The Historic Timber Roof of "Giordano's Warehouse" in Vallombrosa: Design, Story and Collapse

Marco Togni *, Luca Uzielli*, Nicola Venturi *, Alberto Bronzi **
DISTAF – Department of Forest Environmental Sciences and Technologies, Firenze *, CFS – *Corpo Forestale dello Stato*, Firenze**

1. Introduction
1.1 Vallombrosa forest

Since 1869, the publicly-owned Vallombrosa forest (Demanio – State Forest Administration) situated at 1000m above sea level and about 40km far from Florence, hosted the first School of Forestry in Italy: the *Regio Istituto forestale of Vallombrosa*. 45 years later the school relocated in Florence and the forest has been used since then to the present day only as a fine location for practical training in forestry.

1.2 The sawmill

The sawmill, located in Vallombrosa, suffered damage during the Second World War; at the end of the war, after the sawmill rebuilding, the Forest Administration decided to erect a warehouse for sawn timber nearby. The first project was not completed, principally for the lack of money. Then, Prof. Guglielmo Giordano[1] was delegated to design the roof of the warehouse close to the sawmill.

1.3 The commission

In the Fifties Prof. Giordano was already Professor of Wood technology in Florence University and a well known researcher in wood science. After some temporary collaboration with the Administration of Vallombrosa forests, he accepted to design the roof.

His knowledge about wood technology and about forestry, as well as the historical and didactic context of Vallombrosa were considered some important reasons for giving him the mandate to design the timber roof of the new structure. In fact, from a document of that time we know that "[the construction] *will give notions about new technical orientation in timber building, and it will be particularly useful for didactic reasons, which are one of the main functions of the public forest*".

Nevertheless, a further reason for utilizing wood was the cost, lower than other structural materials.

---

[1] Prof. Guglielmo Giordano (Margarita, 1904 – Florence, 2000), father of Wood Technology in Italy, has been professor of wood technology at the University of Florence from 1946/47 to 1980. Thereafter he taught in other Italian Universities for five years. In 1954 he founded the National Institute for Wood Research–CNR, which has been headed by him until 1974 (age limit). He was one of the most important authorities in the field of wood science and a man of internationally proven skill. He wrote several works, reports and papers (more than 200) for specialized magazines and journals and some expert references for encyclopedias and other important collective publications.

2. Design and realization

Prof. G. Giordano, engaged with the accomplishment of the structure, designed the roof starting from the existing columns, made of brick and stone, due to a former attempt of construction, interrupted by a lack of funding. The surface to be covered was 12x18m, and there were 12 columns.
Some of Giordano's purposes for the design are well known [Giordano, 1964]:
- to increase maximum headroom: trucks needed to be driven into the warehouse but columns were only 3m in height,
- to prepare lumbers to be connected to each other in a simple way and to assemble the joints on site,
- to have a good pitch for better removal of snow.

We can hypothesize some other intentions of his:
- to present an innovative way of using wood, for that period in Italy,
- to consume a small volume of timber and short lumbers, for cost reasons.

Prof. Giordano designed a roof whose principal frame was composed of six timber scissors trusses. They were conceived as lattice trusses, using timber elements as short as possible and to be built on site, by local unspecialized workmen (except one carpenter). The span between supports was 11.4m, the total height of the truss was 3.5m. The scissors shape allowed gaining 1.2m more free space, in the centre of the shelter under the structure, and to obtain a roof with two pitches.

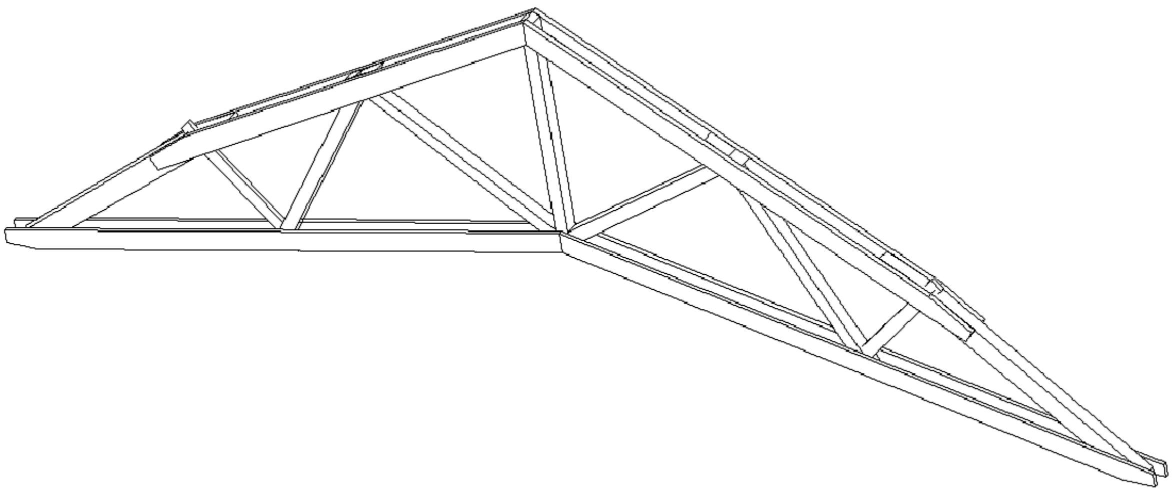

Figure 1.A 3D view of the simplified truss (planks covering some joints are omitted).

The timber used was fir (*Abies alba* Mill.). The felling of trees and the destruction of the forest during the war, together with the difficulties of the sawmill, obliged the Administration to request the sawn timber from Abetone Forest, also property of the Demanio in Tuscany. The request for timber supply was "sawn timber of the first grade[2]". Although the definition of the grade for structural timber did not benefit from the current knowledge, it resulted from the multitude of researches of the last 50 years in regard to properties of the timber for structure, and the correct approach to the incoming "visual strength grading" was already present.
The timber working stress design[3] applied was 80 kg/cm², while the first grade of fir was 110. This value was a mean value between 2nd and 3rd grade. We suppose that Prof. Giordano, not sure about the quality of the timber supplied, chose a safety margin value

[2] Timber for structure , definition of the first grade [Giordano, 1964, Giordano *et al.*, 1999]: "Sound timber without chromatic alteration, Insect attack or decay by fungi; resin pocket, reaction wood, ring shake and any other damage are not admissible. Timber must have regular grain, diameter of sound knots has to be smaller than 1/5 of the lowest dimension of the cross section, in any case no more than cm 5; in the most knotty zone, on the length of 15 cm, the sum of diameters of knots must be lesser than 2/5 the width of the cross section".
[3] The structure was planned with the allowable stress method.

for designing, for the reliability of the structure.

The main structural elements were engineered to join together large planks with rectangular cross section and squared beams, so that the joints were composed by 3 to 5 layers of lumbers. The main cross sections used were: 5x20cm, 4x18cm, 12x20cm, 12x12cm. Other thin boards (thickness from 2.5 to 5cm) were used to coat some joints, distributing the loads. The longest timber members were the four planks composing the bottom chord whose length were less than 6 m.

The connections were joined with simple nails, 100 e 120mm long. To simplify assembly, Prof. Giordano prepared a rigid template for each joint, in which the holes necessary to place the nails in the correct number and position were punched.
Where the load was too high, a T shaped iron was added, inserted in mortise and kept in place with bolts passing through the lumber's thickness. Where the planks were too much weakened by the mortises, a synthetic resin was spread on the contact surfaces of the timber elements before joining, to reinforce the joint.

Each truss was composed of 17 principal elements, plus other shorter ones to be used to fill the gap between some planks, and by 10 joints. Each joint was identified and marked with a letter. Some data are presented briefly in table n. 1.

The data shows the critical nodes could be the central ones, "D" and "N", due to the highest number of timber members which were concurrent, and the high number of nails and T irons, for the high load to be transferred.

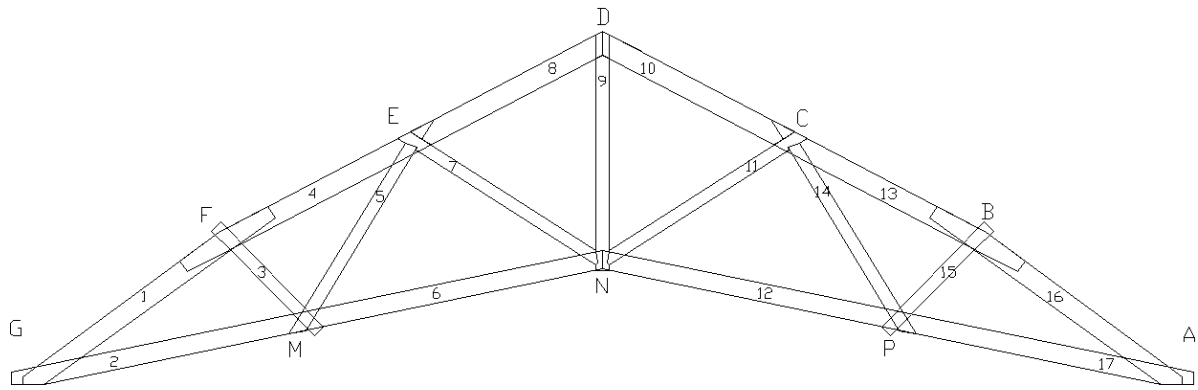

Figure 2. The truss with the labels of the joints and the timber members, as proposed by Giordano.

Joint	Symmetry	Planks coating joint	N. of structural elements concurrent	N. of nails	N. of T irons (and bolts)
heel joints					
A	as G	X	3	15 x 2	2 (1)
G	as A	X	3	15 x 2	2 (1)
on top chord					
B	as F	-	4	13 x 2	4 (2)
C	as E	-	4	11 x 2	-
D	-	X	5	12 x 2 (plus 20 x 2 for filling planks)	-
E	as C	-	4	11 x 2	-
F	as B	-	4	5 plus 8 x 2	4 (2)
on bottom chord					
M	as P	-	4	5 plus 6 x 2	-
N	-	X	7	23 x 2	4 (2)
P	as M	-	4	5 plus 6 x 2	-

Table1. Principal characteristics of joints.

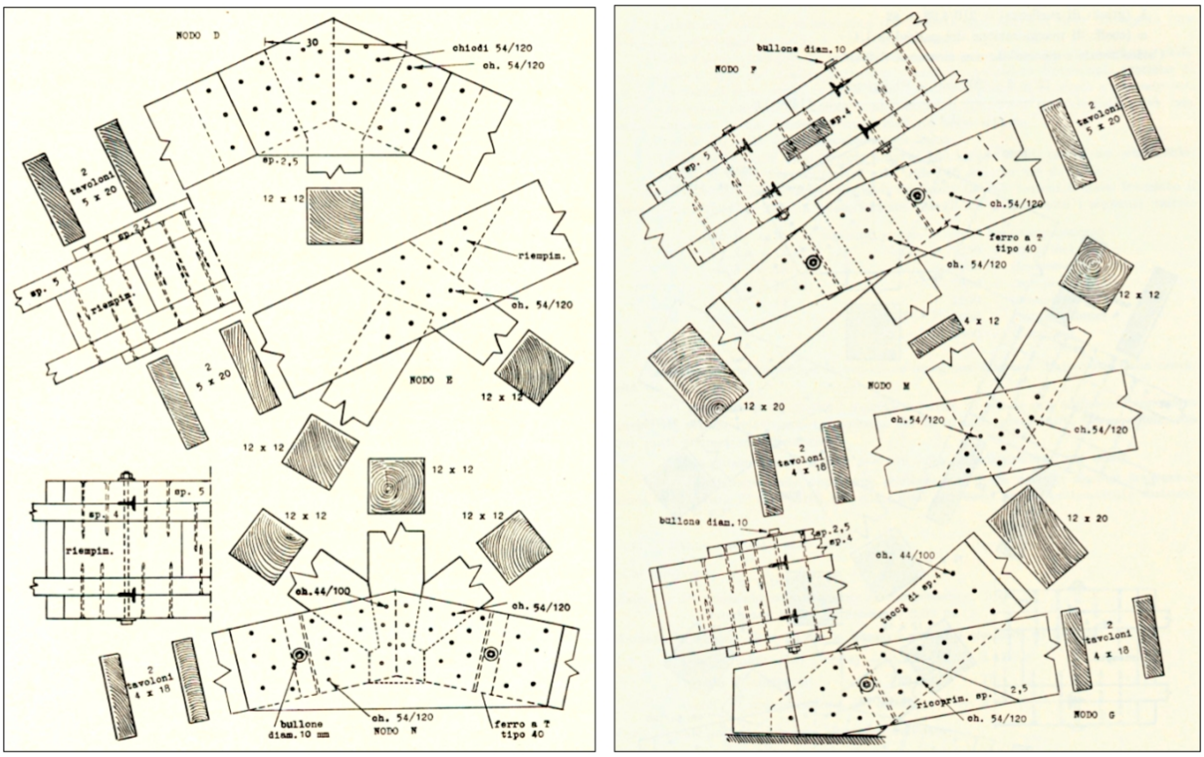

Figure 3. Original illustrations of the composition of nodes [Giordano, 1964, pp. 417-418].

Image 1. The warehouse in the Nineties. Damages on the first truss: the bottom chord was broken (left arrow), the joint "N" was severely disconnected with end tie rod badly decayed and bolts evidently bent (central

arrows). Roof was showing many holes.

The biotic protection was obtained using a chemical wood preservative, whose properties were not specified, to treat all the surfaces of the timber members.
After the data collection on the collapsed structure, the use of creosote oil as wood preservative has been supposed[4], due to the coloration of the timber member and the residual smell. It is important to remark that one half truss, close to the end wall, was not treated with any wood preservative and its timber elements were in perfectly sound conservation conditions.

The shelter was completed by other smaller elements necessary to realise the roof framework (joists, planks and so on, to keep the roof-tiles in place). The wind braces were used to connect the trusses, joining the contiguous chords and king-posts by planks nailed obliquely.

During the construction of the roof some uncertainty about the stability of the columns was detected, so it was decided to reinforce the columns at the four angles of the structure. The strengthening consisted of a concrete course all around the pillar.
For other design properties see Giordano, 1964 (Chapter VI).

3. Lifetime and decay

In 54 years many events characterised the service lifetime of the warehouse and some of them had repercussions on the structure.
The information listed here has been achieved directly observing the rubble, collecting data, collecting timber members and joints, and indirectly through the observation of some relevant snapshots of CFS.

3.1 Strengthening

In the Sixties some doubts about the stability of the columns pushed to reinforce the remaining 8 supports which were in the original shape. The operation consisted in a concrete reinforcement, like the first one dated 1952: the stone/brick part of the columns resulted partially enclosed by concrete. The new layer was thicker on the outer edge at the stand of the shaft, than at the top, to compensate an eventual thrust of the truss (outwards) and to enlarge the base of the column for stability.

3.2 Damage

Impact of a truck damaged the lowest part of the first truss: the bottom chord was hurt and partially broken. Other similar events were not remarkable and they were not reported in archives [AAVV].
The long exposition to weathering caused some disconnection and also some holes in the roofing, made by hip-tiles[5] (Image n.1). Water came through the holes and wetted the timber; in particular the inner part of the connection which, without ventilation, held the moisture for an extended time.
The covering between the first and the second trusses was the most full of holes (probably due to the direct exposition to the hard wind, blowing from below upwards).
The recurrent wet condition, as well as decay (see below), was proved by the patina of green algae (Images n.2 and 3): on some lumbers the biofilm was grown on a trickling line, revealing the presence of water[6], time after time.

---

[4] None chemical analysis has been done.
[5] That sort of covering needs continuous maintenance, to readjust the probable disconnection of the tiles in order to avoid the possibility of water percolation.
[6] Commonly the optimum for algae is UR= 95-100% and T=20-30°C, but a substrate with high MC is also required [Tommaselli e Petrini, 2005].

Images 2-3. The warehouse in the nineties. The green biofilm is present and visible on the roofing, on two columns (image 2, white arrow) and on the plank converging on joint named "N" of the second truss (image 2, white arrows).

3.3 Decay by wood-rotting fungi

The frequent percolation of water from the roof, particularly on the first and second trusses, and the direct exposure to windy rain of the first truss[7], procured the conditions suitable for the growth and the attack of fungi. The most significant decay was due to brown-rot fungi, Basidiomycetes. The treatment of the surface of the timber was not enough to prevent the action of rot fungi, when the moisture and temperature conditions were favourable.

Among the wet zones, the retaining water and insufficiently ventilated parts were the most decayed (connections, wood close to column supports). A contribution to the low ventilation of the heel joints was introduced by the layer of concrete covering the shafts.

Some results of the decay were easily visible on the structure: several rusty nails were partially exposed because of the complete decay of wood around them; after the collapse they were found on the ground floor, rusty, straight and in the original position, without any hint of deformation, to indicate they didn't work.

3.4 Insect attack

Some different galleries due to wood boring insects were found on the timber rubble, overlapped to the wood decay or by themselves.

The holes and galleries of the insect *Hylotrupes bajulus* L.[8], were quite diffused: some intense damage was found on the sapwood, in the external portion of fir beams. These insect attacks, observed directly on the timber, were surely ended: the bore-dust was dark yellow, which means old and oxidized powder.

In a few points of the structure ant attacks have been found (*Formicidae* Family), concentrated in some timber elements. Usually this kind of insect damage does not have a detrimental effect on the whole structure [Bonamini *et al.*, 2001].

Holes of *Anobiidae* were present, principally on the wood already decayed by fungi. From the dimension of the holes and the presence of fungal decay, the presence of the insect *Xestobium rufovillosum* DeGeer ("death watch beetle"), [Gambetta, 2004] has been

[7] The front side of the warehouse, close to the first truss, was entirely open, without portals.

[8] "House longhorn beetle" also called "old-house borer" is a species of wood-boring insect of the family *Cerambycidae*. This beetle prefers sapwood of recently (despite one of its names) felled softwood [Ridout, 2000]. Usually the main damages on timber structures could occur during the firsts decades after the construction [Gambetta, 2004].

supposed, although the presence of another Anobiidae species may not be excluded.

3.5 Alteration of static configuration

The coating of the columns, surrounding the original stone/brick structure with a layer of concrete, achieved with the standing roof, modified the support of the trusses, from the original isostatic design to a partial reduction of the degrees of freedom.

3.6 Condition of conservation

To assess the exact conservation condition of the timber, a quest of all the joints present in the midst of the ruins has been performed. Each connection has been picked up, photographed, analysed and described. Many joints have been lost in the collapse. The kind of failures, the intensity of decay and the condition of the fasteners (nails and bolts) were the target of these descriptions. The results are summarized in table n.2.

Images 4–5. Joint "E" or "C" (left) and heel joint "A" or "G" (right), respectively ductile and brittle failures. Brown-rot decay was in the heart of heel connection ("A" or "G").

It was not possible to associate each joint to the original truss except for 4 decayed connections associated with the first two trusses, thanks to the position in the ruins and to some photos of the standing shelter. "Lost joints" have not been found, nor the parts of the connections which were dispersed and not re-collectable.

Name of connection	Joints surveyed	Joints decayed		Failure pattern		Joints lost	Decayed and lost
		rot fungi	insect	ductile or undamaged	brittle		
A – G	10	20%	0%	80%	20%	2	33%
B – F	10	10%	20%	90%	10%	2	33%
C – E	6	0%	0%	100%	0%	6	50%
D	5	20%	20%	80%	20%	1	33%
M – P	7	57%	14%	43%	57%	5	75%
N	5	40%	40%	60%	40%	1	50%
total	43	23%	14%	77%	23%	17	47%

Table 2. Synthetic report of the joints surveyed

4. Report of the collapse

The critical conditions occurred in the last part of the winter 2004-05, when the temperature lowered intensely. The meteorological conditions worsened from the end of

February, and there were frequent and copious snowfalls[9].
The high and protracted load of snow on the timber roof occasioned the first collapse: on March the 10th, during the night, the first truss crashed. The remains of the roof resisted for a few further days, then the whole structure collapsed.
Among the rests of the timber roof, four columns fell to the ground, and the top sides turned outside after a rotation of about 90°.
The ruins were handled for this study since the summer 2005.

The break-down of the first truss, consequently to the high and prolonged load, was principally due to the joint named "N", already strongly decayed and disconnected. The failure of the joint "N" let the truss fall down, splayed. The static alteration of the support modified the simply supported truss in a thrusting truss which found counter-thrust on the stability of the 2 columns. But the foundation of the columns[10] were not adequate to oppose the added load, so the columns rotated, leaving the truss splaying. The remains of the roof had the main weak point in the second truss: the hard decay of the same joint "N", together with the bad condition of other connections and the lack of co-operation of the columns, favoured the collapse of the structure.

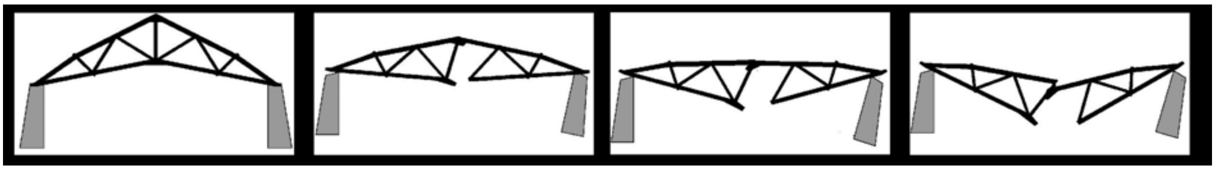

Figure 4. Simulation of the plausible hypothesis of collapse of the first truss.

The actual snow load causing the collapse has not been found by Authors, but some days after the last failure, the snow layer measured on the roof was about 40cm deep, that means a load from 100 to 260 kg/m² according to the characteristics of the snow (free water content). The long duration of the high load has been assumed as concurrent to the two collapses, according to DOL master curve[11].

5. Conclusion

The collapse of Giordano's timber roof was caused by several factors, here listed in decreasing order of severity:
- snow load and duration of load (DOL) were the actual external cause: the roof did not collapse for one particular event but for a prolonged high load, at least 10 days with more than 40cm snow depth;
- failure of the node "N" in tension was the main internal reason: bio-deterioration (brown-rot decay firstly) disconnected the joint;
- condition of conservation of other nodes (principally the heel joints and those on the bottom chords) contributed to the failure: general decay and some localized deterioration by fungi and/or insects were the cause;
- the inadequate foundation of the columns (well known in the Sixties, since the columns had been strengthened), did not help the trusses, due to the change of static configuration;
- the failure of the first truss, and of the related wind braces, destabilized the remaining trusses.

---

[9] Depth of snow recorded on the *snow bulletin of Vallombrosa Meteorological Station*: 1/03/05=60cm; 4-5/03/05=70cm (max value). The day after the collapse the depth of snow was 55cm [Uff. Idr. e Mar., 2005]
[10] After the collapse it has been possible to measure the foundation of the columns whose depth resulted 20-30cm only. The explanation for this occurrence has not been found.
[11] Duration Of Load curve, so-called Madison relationship, development of the research about creep behaviour [Wood, 1947]

Basically, bio-deterioration was the dominant factor and brown-rot fungi was the prevalent one. Traces of previous preservative treatments have been found, however they were not able to prevent biotic decay, because in some points the condition was extremely favourable to decay fungi. Nevertheless only a relative low percentage of connections was bio-deteriorated and just a few joints were severely decayed.

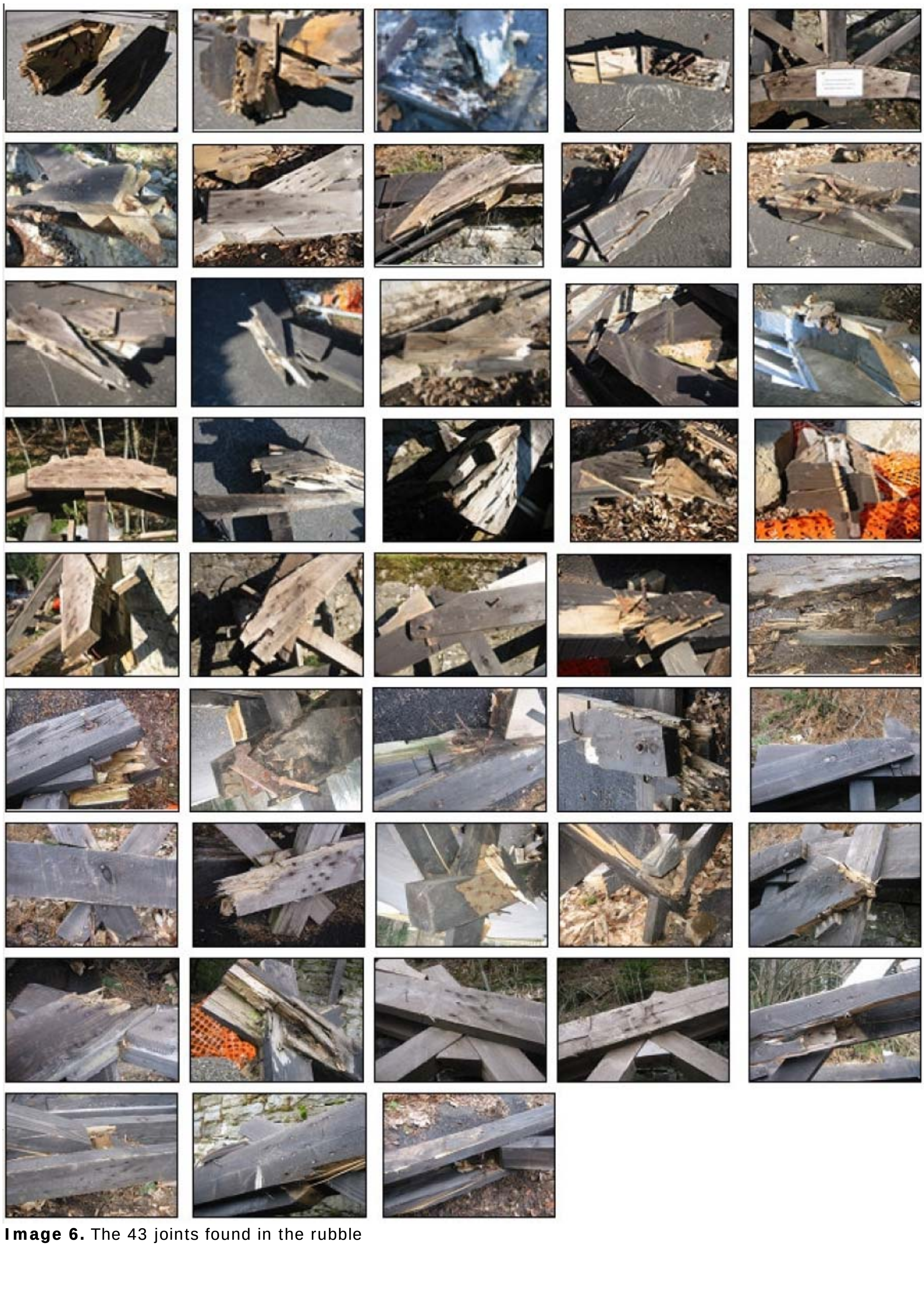

Image 6. The 43 joints found in the rubble


Images 7–8. The warehouse some days after the total collapse and the depth of the snow.


Images 9–10. The foundation of the 4 rotated columns, 20-30 cm deep, with no anchor, and the position of 8 columns remaining vertical (more or less) after the collapse, after removal of the timber.


Images 11–12. Comparison between two symbolic instants of the shelter life: the first truss erected, reproduced in an original photo, dated 1952, and the warehouse without the first truss, collapsed under the snow load, in 2005.

The lack of maintenance of the last decades produced these conditions and consecutively a slow decline, until the events of 2005 (information about the maintenance operations of

the first period has not been found).
A continuous maintenance action would have been necessary first of all; secondly some ordinary repair actions would have been effective, in order to keep water away and to prevent the collapse.

The project

Some joints and one complete truss, although split in three parts because of the collapse, have been preserved from demolition, and conserved in an airy and sheltered area. There is a plan, thanks to the interest of CFS, for actualising the wide project of a museum of forestry in the Vallombrosa location, in which the reproduction of Giordano's roof will find the expected place and role.

Acknowledgements

The research has been performed with the help of the CFS (Corpo Forestale dello Stato). Authors wish to thank the whole personnel of CFS in Vallombrosa, particularly Dr Giovanni Galipò for his fundamental support.

Bibliographical References:

- AAVV – Documents, notes, planes, relation from archives in Reggello Municipality (Florence)
- Bonamini G., Noferi M., Togni M., Uzielli L. 2001, - *Manuale del legno strutturale - Ispezione e diagnosi in opera* - Mancosu, Roma
- Gambetta A., 2004, – *Analisi e trattamenti curativi – Difesa dagli xilofagi* – in "Il Manuale del legno strutturale Vol.IV - Interventi sulle strutture" (Ed. Bonamini G., co-ordinator Uzielli L.,) Mancosu S.r.l., Roma
- Giordano G., 1964, - *La moderna tecnica delle costruzioni in legno* III edizione. Hoepli, Milano
- Giordano G., Ceccotti A., Uzielli L., 1999, - *Tecnica delle costruzioni in legno*, Hoepli, Milano,
- Pro Loco Notizie: "*La fine del Capannone Giordano a Vallombrosa*" - Notiziario a cura della pro loco Saltino-Vallombrosa, anno 2005 n° 5 pag.2. Polistampa, Firenze, 2005
- Ridout B. – *Timber decay in buildings* – E & FN Spon, London, 2000
- Tomaselli L., Pietrini A.M., 2005, – *Alghe e cianobatteri* – in "La Biologia Vegetale per i Beni Culturali" – Vol. I, Biodeterioramento e Conservazione – (Eds. Caneva G., Nugari M.P., Salvadori O.), Nardini, Firenze
- Ufficio Idrografico e Mareografico – Pisa – Presidenza del Consiglio dei Ministri – *Vallombrosa Meteorological Station – Arno Basin* – March and April 2005 data sheets
- Venturi N., 2005, - *Storia, tecnica e degradamento di una struttura lignea degli anni '50: il capannone progettato e realizzato da Guglielmo Giordano a Vallombrosa (FI)* – Wood Technologies Degree Thesis, Florence
- Wood, L. W., 1947, - *Behaviour of wood under continued loading* - Eng. News-Record, 139(24), pp. 108-111