Advanced Materials Research Vols. 133-134 (2010) pp 1107-1112
© (2010) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.133-134.1107

"Respecting the Diversity" The Timber Roof of the "Cannons Loggia" in the Thun Castle (Italy)

MASSARI Giovanna A.[1, a], RIGGIO Mariapaola[2, b] and GADOTTI Francesco[3, c]

[1]Dep. Civil and Environment Engineering (DICA), University of Trento, Trento, Italy

[2]Dep. Mechanical and Structural Engineering (DIMS), University of Trento, Trento, Italy

[3]Ma.de. Srl, Trento, Italy

[a]giovanna.massari@ing.unitn.it, [b]mariapaola.riggio@unitn.it, [c]francesco.gadotti@made2008.it

Abstract Historical timber structures can be considered a paradigm of the "diversity", which characterizes each individual artefact or part of it and represents a mark of heritage authenticity. In this paper, the term "diversity" indicates both the "variability" of the structure at its different hierarchical levels, and the "variation" in the typological form. Recognising, capturing and interpreting these peculiarities have been a main task, in the restoration of a timber roof in the Thun Castle (Trentino, Italy). After an exceptional snowfall the roof over the Cannons Loggia partially collapsed. In order to properly investigate the causes of the damages occurred to the structure and provide the necessary information for the intervention planning, a throughout investigation campaign was carried out. The adopted approach to repair aims at respecting the roof "diversity", which is at the same time the mark of its originality and the cause of its deficiencies, relying on reversible and minimal interventions.

Keywords: Historical timber structure, integrated survey, NDT of wood, strengthening techniques

Introduction

Historical timber structures can be considered a paradigm of the "diversity", which characterizes each individual artefact or part of it and represents a mark of heritage authenticity, according to the Nara Document (1994). The authenticity of a timber load bearing structure can be identified with its original configuration, the material used, the assembly made by the carpenters, the past strengthening work, but, also with the alterations and changes that were and still are consistent with the structure. In the restoration of a timber roof in the Thun Castle (Trentino, Italy), recognising, recording and interpreting all the peculiarities, which identify and distinguish the artefact, have been a main task.

In winter 2009, an exceptional snowfall caused the partial collapse of the roof over the "Loggiato dei Cannoni" (Cannons Loggia). A comprehensive survey of the condition of the structure had been exigently carried out, in order to highlight any contingent vulnerability. The adopted surveying and diagnostic methodologies aimed at identifying the structure at the different hierarchical levels: from each individual unit and connection between different units, to the structural system (truss) and complex (roof). Geometrical and material variability has been recorded in details. For this purpose, different techniques have been adopted and integrated.

On the basis of the investigation results, the diagnosis of failure and the safety evaluation were performed, followed by the design of the strengthening intervention.

Historical Background

The Thun Castle (Fig. 1) is one of the most noteworthy residential monuments in the Trentino province and is also the result of a series of architectural interventions that have occurred over the course of time (Botteri Ottaviani et al. 2007). In the 12th century, the Tono family erected a gothic castle on the ruins of the ancient castrum Novesini, close to the Ton village. After a ruinous fire in 1528, the building was converted from medieval fortress in a more modern and comfortable

Renaissance dwelling. The two internal curtain walls between the outer and the inner ward, separated by a ditch, date back to this period (Fig. 2, Fig. 3). The “escutcheon door” (porta blasonata -1541-), the entrance to the innermost wall, introduces to the Portico or “Loggia dei Cannoni”, used to shelter the cannons. In the 17th and 18th centuries several improvements to the setting at the castle were made. There followed years of neglect and dereliction. In 1926 the castle was sold to a member of the Bohemian branch of the Thun family, Franz Thun Hohenstein, who is responsible of many interventions in the building, and probably, also of the erection of the new timber roof of the Loggia. As he stated in a interview, in 1929, he directed the building works without the aid of architect or engineer, but just with the help of a craftsman (Guatelli 1929). These works were to be the last major rebuilding at Thun Castle, until a series of phased conservation programmes were carried out from the 1990s onwards, when the castle was taken over by the Trento Province. In winter 2009, an exceptional snowfall caused the partial collapse of the roof over the Loggia. Provisional security frames were immediately erected, in order to shore up the trusses. Consequently, an accurate investigation campaign was undertaken with the aim of providing the necessary information for the intervention planning.

Figure 1: Thun Castle (aerial view)

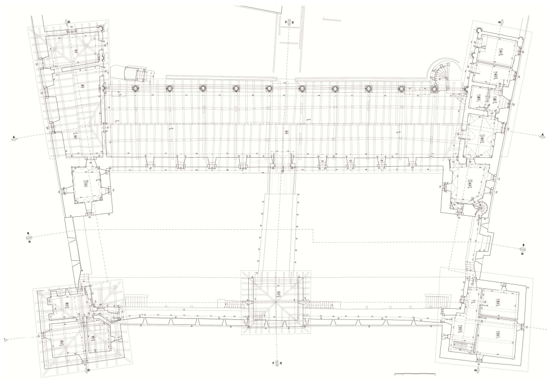

Figure 2: Walls, flanking towers and Loggia (plan)

Geometric and Static Features of the Portico’s Roof

The architecture of the "Loggia" corresponds to the military and defensive character of the fabric: there is no room for ornamentation. The colonnade is composed by ten unfluted stone columns and two engaged columns at the end, which rest on a rustic stone basement and bear a wooden architrave. The wood roofing system consists of ten timber trusses spaced at the mean distance of 4.10 m and spanning 8.50 m. The principal rafters support one purlin at each slope. The trusses rest on the one side on the wooden architrave, on the other side, directly on the masonry wall, without the interposition of wall plates. Tie beams are tenoned to the architrave plates. The rafters are connected to the tie beam and to the post with plain butt joints assembled with nails; some rudimental birdsmouth joints are also present, but in most cases the abutment is insufficient to let the joint properly work (Fig. 4). The lower end of the post is tenoned to the tie beam; iron straps are occasionally present.

The overall geometry of the roofing system is rather irregular. The trusses exhibit prominent out-of plane and asymmetry. Supplementary elements (boards) were originally added, in order to even the different heights of the principal elements.

The geometric survey of the Loggia’s roof was carried out in two months, immediately after the erection of the provisional frames. This phase, performed in emergency condition, has continued and deepened a previous survey campaign, carried out on the whole northern wall complex of the Castle.

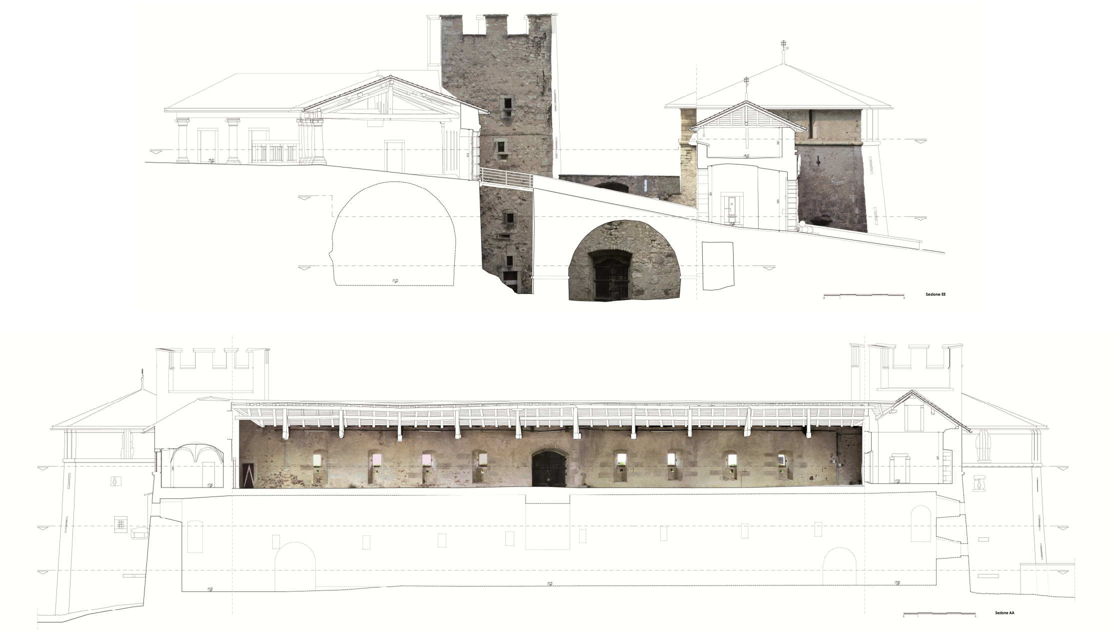

Figure 3: Transversal and longitudinal section of the walls, the flanking towers and the Loggia

The spatial configuration of the timber elements and of the columns has been determined through a thick topographic mesh, associated with the topographic polygon of the whole wall complex (laser station Topcon GPT 1001, Software Geopro Meridiana). 2D photogrammetric methods have been applied to obtain the metric rectification of the digital pictures and the photo-mosaic of each front of the ten trusses and of the zenithal view of the roof boarding (semi-metric camera Rollei 6008, software Geopro Photometric). The rectified images have then been used for a high-definition representation of both the geometric and textural features of the elements (Fig. 5). In order to assess the actual geometry of each joint and record the contingent variation of dimension and shape of the transverse section, which has to be taken into account in calculation, a traditional direct survey was carried out on each element (Fig. 4). The present profile of elements has been assessed, considering the inherent variability of timber. Deformations have been analyzed distinguishing those load-related from those due to creep, as well as from the irregular constructive profiles.

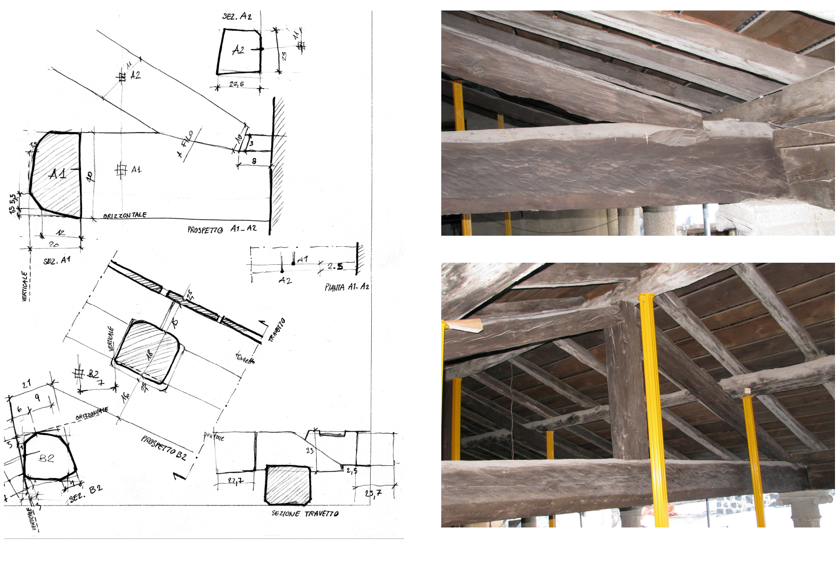

Figure 4: Truss T03 - Sketches on site and photographs

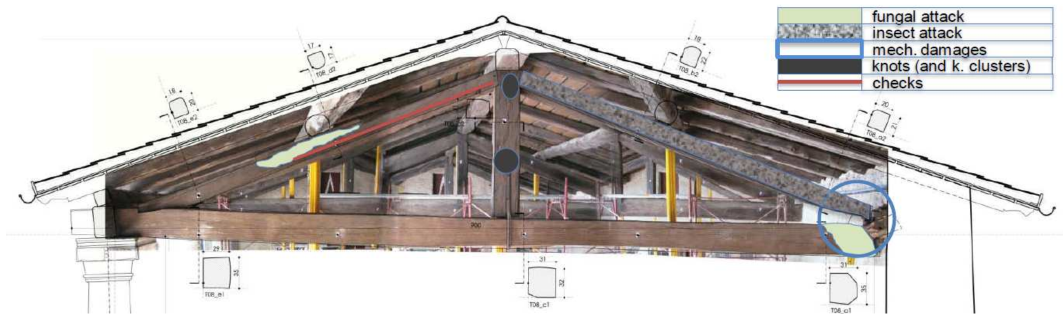

Figure 5: Thematic map –Truss T08-front east

CASTEL THUN
Vigo di Ton, Provincia di Trento

Timber trusses of the "Loggiato dei Cannoni"

Truss	N.1
Tie beam	

Visual inspection report

	Biotic attack	fungi	local
		insects	present (House longhorn beetle) on intradox and west face locally, depth > 4 cm
	Defects	Knots	Group of knots at the joint with rafter E2 and at the extradox
		splits	Present, max depth 7 cm on the west face
	Damage		
	other	Slope of grain 1:14	
	MC	average: 17 [%]	

NDT

Pilodyn	17 ÷ 19.5 mm

Resistograph	Date	Profile N.	from	Direction	Position [cm]	R_{ML} [%]	C_{dif} [%]
	26.03.09	prof038	west	horizontal	70 (from joint C1-E2)	314.83	-0.06

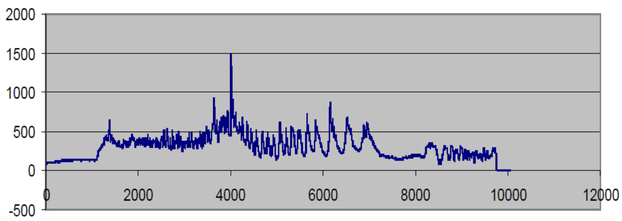

Figure 6: Thematic fiches T01

The Timber Material

Data recorded during the inspection of the roof have been organized in thematic maps and fiches, for the structural system and each member (Fig. 5, Fig. 6). The wooden species deduced through macroscopic analysis (UNI 11118:2004) are local spruce (Picea Abies Karst.) and larch (Larix decidua Mill.). Workmanship quality has been analyzed, being one of the most important parameters defining the "uniqueness" and "diversity" of the timber construction. Indeed, it influences both the technological characteristics of timber and the aesthetical connotation of the artifact. The timbers of the portico roof consist of logs mainly hewn and reduced in roughly square section, or alternatively, simply cleft and split in half. Economical reasons could have affected the mentioned technical choices, as well as that of using second-hand timbers. The effects of the roof workmanship on the quality of the timber material are manifold and in some cases opposite. For instance, the use of axe, on the one hand, permitted to shape the timber in accordance to the natural grain, on the other hand, left large portions of sapwood, which is more vulnerable to biotic attack.

Environmental conditions also have influenced the preservation state of the wood material. The thermo-hygrometric environment of the roof, and the consequent hygrometric state of the timber (EN 13183-2:2002) were identified. The roof timber has been assigned to the "hazard Class 2" (EN 335-1:1987); indeed, even if covered, some elements were locally wet (moisture content >20%, measured with the resistance method) and/or exhibited discoloration and stains caused by wetting. Fungal attack was identified only in limited areas, while sapwood portions were generally infested by insects (Anobium punctatum -Furniture beetle- and Hylotrupes bajulus - House longhorn beetle).

In order to map decay on the elements surface, dynamic indentation tests (Pilodyn®) were carried out along each member. The highlighted decayed areas were more deeply investigated by means of resistance drilling tests (IML Resi B 1410®). The integral of the drill resistance function divided by

the penetration length was used to give an objective interpretation of the tests. Residual cross sections have been estimated through qualitative analysis of profiles.

Local mechanical damages were found, where decay already reduced the resistance of the material. In winter 2009, the high and protracted snow load on the northern pitch caused the rupture of the tie beam in a truss, at the interface with masonry, where rot already reduced the resistance of the connection (Fig. 5). Failure propagated with the displacement of the truss members and the degradation of the connections.The connection of the trusses to the bearing wall is one of the most crucial points of the whole roof system, as evidenced by past repairs.

Diagnosis, Safety Evaluation and Design of the Intervention

Data collected during the investigation campaign were used for the analysis of the trusses. Geometrical variability was taken into account, even with the necessary simplification, in the 2D FEM models. Safety check of the joints was carried out considering the actual geometry of the connection. Mechanical material properties were assumed by visual strength grading (EN 338:2004). The Italian standard D.M.LL.PP. 14.01.2008 introduces a reduction factor FC>1 for material strength, which depends on the reliability of data about the structure. In the calculation it was assumed FC= 1.2.

The basic form of the truss used in the Loggia is the king-post truss without struts, which is more appropriate for small spans. The structural form and the presence of poorly proportioned members resulted in large deflection. Deformations, breaks and kinematic movements are also consequent to the incorrect execution of the joints, which produced a not homogeneous distribution of the stresses. Discoloration on timbers and local wet areas are evidence of localized hollow of the pitches with stagnation of rainwater. The lack of templates and wall plates and the eccentricity of the joint connecting the rafter and the tie beam caused the presence of shear stress at the tie beam tail, between the joint and the wall and bending stresses on the masonry wall. This stress state is particular dangerous, especially if coupled with the decay of the eaves, due to moisture stagnation in the built-in portions of the tie beams. The truss failure was caused by a combination of these factors. The outward thrust produced by the roof, after the tie beam failure, caused the southern support to spread. Kinematic movements have been developed also in the adjacent structural systems.

The structure's history of problems, engineering analysis, and experienced observation of the trusses indicated that they were over stressed by their own dead load and that merely repairing damaged members and restoring the roof to as-built condition would not be a remedy. In this case the problem was to strengthen the structure so that it could be able to carry loads safely and without further distress. This could be done seeking to make the existing structural arrangement work or changing the structure to one that would work better. The latter approach, however, raises a basic problem in the philosophy of repair: is it legitimate the alteration of the original static configuration? Does this type of repair compromise the authenticity of the artifact?

In this case the most satisfactory approach to repair was to change the structural behaviour to the more normal sequence of load transfer, by introducing punctual and reversible elements, which could be at the same time compatible with and distinguishable from the original structure. Steel templates with neoprene pads have been designed to center the load from the northern joint and transfer it to masonry. Teflon plates at the interface between tie beam and column provide a roller at the southern support. The reinforcement of the two heel joints have been designed so that axial forces are transmitted from the rafter to the head of a steel plate inserted into the tie beam end and then from the plate to the tie beam by means of bolts (Fig. 7). The addition of timber struts propping the rafters, directly under the purlins, avoid bending into the principals. Substitution of members has been proposed only for those elements that were severely and extensively degraded.

Final Notes

The investigation highlighted the structural singularity of a neglected part in a vast monumental complex. The workmanship quality and the design of the structural system, on the one hand, mark the

artifact and connote its character, on the other hand, produced negative consequences for the building standing. The multiscale and integrated survey allowed detailed analysis at the different scales of the building, highlighting singularities in the structure and avoiding mystifying simplifications.

The necessity of both preserving and reinforcing the original structure motivated the designed repairs, which are based on issues of reversibility and minimal interventions.

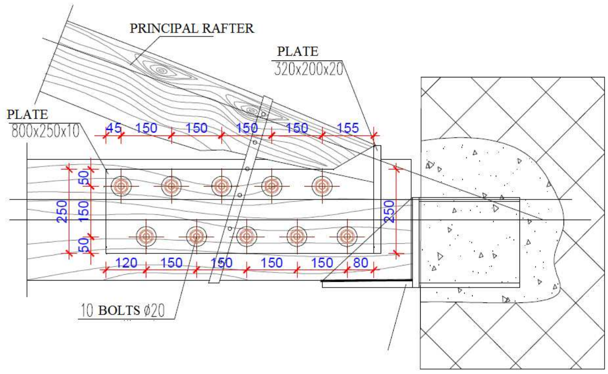

Figure 7: Strengthening of the birdsmouth joint and of the connection with the masonry wall

Acknowledgements

The authors wish to acknowledge the "Soprintendenza per i Beni Architettonici P.A.T." (S. Flaim, M. Cunaccia, M. Favero, V. Barbacovi) and "Museo del Castello del Buonconsiglio, Monumenti e Collezioni Provinciali". The first author, coordinator of the scientific group responsible of the geometric survey, is grateful to M.C. Bonora, F. Luce, C. Pellegatta and K. Svaldi. She also thanks F. Avanza and L. Mattei for their help during on site survey. The second author wishes to thank the DIMS Lab. University of Trento. She was supported by the P.A.T., with the post-doc fellowship titled "DIGITIMBER (DIGItal technologies in TIMBEr Restoration)".

References

[1] (1994) The Nara Document on Authenticity. Nara, Japan, 1-6 November. [Online]. Available: http://www.international.icomos.org/naradoc_eng.htm
[2] Botteri Ottaviani, M, Dal Prà, L and Mich E (2007). *"Arte e potere dinastico. Le raccolte di Castel Thun dal XVI al XIX secolo."* Provincia Autonoma di Trento
[3] *D.M.LL.PP. 14.01.2008. Norme tecniche per le costruzioni*, G.U. Repubblica Italiana, n. 29 4.2.2008, Suppl. Ord. n. 30, 2008.
[4] *EN 13183-2. Moisture content of a piece of sawn timber - Part 2: Estimation by electrical resistance method*. European Committee for Standardization. Brussels, 2002.
[5] *EN 335-1. Durability of wood and wood-based products - Definition of hazard classes of biological attack - Part1: General.* European Committee for Standardization. Brussels, 1987.
[6] *EN 338. Structural timber - Strength classes.* European Committee for Standardization. Brussels, 2003.
[7] Guatelli, E (1929). "Il castello di Thun." *La lettura* XXIX N.8, 1 August 1929
[8] *UNI 11035-1. Structural timber. Visual strength grading: terminology and measurement* of features. UNI, Milano, 2003.
[9] *UNI 11118. Cultural heritage - Wooden artefacts - Criteria for the identification of the wood species*. UNI, Milano, 2004
[10] *UNI 11119. Cultural Heritage - Wooden artifacts – Load-bearing structures – On site inspections for the diagnosis of timber members.* UNI, Milano, 2004.
[11] *UNI 11138. Cultural heritage - Wooden artefacts - Building load bearing structures - Criteria for the preliminary evaluation, the design and the execution of works.* UNI, Milano, 2004.