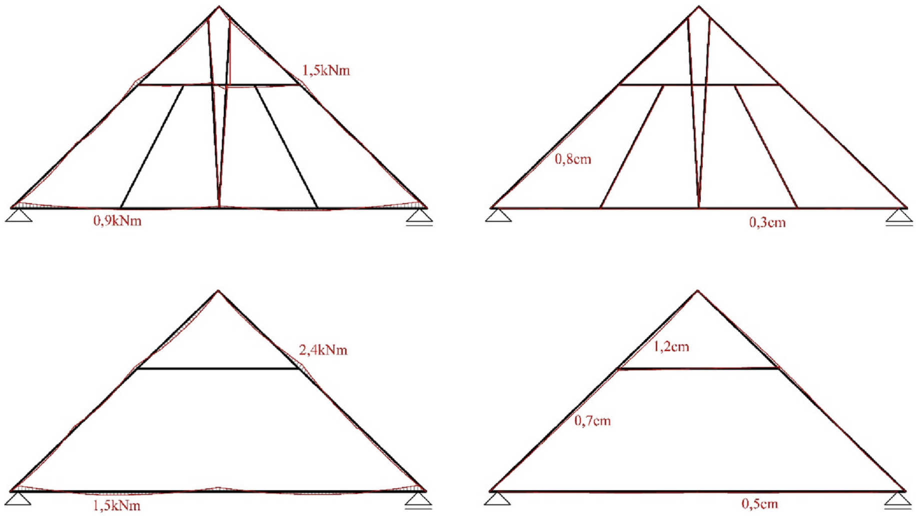



**Fig. 8.** Version 1 of interventions. Structural analysis (bending moment and deflections) of a main and secondary truss..

**Version 2** (Fig. 9, Fig. 10) implies angle braces that take over the loads in the lower part of the common rafters. The angle braces thus contribute significantly to decreasing the deflections. The main issue recorded is related to the structure behaviour to horizontal actions, as bracing is only ensured by the laths supporting the covering.

**Version 3** (Fig. 11, Fig. 13a) ensures compliance with all load-bearing and stability requirements, but with higher costs, as it involves significant increase in material and labour consumption. The double king post trusses could only be removed if other elements are used to take over the load of the timber slab, but this is not possible in the current configuration, as the queen posts play most of the role of columns within the longitudinal bracing frame.

**Version 4** (Fig. 12, Fig. 13b) implies high consumption of material and labour. The load bearing and stability conditions ale fully met. The longitudinal bracing truss is to be reconfigured and the queen post trusses are to be undone, which complicates the execution works.

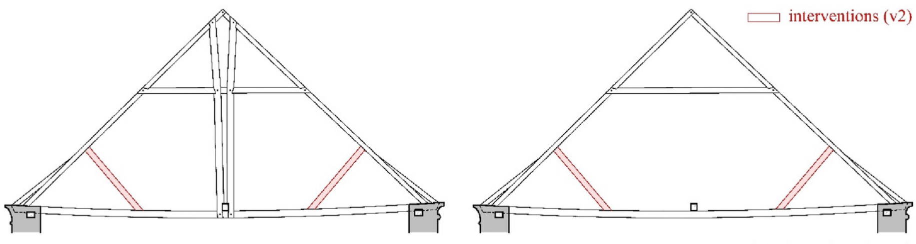



**Fig. 9.** Version 2 of interventions. Main truss and secondary truss.

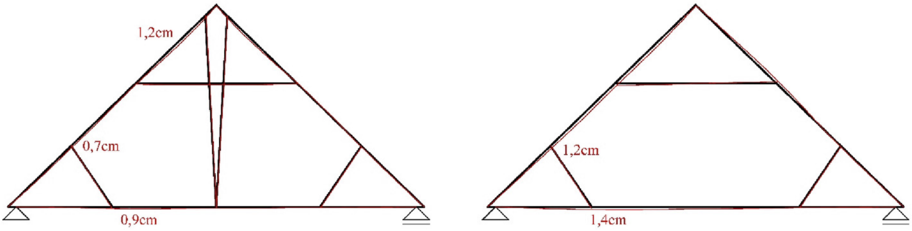



**Fig. 10.** Version 2 of interventions. Structural analysis (deflections) of a main and secondary truss.

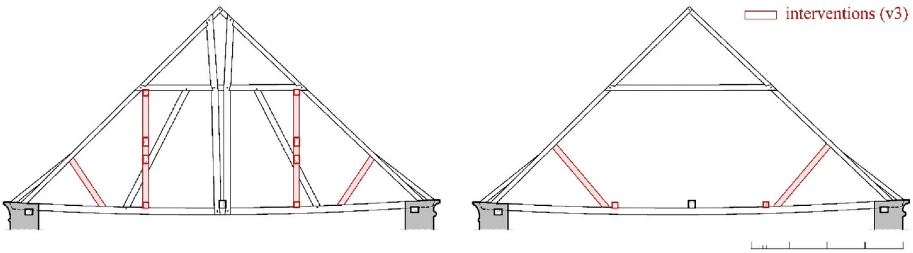



**Fig. 11.** Version 3 of interventions. Main truss and secondary truss.

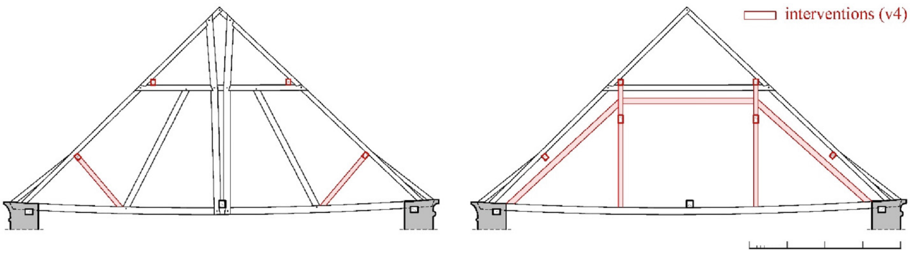



**Fig. 12.** Version 4 of interventions. Main truss and secondary truss.

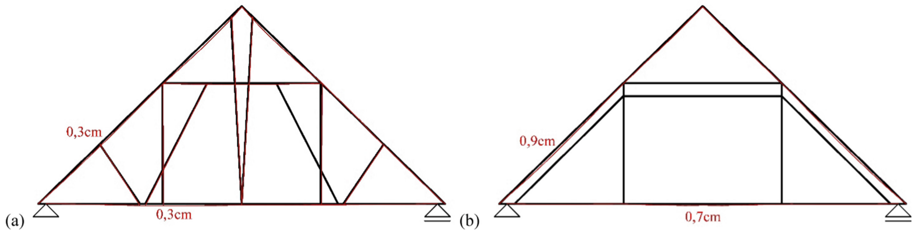



**Fig. 13.** Version 3 and 4 of interventions Structural analysis (deflections) of a main and secondary truss. Main truss from version 3 (a) and secondary truss from version 4 transformed into a main truss (b).

## 5 Conclusions

In order to find adequate solutions for interventions on historic structures, one must take into account several points of view, while having an overall image of the entire problem. The coordination of a team of specialists is very important, keeping in focus the hierarchy of values and their priority. Each case is different, some more challenging than others, but the main concern should always be the preservation of historical values. The real challenge starts when one deals with solutions which tend to do good on one hand, and bad on the other. These cases emphasize the best the importance of theoretical analysis *a priori*, putting in balance the advantages and disadvantages for all the cases of intervention. One should not forget about the general principles of restauration, which should be taken into account and aplied to solutions for repairs and consolidation, considering safeguarding the values, as well as of intervention implementation and efficiency.

## References

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