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The Reconstruction of the Timber Roof of the "Pieve" in Cavalese

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ABSTRACT: In case of exceptional destructive events (earthquakes, floods, fire), the advisability of completely reconstructing a vanished artefact can come into question.
The case study reported by the authors concerns the timber roof of the "Pieve" in Cavalese (Italy), destroyed during a fire on March 29th 2003, for which a philological reconstruction has been chosen. Such design choice, far from being a simplistic solution, involved the participation of different expertise and a thorough investigation on the relevant typology and technical features.

1 INTRODUCTION

1.1 The "Pieve" in Cavalese

The "Pieve" in Cavalese belongs to one of the most interesting ecclesiastical complex in Trentino (Italy) (Fig.1). The basilica lay-out consists of a nave and two side aisles, partitioned in six bays. A four-bay additional aisle was built at the north side in 1610, while a polygonal chapel was built east of the northern aisle, in 1640. In the second half of the seventeenth century a sacristy was added at the southern side, close to the rectangular apse, that is divided in two bays. A rectangular chapel (Firmian Chapel) was built in the second half of the seventeenth century at the southern side, in correspondence of the fourth bay of the nave and close to the bell tower. A porch is set in front of the main entrance.

The roofs geometry reflects the complex lay-out of the building.

The nave is covered by a gable roof, while both the apse and the porch have hip roofs. Shed roofs cover the north aisle and the sacristies. The Rosario's Chapel has a polygonal hip roof, while helmet-like domes cap the bell tower and the Firmian Chapel. Larch shingles are used for the roofing, except for the cooper shingle roof of the bell tower.

Figure 1 : The "Pieve" in Cavalese

1.2 The fire

A fire on March 29th 2003 destroyed the most of the timber roofs of the Pieve.

All the phases of the fire are reported by a series of pictures shot from the very beginning of the ignition (Fig. 2). The fire started in the roof of the nave, just under the bell tower, that was surrounded by the scaffolding built during the roofing maintenance works.

The Fire Brigade arrived just after some minutes from the discovering. They concentrated their efforts on saving the underlying masonry structures, thus adequately choosing the capacity of the nozzles.

Once the fire was extinguished the destruction of the roofs was complete. All that could be salvaged from the wreckage were some burned wall plates and some portions of timber elements inserted in the masonry walls (consequently protected from direct exposure to fire). The only roofs that have lain untouched are the one of the porch and the belfry, lying at significantly different heights from the burned roofs.

Figure 2 : The fire

1.3 The options for restoration

The lost of the roof causes the mutilation of a monument, whose importance is relevant not only to its intrinsic artistic and historical value, but also to its social value in the local community.

The choice of leaving the church roofless, as well as any similar sort of 'Ruskinian' non-intervention, was rejected. In fact a new roof was necessary to protect the underlying structures. Moreover the need for the visual and aesthetic reintegration of the mutilated building could be met just by reconstructing the roof in its original form.

Reconstruction involved not only the external *facies*. Indeed, a thorough study aimed at philologically reconstructing the internal timber structures, with respect to their original typology and structural behaviour. The research focused on the design of both the global structural system and the single building details, such as the joints.

2 THE RECONSTRUCTION PROCESS

2.1 Provisional emergency actions

A cover for the roofless parts of the building was obviously required. A first cover consisted of PVC sheeting laid on the vaults extrados. Afterwards an external scaffolding was built to bear the temporary metallic roof frame (Fig. 3).

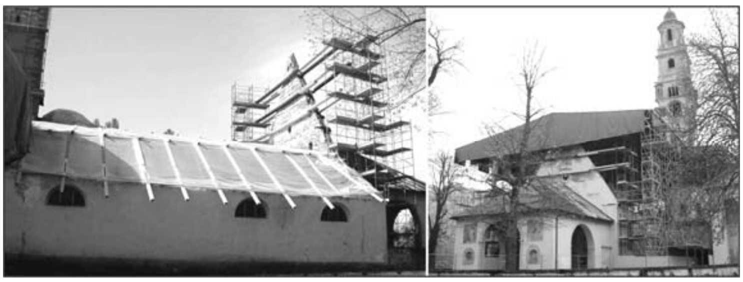

Figure 3 : Provisional emergency actions

The cover had the task to protect the remaining masonry structure from the weather, to provide an operational platform for the acquaintance and the repair of the masonry vaults as well as for the construction of the new roof.

Moreover, urgent safeguard measures were taken to avoid the collapse of some masonry structures, such as the gable, that suffered stability problems due to the lack of the timber bracing.

2.2 The typological design of the trusses

This phase has been a challenging task for the designers, because of the lack of iconographical documentation of the original roof, such as geometrical surveys.

The reconstruction of the nave's trusses has been based on some photographs, taken some weeks before the fire, the remnants of the burned timber elements on the site and a comparative study on similar typologies. The latter has been carried out on churches in the neighbouring areas, taking into account the number and layout of their aisles as well as the height and the slope of their roof pitches. Another important analogy taken into account is that the roof framing has to accommodate the interior vaulting system, which rises higher than the top of the walls of the building.

The comparative study, however, gave only partial answers about the original features of the vanished roof. Indeed, even among the same building typology, several "variations on the theme" occur, at the different scales, from the details to the overall structural configuration. Comparison was made of the roofs of the churches of "Nostra Signora" in Egna (second half of the 15th century, first half of the 16th century) "Santi Martiri" in Sanzeno (15th century) and "San Giovanni" in Vigo di Fassa (latter half of the 15th century) (see, for details, Sommariva, 2003). The geometry of the trusses of the three analysed churches is shown in Fig. 4.

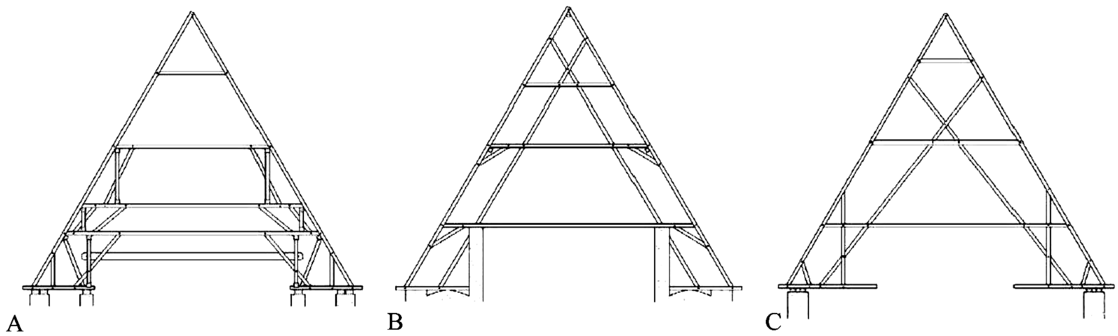

Figure 4 : Truss typologies for different churches in the neighbouring areas:
(a) "Nostra Signora" in Egna; (b) "Santi Martiri" in Sanzeno; (c) "San Giovanni" in Vigo di Fassa.

In Sanzeno and in Vigo di Fassa, scissors braced trusses are used to cover the vaulted nave, while in Egna the rafters are braced only by collar beams. All the trusses are closely spaced (about 90-100 cm). The spatial bracing system is provided either by boarding or by wind braces in the plane of the roof.

Recurrent carpentry details are recognizable in all the analysed roofs. In particular, the half laps are especially used at the diagonal crossing of in-plane continuous members. The dovetails and the birdsmouth joints are used when one of the two connected members terminates at the joint.

The roof framing of the Pieve in Cavalese consists of two alternating truss typologies (type A and B in Fig. 5). In truss type 'A', three horizontal straining beams connect the rafters at different levels, in order to reduce sagging or spreading of rafters. In addition, diagonal braces connect the lowest horizontal beams to the rafters. The truss type 'B' is a scissor truss. Horizontal beams are also present at two levels. Both truss types bear on the external walls as well as on longitudinal beams. The longitudinal members at the level of the hammer beams, as well as the other bracing longitudinal timbers, at the level of the collars, bear on a complementary transversal frame. Hence, between the series of the two trusses, one complementary frame, bearing on the wall plates and on timber pillars, is interposed (Fig. 6).

The cross-sectional dimension of the members is especially determined by the presence of timbers in compression and lap joints. A two-layer diagonal boarding braces the roof in its plane.
The connections are traditional carpentry joints reinforced by steel connectors (double-threaded screws), in order to maintain the functionality of the joint in adverse and unpredictable conditions, as well as to avoid splitting along the grain in lapped joints.

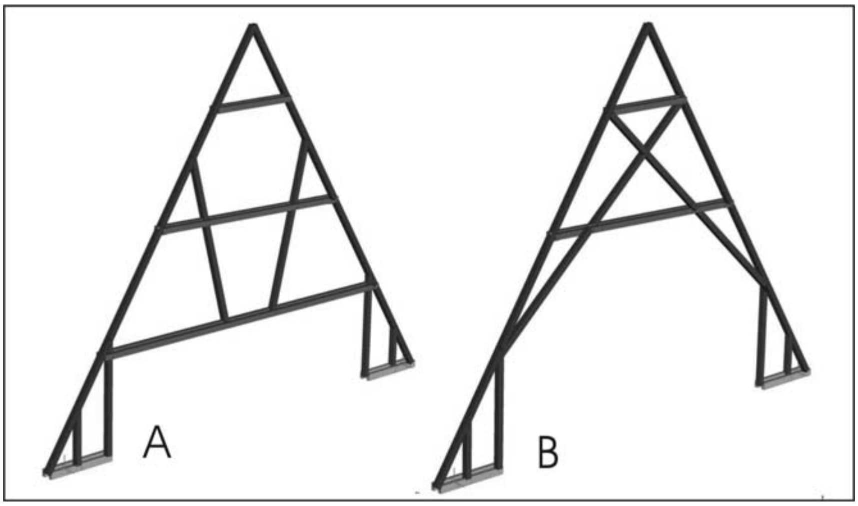

Figure 5 : The “Pieve” in Cavalese. The two truss typologies.

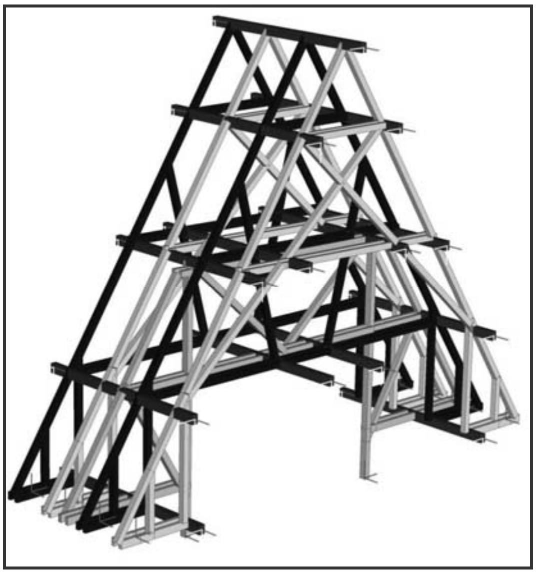

Figure 6 : The “Pieve” in Cavalese. The roof framing ‘modules’.

2.3 The structural design

In this work, reconstruction has been performed conforming to the theoretical original structural behaviour as well as according to the modern scientific and technological achievements and standards.

At this purpose geometry and mechanical behaviour of the roof structures at the different scales have been modelled.

The material used for the new trusses is ‘duo-glued wood’, which can be considered and graded as massive wood, according to the standard DIN 1052 (1998). In particular the same species of the original timbers, that is Larch (*Larix decidua* Mill.), as proven by the dendrochronological analysis, has been used.

Timber has been modelled as linear elastic. The mechanical characteristics of the material are reported in Table 1.

Table 1 : Mechanical properties of Larch wood (*Larix decidua Mill.*)
(softwood, strength class S13 according to DIN 1052-1 / A1)

Allowable stress	Direction	(MPa)
Bending	// fibres	13.0
Compression	// fibres	11.0
Tension	// fibres	9.0
Compression	⊥ fibres	2.0
Tension	⊥ fibres	0.05
Shear	// fibres	0.9
Shear	⊥ fibres	0.9
Torsion		1.0
Young modulus	E//	10500
Shear modulus	G	500

As regards the loading conditions, self-weight loads are automatically computed in the model, given the density of the material equal to W = 600 kg/m^3 (according to the value assumed by Italian standard). The dead loads of the roofing are due to the contribution of boarding, sheathing and shakes. Altogether the unit weight is equal to Q = 431.64 N/m^2.

Roof loading by snow has been determined according to the national and European codes: the resulting magnitude of the basic snow loads, depending to the geographical location and the height above sea level, is rather high (more than 5 kN/m^2). Moreover, extra loads caused by snow sliding down the pitched roofs on to snow guards must be considered, thus resulting in an average magnitude of snow loads higher than 7 kN/m^2.

The static equivalent pressure, used in the determination of wind loads is calculated as follow:

$$p_v = q_{ref}\, c_e c_p c_d = p_v(h) \tag{1}$$

with the maximum and minimum value, respectively equal to p_v ($h_{\min}$ = 8.0 m) / c_p = 1110 N/m^2 and p_v ($h_{\max}$ = 21.2 m) / c_p = 1617 N/m^2.

Shapes coefficient for leeward slopes is constant, while for windward slopes they vary, depending on the roof pitch.

Combinations of negative and positive wind pressure and snow loads on two or three slopes have been considered. Moreover a limit state has been considered for a condition of negative wind pressure and reduced dead loads, in order to check the behaviour of roof connections and roof-to-wall connections towards uplift loads.

Figure 7 shows the results of the analysis, as regards normal, bending and shear. The reported results highlight the importance of 3D analyses for the study of complex timber structures. Indeed it is shown the state of stress of two trusses, typologically identical but in two different positions in the roof (either adjacent to the transversal bearing frame, or at ca. 1,00 m. from it). The stiffness of the trusses supports varies along the span of the longitudinal beams and of course is higher at the transversal frame, where the beams rest. Therefore, the resulting stress distribution couldn't be highlighted by the 2D analysis of a single truss.

The value of shear stresses is punctually higher (approx. 6÷8%) than the allowable stresses. However, the latter can be up 25% for a load condition that considers wind loads (according to DIN 1052 standard), thus satisfying the strength verification. For all other normal stresses parallel to the grain, the values in each element are sufficiently small: this is clearly the consequence of the particular typologies of carpentry joints adopted

Detail verifications have been performed to check the behaviour of connections, as well as of critical point of the structure. The results of this checks guided some peculiar design choices, in particular in order to control the load path along the members and to avoid dangerous structural faults.

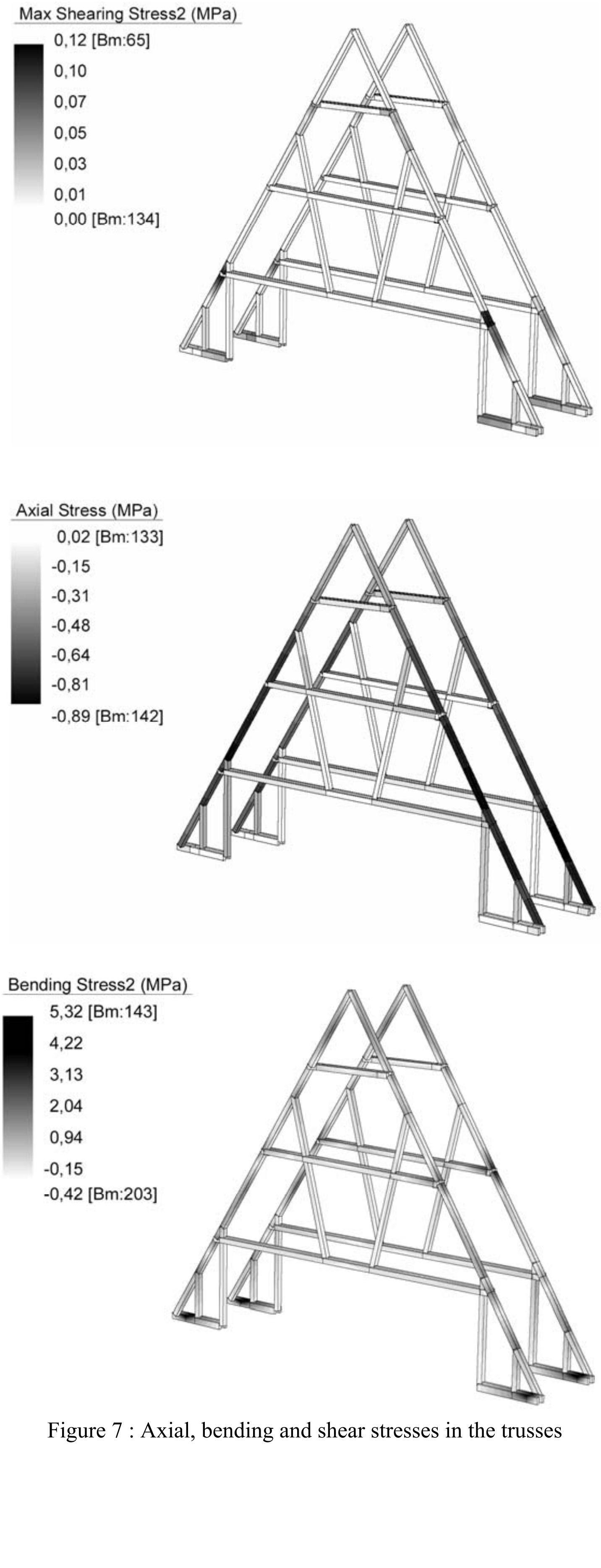

Figure 7 : Axial, bending and shear stresses in the trusses

3 CONCLUSIONS

The design choices in the case of the complete destruction of an ancient artefact depend on the importance of the artefact itself. The availability of material and documental evidence represent an important precondition to carry out reconstruction according to the Venice Charter. Nevertheless in the event that other sources of information are lacking, some aid is provided by the typological analysis of similar artefacts. The typological study has to be coupled with the structural analysis, as well as with all the other methods adopted in the acquaintance phase, in order to provide a scientifically based reconstruction.

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