MSc Wood Based Building Design
For Sustainable Urban development

Hidden Architecture

The timber roof structure of the dome of Vercelli

Inspection-Diagnostics- Interventions

A Master's thesis submitted for the degree of "Master of Science"

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Milan, 05.02.2010

Acknowledgment

First of all, I thank my family, for listening and supporting in the last couple of months.

I deeply thank my advisor, *Prof. Arch. Clara Bertolini Cestari* (Politecnico of Turin) and my tutors *Dr. Alan Crivellaro* (University of Padua) and *Dr. Y. Amino* (TU of Vienna), whose help, advice and supervision was invaluable.

Finally, I would like to thank the design and leading architect of the restoration site of the dome of Vercelli *Prof. Arch. Daniele De Luca* and his collaborators *Arch. Riccardo Pasquino*, *Arch. Germana Corradino*. The various times they had to accompany me, visiting the site and the material they provided (plans, documentations, historical resource…) is greatly acknowledged. Without their availability and support, writing the thesis would have been impossible.

CONTENT

Abstract

The Master Thesis on the subject “Hidden Architecture- The timber roof structure of the dome of Vercelli: Inspection-Diagnostics- Interventions” intends to offer an innovative and sustainable approach to the conservation of the timber roof structure of the cathedral of Vercelli.

With this approach the whole knowledge, from the historical analysis, to the diagnosis on the conservation state, until the intervention proposals results of basic importance.

The timber roof structures of Vercelli’s Cathedral cover about 3600 m2 with constructive typologies of exceptional interest in the frame of cultural heritage.

A very large amount of historical information is available from the archives of the church and some of these refer also to the wooden roof of the church.

The timber roof trusses are made of squared wood beams. An evaluation of the timber member has been carried out on the following pages. The aims were to detect the eventually present wood damage and to asses, quantitatively, the mechanical strength of each beam.

Both inspection and strength grading methodologies have been carried out following the Italian

standards UNI 11119 “Load-bearing structures – On-site inspections for the diagnosis of timber members”, UNI 11138 “Building load-bearing structures – Criteria for the preliminary evaluation, the design and the execution of works”, and UNI 11161 “Guidelines for conservation, restoration and maintenance”. These standards, which will become European standards in the near future, contain objectives, procedures and requirements for the state of conservation diagnosis and for the strength and durability evaluation of timber members in load bearing structures. It works through the execution of in situ inspections and the use of non-destructive techniques and methods.

All the information gathered by the analysis and diagnosis have been essential for the decision by which intervention techniques have been chosen.

The disciplinary fields involved in the thesis are: history of architecture, wood technology, technology of architecture, survey, dendrochronology, structural analysis, restoration and maintenance.

The main aim is the minimum intervention with the maximum conservation of the material, with indications on maintenance processes and methods.

Some intervention proposals will be presented on the following pages and their advantages and disadvantages will be critically evaluated.

In the last chapter of the thesis a proposal for a future use of the hidden timber structure has been made. A project about how the culturally valuable roof could become accessible for potential visitors has been planned.

Introduction

Illustration 1 choir apses

Writing this thesis involved not only research, but observing on site one of the most important current restorations of a timber roof. Being a part of the on site team was essential to my being able to write this thesis. I saw the difficulties in developing such a project and I had to learn that conservation is a multidisciplinary work, where experts from many diverse fields have to put all of their knowledge together (the historian, the wood technologist, the chemist, the engineer, the architect, the craftsman and many more).

The roof of the cathedral of Vercelli has about 3600 m^2 gross area. In the last several years the structure of the dome has suffered water infiltrations, which have already caused damage and may cause further major damage if not corrected. Therefore a comprehensive preservation and conservation initiative is urgent. The main structure in its entirety and typology is still intact (for example beams with a length up to 17m).

The roof is a part of the building. Of course you can ask yourself, if restoration is sustainable. . Generally a restoration saves more than 50% of replacement costs for a complete roof with a new cross laminated timber structure (Prof. C. Bertolini Cestari).

Often, like in the case of the Dome of Vercelli, only some punctual interventions are necessary to save the original structure which means less waste and less pollution.

General reflections and topical aspects
Built heritage wooden structures from past periods represent a specific category of artefacts that are of particular importance and recognized interest in the rich heritage of cultural goods relating to historic or traditional buildings. These historic buildings show diffusion at the local level, type of structure, technological characteristics, artistic and formal value, etc.

Sadly, in the majority of cases these structures, were not deemed worthy of the same attention as the buildings of which they were an integral part. They were frequently subject to inappropriate intervention, replacement, or, even worse, demolition.
It was not until fairly recently that it became generally recognized that, as far as possible, these structures should be renovated and conserved in terms of their static purpose and in a manner that is respectful of and coherent with their original concept as well as their material: wood.
Nevertheless, in practice many structural renovations carried out in recent times have betrayed the idea of conservation, sometimes even involving the unwarranted demolition of centuries-old roofs. Such arbitrary or “excessive” intervention frequently stems from difficulties in assessing the state of conservation of the material and of its real load – bearing capacity, the incorrect evaluation of the structural behaviour of these elements, or the adoption of superficial procedures guided by profit rather than by the real needs of the works in question. Despite the revival of interest in wood and the proliferation of studies on this material, its load bearing capacities continue to be questioned by operators whose inadequate knowledge and total lack of confidence are revealed in the use of consolidation techniques using supports made from innovative “new” materials thought to hold the answer to all structural problems. This is a short sighted approach that disregards the effects of such interventions in the medium and long term. Many techniques described in the current technical literature (though sometimes innovative) are failing to keep pace with a conservation trend that is emerging, not just with respect to monumental restoration but also as far as historic or merely traditional buildings are concerned.
There are too many cases of unjustifiable radical interventions where wooden ceilings have been consolidated with steel structures and layers of reinforced concrete, or roofs have been partially or completely reconstructed using steel or Glulam components.
Not only do such projects share a lack of confidence in the traditional materials, construction techniques and skills, but they frequently neglect one of the fundamental steps of structural renovation project management - the diagnostic phase. It is mainly on the diagnostic phase that I have worked for my thesis: from the diagnosis on the material, to the mechanical characterisation of the elements, from the structural analysis with mathematical models for the single trusses and the overall structure, until the restoration interventions.

1 Description of the dome

Sketch 1 Dome of Vercelli

State of art:
The Dome of Vercelli, also called the cathedral of San Eusebio, is a symmetrical, latin coss- shaped building. The ground floor has a size of 3634 sqm. It consists of 3 aisles, of these the much larger one in the middle overpasses the two side aisles. Where the extremely high dome covers the cathedral, the two transepts intersect the main aisle. At this crossing point are modern multi liturgical objects placed, like the ambo, the altar and the Episcopal seat.

Illustration 2 Transept / Main aisle - Choir / Side aisle

The two side aisles end with flat chapels, while the main aisle continues with semicircular apses after the transept. Along each of the two side aisles are three minor chapels before the transept. On the right side are: the altar of the feretory, the altar of S. Onorato and the altar of S. Giovanni Nepomuceno. On the left side are: the altar with the baptistery, the altar of S. Emiliano (now dedicated to S. Elena) and the altar of S. Guglielmo. At the two ends of the transept are the much larger octagonal chapels of S. Eusebio and Beato Amedeo. Besides these, there are little chapels on the right side the altar of the crucifixion, and on the smaller side of the aisle the altar of S. Ambrogio. On the left side is the altar of S. Filippo Neriand and at the end of the aisle is the altar of the Madonna.

Illustration 3 Chapel of S. Eusebio

The five spans in divided aisles are covered with a ribbed vault, massive, quadratic posts and engaged columns. The two transepts on the other hand side are closed with barrel vaults. On the top of these vaults and the smaller cupolas are timber constructions mainly out of oak wood which carry a tile roof covering. The dome and the larger cupolas are completely made of stone and covered with lead and copper.

Illustration 4 pronaos

The hipped roof is the part which has been retained nearly unchanged in the course of time (both structural technique and form). The form traces back to the four or more pitched roofs, with a primary structure out of trusses or beams and angle bars on the bisecting line. The main timber elements have been worked better and with more accuracy than the smaller elements with less importance for the structure. In other cases the different working techniques (for example sawn and not chopped) are indications that the elements have been replaced or added in later periods.
At the outside of the cathedral the facade presents itself with a vast pronaos, covered with a barrel vault, which is interrupted in the middle with a low cupola.

The facade is decorated with classical elements, constructed with huge Corinthian columns, pilasters and an overlapping pediment on an attic with gigantic sculptures of Salvatore and the twelve knight’s heads. On the right side rises the antic roman campanile. This quadratic tower has a granite base and the rest is constructed of facing bricks, separated by pilasters and divided by frames carried by semicircular arches.

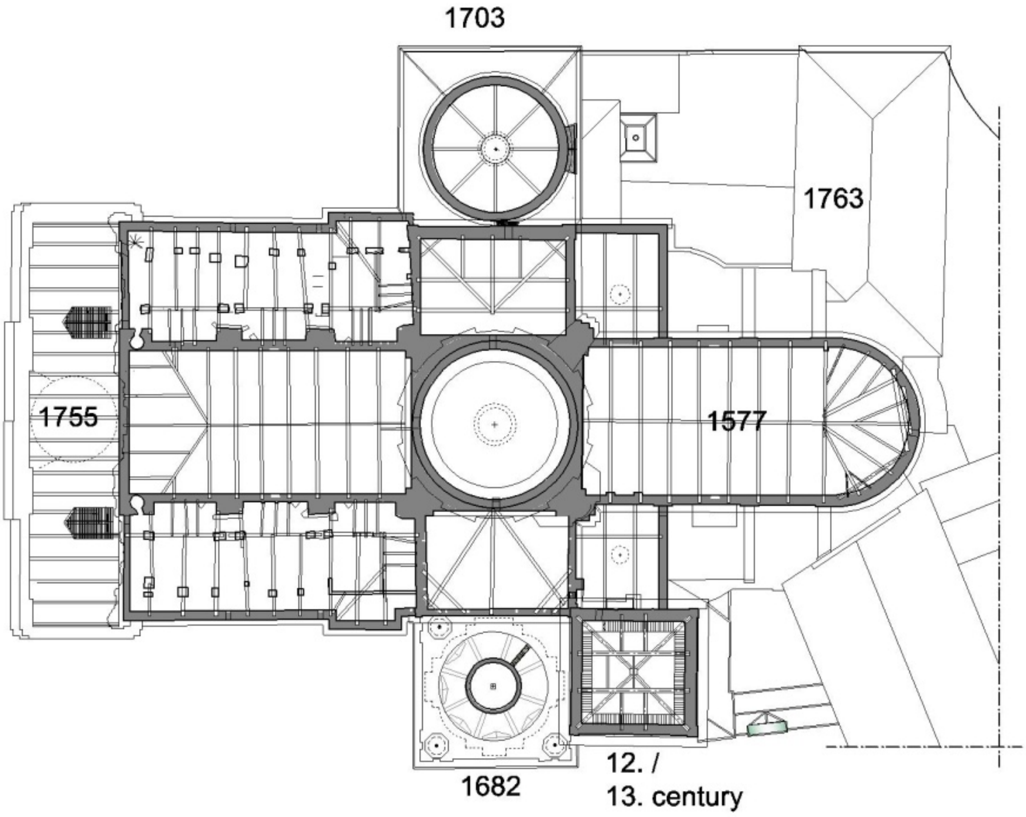
Illustration 5 Dome S. Eusebio View Piazza S. Eusebio

Illustration 6 Dome S. Eusebio View campanile

1.1. The Urban situation

Illustration 7 Urban situation

1.2. History of the building



Plan 1 Years of construction

An initial assessment is more realistic if it starts with archival research. The scope involves getting information about the age of the church, previous repairs, and the original timber species used for construction. The archival research can give indications of how long the structure has gone without maintenance. These dates can indicate the age of the timber structure and give important indications how to intervene now.

1.2.1. Former Basilica of S. Eusebio

The ancient basilica of S. Eusebio:
It is difficult to say when the first primitive church was founded on this spot, where the "Duomo di Vercelli" now stands. Considering its Christian history it is probable that around the 3rd Century A.D., the population started to use special buildings (domus ecclesiae) to practice the Christian religion. Considering the architectonical footprint in the urban space and the interventions taken to follow the religion of S. Eusebio the most likely source is the "Vita Antiqua" (author unknown). It is likely that the church, founded by the bishop Eusebio, was the first Christian building in Vercelli (maybe the oldest one in whole of northern Italy except for Milan), because there are no documents describing any older church. In a letter of Ambrogio di Milano written in 396 there is a description of a cemetery and of the tomb of the martyr S. Eusebio, which was amplified to a monument. There is nearly no material about the state of the building at this time, but we assume that before the construction of the actual Dome there was a huge Basilica with five aisles, an overhanging transept, and a four-sided-portico. According to the political situation (time of prosperity of the city) the first phase

of the realisation may have been in the $8^{th}/9^{th}$ century and the second one in the $10^{th}/11^{th}$ century, where the building gained “the title” Cathedral. The façade was richly decorated as is the current one and lined up with the altar of S. Onorato and S. Emiliano (today). The external walls were situated at about the middle of the current walls of the lateral aisles. The footprint of the basilica results probably from the political and religious importance of the city. Previous cathedral:

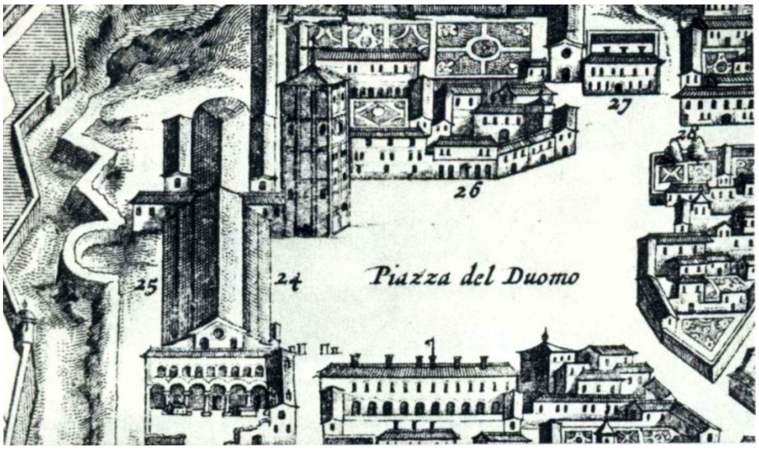


Illustration 8 The antic Dome drawing “Theatrum Sabaudia”

According to *Modena* e *Cusano*, the *bishop Attone* (924-961) ordered to build a new, marble baptistery with two side seats and a huge marble basin. *Bishop Ingone* (961-978) finished the baptistery. It is likely that the church changed over time mainly because, different historians report about a different amount of columns (*Modena* 52, *Ranzo* 40, *Cusano* 60 and *Mella* 36). The restorations of the ancient church may have paralleled the work done on the frescos. The restorations in the main aisle showed the 40 first bishops of Vercelli. Later *Govanni Ferrero* was ordered to redraw the frescos and show the episcope. Also in this case reports of the historians differ. They describe the sense of the life of the apostel *San Pietro*, *San Paulo* and *San Filippo*.
In the 9^{th} or 10^{th} century the altars of the side aisles were changed. Probably in the same period, the façade of the cathedral has been restored, in particular the entrance door. It was decorated with 3 pictures, showing *S. Eusebio* in the middle and *S. Emiliano* and *S. Onorato* on the sides. In front of the cathedral was a two story four-sided-portico to celebrate rituals. In the 12^{th} century a cross with a thin golden layer was installed in the presbytery. After many replacements the cross was mounted above the main altar.[1]
In the 13^{th} century another prestige item, a marble statue (now in the museum “Lione di Vercelli”), was added to the cathedral.
From this antique church remains only the tower. According to *Corbellini* the tower was erected while *Uguccione* was bishop (1151 to 1170). Another historian Conti wrote that this tower 1404 still wasn`t finished.
De Rossi assumed that during the definitive destruction of the ancient dome graves and pagan items were found. A marble sarcophagus (probably 1^{st} century)

[1] 1995 an archaeological dig uncovered the structure of a cupola (10.-12. Century) or of a later vault (apsis). Further they discovered a coloured mosaic, which was created in the same period.

was uncovered, which indicates that the ground of the dome was already an important place in pre Christian times. [2]

1.2.2. New Dome

16th century

The realisation of the chorus (1562-1582), Arch: *Tibaldi*
Before the construction of the new dome could start, the old basilica had to be demolished. According to the historian *Cusano* the dome was dismantled in one night from the 22nd to the 23rd of December in 1570. During this period *Cardinale Guido Ferrero* was bishop of Vercelli and this means that he must have ordered the demolition, probably because of the poor and dangerous conditions of the ancient cathedral. Other writers are talk about a slower and later break –off at the beginning of 1571.
In the library “Capitolare di Vercelli” you can find a document from the 4th of april 1577, containing information about the realisation of the new dome executed by Ribaldi: “*che la detta fabbrica nella quale s’hanno da spendere li suddetti dieci mila scudi s’intende che sia il choro voltato et coperto, con le finestre, cornici conci et colonne di due Capelle, le due sacristhie similmente voltate coperte et con il suo paumento secondo il modello fatto da m.r. Peregrino Architetto di Millano”*
In 1572 the first works based on the project of the architect *Ribaldi* started. The bishop *Francesco Giovanni Bonomio* (1572 – 1587) overtook the building lot shortly after the construction site was opened.
The Milanese constructor *Saracco* took over the site inspection after a visit of the bishop *di Lodi* 1575, who saw the poor conditions of the lot and decided to invest another ten million Scudi[3].

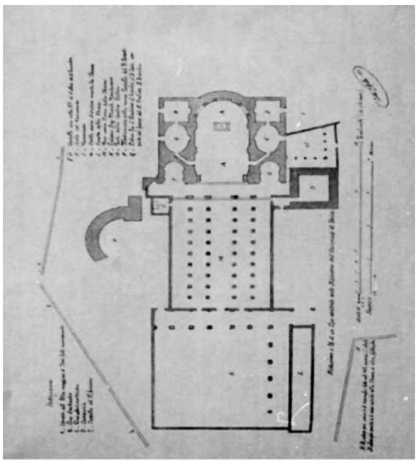


Illustration 9 Eduardo Mella, copy of a drawing from Guarini, 1872

The contract with *Saracco* was very defined and demanding. It contained not only when the work had to be finished (within 3 years) and the form of the dome (plans, descriptions where to place walls and columns), but also the exact definition of the materials, which had to be used. The timer for the roof for example had to be made out of strong oak with big cross- sections.
Proceeding the construction of the chorus in 1581, the corpus of *S. Eusebio* was recovered.
In 1582 the work stopped unfinished, because the bishop *Bonomio* ran into high debts. The dome must have been nearly finished at this point (some interior walls may have been missing), because a relief of *Guarini* shows that the dome had been realised very similar to the contract.

2 Restorations in 1871 entrusted a mosaic which today is still visible. It determinates the area of the covered tombs in the presbytery and in front of various chapels.

3 A Scudo is a silver or gold coin with a shield showing the symbol of important families (Savoia..) or the church. In 1866 the Scudo got substituted by the Lire, though some of them have been in use till the first world war.

After the intervention on the chorus, which ended about 1582, the cathedral had no significant works except the Chapel of *Beato Amedeo IX*. Of course the church couldn't stay without any kind of intervention. Under the bishop Giacomo Goria (1611-1648) the vaults were strengthened, and the walls and the choir were repainted.

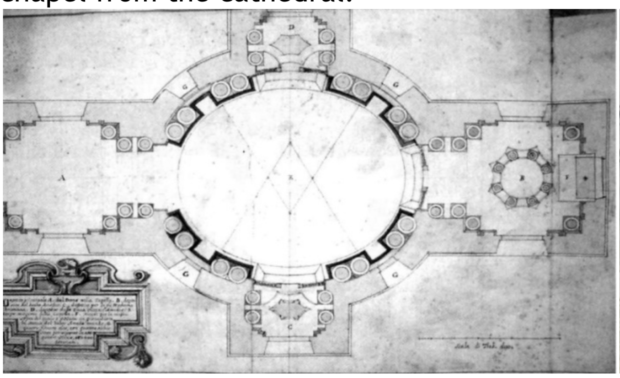
After this period many small modifications followed. The altar was displaced several times. Carinale *Constanzo Sarnano* (1587 – 1589) ordered a new organ. The bishop of *Marcantonio Vizia* (1590 - 1599) changed the seats of the chorus.

17th century

The successor *bishop Stefano Ferrero* (1599 -1610) donated a reliquary casket to preserve the relics of S. Eusebio in the possession of the basilica. In 1630 the black death arrived in Vercelli and the *bishop Giacomo Goria* wanted to built a crypt under the dome. Though there was already a very detailed project for a crypt, it had never been realized.
The erection of the altar of the Madonna took longer than 10 years. The architect *Francesco Rusca Castell,* who constructed the Dome of Como, constructed the altar from 1635 till 1646. In this year the altar of the chapel of *S. Ambrogio* was renovated as well. It has an inscription on an arc from the *bishop S. Flaviano* (530-540). Now this arc decorates, as an altar screen, with the altar in the middle.

After a visit in 1663, the bishop *Michelangelo Broglia* described the desolate condition of the cathedral. Also bishop *Vittorio Agostino Ripa* reported in 1684 signs of destruction and many problematic points of the church caused by economic difficulties and a leaky roof.
In 1681 the balustrade in black marble, which separates the presbytery from the two lateral chapels, was realised. According to the historian *Viale* the whole work was done by an artist of the court of *Garove*.

After the beatification (1681) of the prince *Beato Amedeo IX* (who died in Vercelli (1472) and who's mortal remains were conserved in the cathedral of Vercelli) the royal *Giovanna Battista of the Savoia* suggested celebrating the event by building the chapel *Beato Amedeo*. The architect *Guarini* was assigned to design the chapel on the ancient walls of the previous project of *Ribaldi* (see picture 10). This project was never realised. In 1682 a project of *Garrove* or *Garove* was chosen and the first brick was hand set by the royal *Giovanna Battista of the Savoia.* About one or two years later the vault of the cupola was constructed (already with elements in lead). In 1688 the two statues, eight angels in white marble and 16 individual pieces in black marble for the altar made by *Carlo Busso* were finished. After the access was enlarged in 1697, a fence separated the chapel from the cathedral.



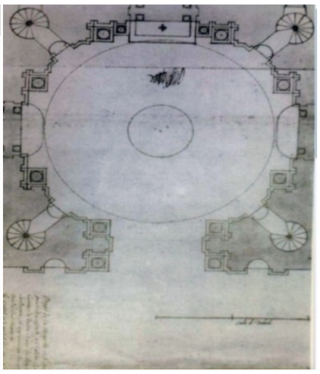


Illustration 10 Garove, project of the Capella Beato Amadeo, (before 1672)

Illustration 11 Plan of a not executed project, Capella Beato Amadeo IX

18^{th} century

In 1702 a document was written, reporting mainly about the wall erected in between the new choir and the antique church, the weak joints of the covering and the partly broken connection points of the Chapel of *S. Filippo Neri*.
Another intervention of *Garove* took place in 1703. In his plan you can see the new design of the entrance for the chapel and parts of the old church. It shows the side aisle with its previous ancient wall, separated by columns into the direction of the centre and an overlapping cross vault.
In 1703 the old chapel of *Beato Amedeo*, next to the altar of *S. Filippo Neri*, was dismantled. The historian *De Rossi* documented this demolition and wrote that they found corpuses and other objects.

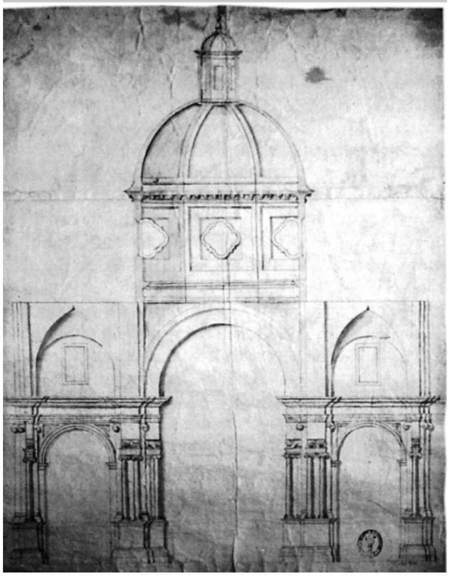


Illustration 12 project of Stefano Negro, about 1707

After the digging, the *Canonici* (because at this time there was no bishop in Vercelli) initiated to reinforce the arches and the vaults in front of the side chapels next to the presbytery and the arc of the main aisle with 4 new pillars. Like this the stone lions and columns carried the structure, in the way that the old project of *Tibaldi* had foreseen. These columns had a diameter of about 60cm and a height of 5,40m. In 1707 and 1708 one by one these columns had to be transported from Lugano to Vercelli. In the same year a wall to separate the old from the new church had been constructed.
The project of *Stefano Negro* (see Illustration12) about 1707 has great importance regarding the time. It shows the point where out of the fifth aisle the cathedral became one
In 1709 a new room for the janitor was built, the choir and the side aisles were painted, a new pavement in terracotta was realized and the organ was repaired.
In 1710 the altar of *S. Filippo Neri* was erected where previously the foundations for the side aisles were realized, this lead to an elevation of the ground floor.
In 1711 the pavement for the presbytery and the choir was created using black and white stone squares in the same way as the floor of the Madonna altar the following year.

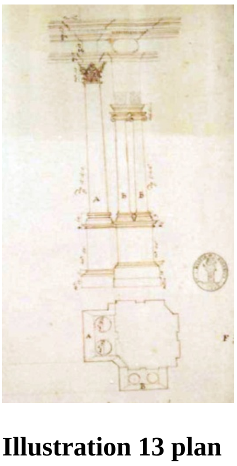


Illustration 13 plan without date and author

In 1713 the work for the sidewalls of the church started. They arrived up to the roof and reached the outer walls of the ancient church.
In 1714 the old church was completely demolished - even the antic baptistery of bishop *Attone* wasn't spared.
In the same year the four slabs ending underneath the vault were mounted and a temporary ceiling and the stairs in front of the altar of the Madonna were built.
In 1715 the tabernacle of the altar of the Madonna was realized and the work of the cupolas from the side chapels and the timber roof including the clerestories out of sheet metal were completed.
The reports of the historian De Rossi finished in 1717, when they found many roman and Christian tombs (3°-4° century) in the pavement of the ancient basilica.

Between 1708 and 1715 the idea came to modify the columns from Ionic to Corinthian style. The plan (see picture 13) shows a part of the choir and tree slabs of the main aisle. The columns of the painting are more cantilevered and realized in terracotta. The plan describes as well the work for the foundations of the other two slabs and the static system of the 20 columns which were supposed to carry the dome.
Further two plans (see illustration 14) document the works on the cathedral. The yellow parts show existing structures and the red parts are new constructions to realize. The first plan seemed to be made between 1708 and 1714 and the second one where only some sidewalls are missing) is younger from about 1745. This plan shows a staircase which has never been realized.

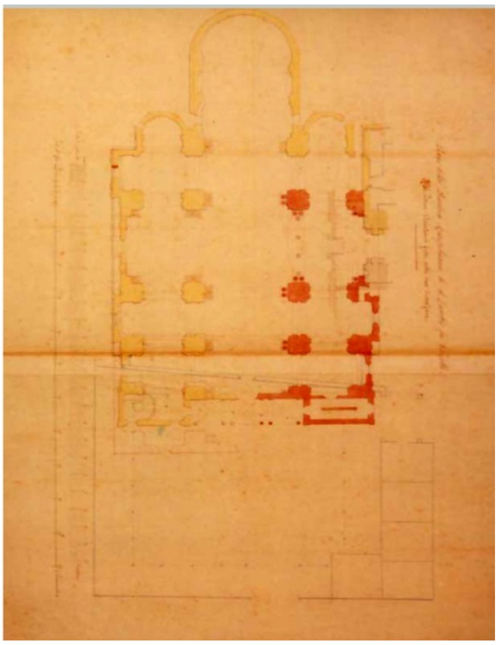


Illustration 14 plan attributed to E. Mella 1714   second drawing (about 1745)

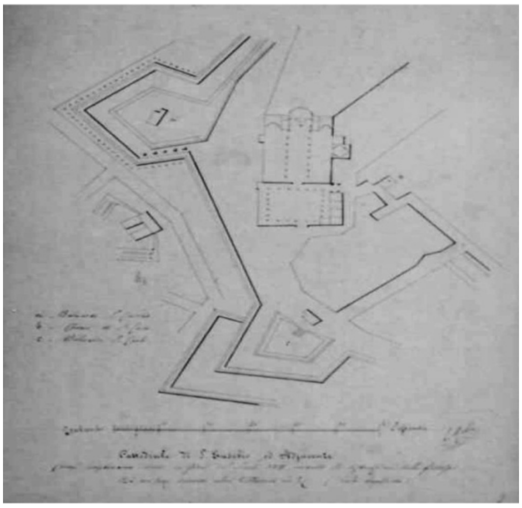


Illustration 15 Eduardo Mella, Cathedral of S. Eusebio (the way it looked like in the end of the XII century)

The roof covering in lead[4] was reconstructed in 1715.
In the same year the atrium of the opposite side of the chapel was demolished.
In 1724 the antique colonnato was dismantled and probably a temporary wall closed the church.
The Cardinal *Vincenzo Ferrero di Sauze* (1730 – 1742) donated a bigger altar out of fine marble, a marble statue of *S. Eusebio* placed in a alcove of the choir, and one of the windows which may be another opera realized probably by a French Sculptor (*Mançon*).
From 1745 to 1746 a second balustrade of the presbytery was erected. The work

[4] which has been removed during the occupancy of the French in 1704

was done by the artist *Pellagatta* and *Giudici*. During this work the benches and seats in the presbytery were removed and indications about the construction of temporary walls in the facade were given.
In 1748 the architect *Giovanni Battista Borra* finished the work of the altar of *S. Guglielmo*.

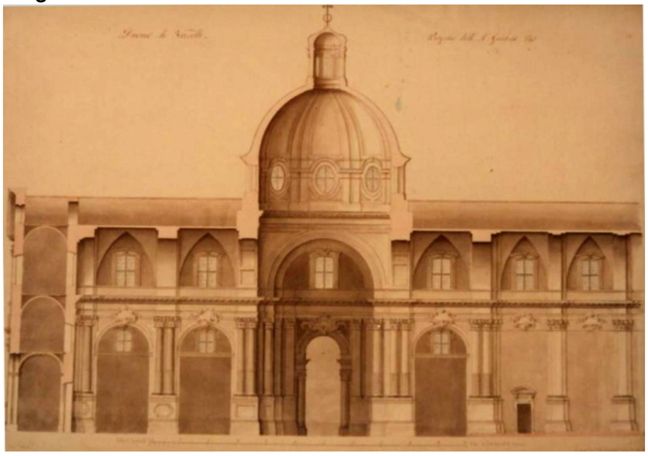
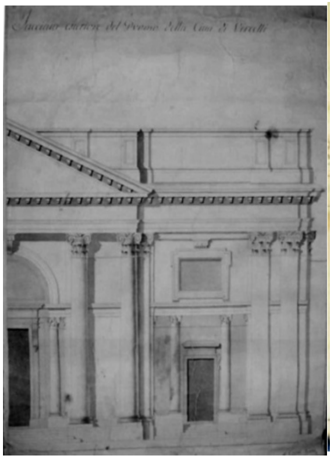


Illustration 16 Original project section attributed to Guibert (probably 1749)

A panting (see picture 16) from about 1749 doesn't correspond with the plans, but gives information about the dimensions.
In 1755 the eight Ionic columns with the lions were removed. Like this the floor and the internal structure was redone.
In 1756 under bishop *Solaro di Villanzona* work on the Dome continued. In the same year the King *Carlo Emanuele III* accepted the use of material from the destroyed fortresses (occupation of the French in 1704).
The archdeacon *Giuseppe Maria Langosco* stood in good contact with the architect of the king, *Benedetto Alfieri* and his staff, *Benedetto Feroggio* and *Luigi Michele Barberis*, who put into execution the work of *Alfieri*. In 1756 the architect refused to use mirrors on some windows of the choir, proposing some in black coloured niches, because they seemed real. In the same year came *Feroggio* to Vercelli to make a necessary relieve. Meanwhile under the direction of *Michele Nervi* the last posts next to the wall of the facade found their final place.



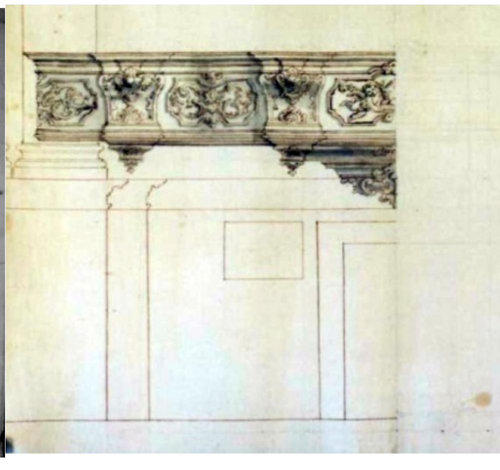


Illustration 17 Drawing balcony, Sezzano, 1758

Illustration 18 project facade, Alfieri, 1757

In 1757 the whole attention went to the enormous colonnato and the facade. *Barberis* overtook the construction site and the project was partitially modified. In the mean time the drawings for the capitals and the cornices were finished. In

1758 *Sezzano* made the plans for the façade of the organ and the balcony. The master mason *Battista* built the vaults with indications of *Barberis*.
In 1760 the timber panels for the entrance door arrived and the layout for the construction of the altar in the baptistery was finished.
In the same year *Alfieri* developed an urban concept to connect the principal monuments of Vercelli with public streets (of course also the dome has been considered).

Illustration 19 urban project, Alfieri, 1760

In 1761 *Barberis* mentioned in his documentation of the work that some of the stone elements of the façade were missing. In the same year *Barber is* ordered to start the work of the engaged columns of the chapel of S. Eusebio, but he had to wait. The drawings were finished in 1763 and finally in 1764 the construction of the chapel began.

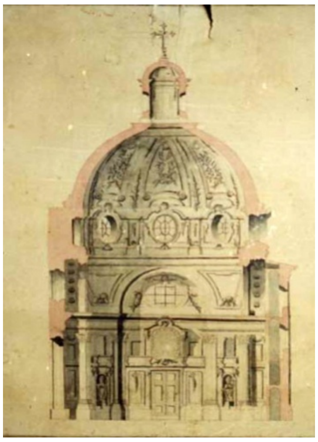


Illustration 20 project section Cappela di S. Eusebio

From 1759 to 1761 some modifications were made to remove the austere character of the chapel. *Barberis,* in close collaboration with the architect of the court *Alfieri,* was ordered to dismantle the antique altar, and build the new one according to *Alfieri's* plans. The walls were covered with marble and the terracotta floor was replaced by new marble plates. Maybe also the stucco and the pendentives of the cupola were refurbished. About 20 years later (1781-1782) the work which conformed the entrance of the church with the one of the chapel of *S. Eusebio* ended, but this was not everything. A new plaster, stucco, decorations of the altar (ornaments out of gilded bronze) followed.
Probably the oldest parts of the decorations can be found in the architrave above the remodelled angels decorated with little volutes and maybe ancons inside ancons on the spandrel wall. After this intervention of *Alfieri* and *Barberis* the look of the Church changed completely and the initial design aspect *Garove* wanted was lost.

In 1780 *Barberis* drew the choir of the church and he got the money to supervise the construction of the dome (cupola), which he never built.

19th century

The construction of the dome (1808-1861)
The idea of realising the cupola never died and therefore in 1808 *Nicola Nervi*, the son of *Michele Nervi* who worked for *Alfieri*, got the task to design the timber

scaffold on which the work of the dome could get executed. In 1812 *Carlo Emanuele Mella* made a plan to show the state of the art of the cupola.

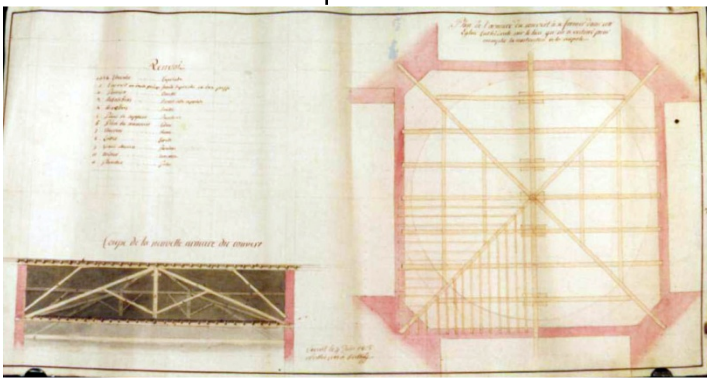


Illustration 21 study, Michele Nervi, 1808

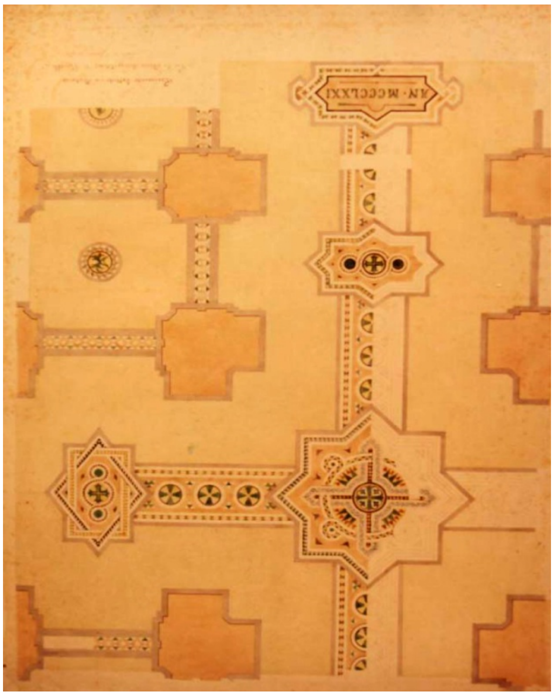
The aisle way from the main sacristy to the choir was realised in between 1812 and 1821.
Carlo Emanuele Mella directed the work of the neoclassic altar for the first chapel in the right aisle, which contains the feretory that was realized in 1713 for the smaller sacristy. The altar was built out of elements of the altar of the destroyed church of S. Maria Maggiore and maybe two columns of the antic church of *S. Eusebio*.

Illustration 22 Project cupola, Larghi

Illustration 23 Altar reliquio, Mella 1838

In 1847 the architect *Larghi* took over the project of the dome. In 1856 he examined the condition and the static capacity of the four columns on which the dome should be built. A huge column out of bricks in the middle of the dome was constructed to help execute the work in the centre (like a crane). Step by step additional material was ordered. First, in 1857, the bricks, steal and timber (oak and larch) for the structure, and in 1859 lead and copper to finish the dome. To maintain a perfect result, the materials had to be high quality elements. The Bricks for example had to be cooked to maintain an optimum strength, not vitrified, the angles had to be intact and the surface had to be flat. Also a metal staircase was installed to maintain the cupola. The sculptor *Pietro Rossi* and the painter *Antonio Costa* executed the work to cover the dome. 1860 the work of the metal balustrade at the inner side of the dome, the stucco and the gesso were executed.

To restore the decorated engaged columns the stucco decorators *Cattaneo* and *Ottino* were chosen.
In 1859 to finish the dome and make it not only resistant to outer influences like weather, but also to fire, the cupola was covered with metal elements. To achieve an optimal result two layers were built - a horizontal and a vertical one. The outer one is tinned copper and the inner one a mixture of lead (1/3) and tin (2/3).
1860 the inner decorations were chosen. Afraid of “overloading” the interior with ornaments, it was decided to paint only the friezes and the baseboards. Gesso and glossy stucco were forbidden. Only lime, sand, pozzolan, and plover of marble (royal stucco) were allowed to decorate the cupola. The work had to be executed with a lot of care by specialists.
Some critical voices claimed that a different typology for the cupola would have been better, mainly because of the window openings and that it was careless to build the cupola on the four existing columns which could barely take the load.
Since 1854 they thought about a solution for the heating system, the first offer came in 1862. It was a system based on steam, but it was never realised.
In 1871 the 1500th anniversary of the death of S. Eusebio arrived and the decision was made to change the pavements. They were replaced by red and white squares in 1587 for the whole church. *Edoardo Arborio Mella* was responsible for the construction site and documented exactly all the discoveries like burials during the work. The pavement out of raw serizzo was replaced by stone plates from *Masserano* worked with fine grain. In other parts of the church the restoration proceeded. In the same year the choir and the chapel of S. Eusebio were been covered by marble. The decorations were completed in 1873.



Doing this decorative work fissures at the columns carrying the dome were noticed. The building surveyor *Locarni*, proposed to insert a steel tube in the existing column. The altar was realized by Locarni himself. It is likely that this proposal was never realised.

Illustration 24 project of the pavements of the aisles

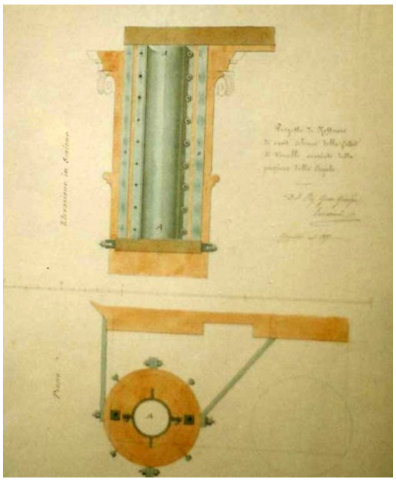


Illustration 25 project reinforcement of the columns, Locarni

In 1875 *Locarni* realized the little gardens next to the church. In 1881 the surveyor together with *Carlo Costa* carried out the task to redo the decorations of the chapel of S. Eusebio. The four in the angles positioned statues, which carry the cupola were realized by prof. *Francesco Porzio*. They represent strength, faithfulness, grace of charity, and prudence. The carvings on the choir are from prof. *Giuseppe Antonimi from Varallo* and the new organ was realized by *Gioseppe Tonoli from Brescia*. The castings in bronze are from Francesco Mo, the coloured windows from Gugeliemi and the building work on the walls are from Alessandro Del Piano. The seats in the choir were realized by *Barbaris*. After the work was finished in 1882 the chapel had a new Renaissance touch.
In 1893 *Locarni* made the design of the cast iron fence protecting the pronaos of *Alfieri*.

20th century

The company *Lehman* prepared, in 1901, the installations for the steam heating system and positioned a boiler underground.
In the fifties there was a humidity problem especially in the roof. For that Mr. *Novella* was made responsible for the maintenance of the cathedral. The first step was taken in 1954 with the restoration of the chapel of the Madonna. The decorations from *Carlo Costa* were repaired by *Capriolo*, the golden parts of the altar were renewed by the enterprise Sala di Verolegno and the polychromatic windows were realized by *Carlo Demarchi*.
The walls were coated and received a new skirting by the concern *Odone*. The plan for the electrical installation was done by the company *Rossato* and the mending job of the timber roof was done by the enterprise *Cantone*.
Under the direction of *Capriolo* the decorations (rosettes out of stucco) of the chapel of the crucifix started. In the chapel of the Madonna a new marble skirting was added and the walls of the Chapel of S. Ambrogio were uniformly coated.
In 1958 the electrical plan for the chapel of S. Eusebio was realized by the company *Manzo*.
In 1955 the whole roof structure was reviewed and the most necessary interventions were completed.
Under the direction of the architect *Frascaroli* the chapel of Beato Amedeo was restored. The paintings were redone, the gilded ornaments and cornices were coloured again, the pavement was redone, the illumination was done, the covering in lead, the plaster, the tinsmithery and the stucco were strengthened.
In 1967 the coloured pulpit was removed.
Water infiltrations stared to destroy the decorations of the dome; the stucco and the plaster started to crackle. The restorations of the cupola began in 1968. 8/10 of the roofing of the dome had to be canopied again with copper using the original tint-coating. The interior parts were restored by a company for artistic restorations in Milan. The stucco was repaired and where repair wasn't possible it was replaced.
In 1969 the vaults of the dome of Vercelli were also renovated and a new electrical system for the illumination was foreseen.

In 1970 maintenance work was done on the roof of the main aisle, and the following year also on the side aisles of the Cathedral.
In 1972 the cupola in lead, the plaster and the stone skirting of the chapel of Beato Amedeo were renovated or redone.
In 1975 the roof of the campanile was redone.
In 1976 a waterproof layer was added to the chapel of S. Eusebio.
In 1977 the outer side wall in the direction of the square D`Angennes was restored and in the following year on the opposite side.
In 1980 the restoration of the pronaos started and the statues at the outside of the cathedral were cleaned.
In 1983 it was necessary to reinforce the columns of the Dome of Vercelli.
In 1990 the walls of the tower were refurbished.
In 1992 it was necessary to intervene again on the cupola of the chapel of Beato Amedeo. The old roofing was removed and replaced by a two times thicker coating in lead.
In 1994 the archbishop *Bertone* decided to realize a crypt under the chapel of S. Eusebio. The project was done by the architect *Berruto*. During the work they found various graves, tombs and remains of the walls of the antic basilica.
In the last years the archbishop *Masseroni* has proposed many different interventions. Recently the multi liturgical location at the centre of the transept has been recoated. Under the dome, a new altar, a seat for the bishop and an ambo have been placed. At the zone of the sacristy some maintenance work on the roof has been done and the mosaic pavement has been renovated.
Recently mainly because on the north side some water infiltrations risked further damage to the structure the most necessary interventions have been done.

2 Planed interventions

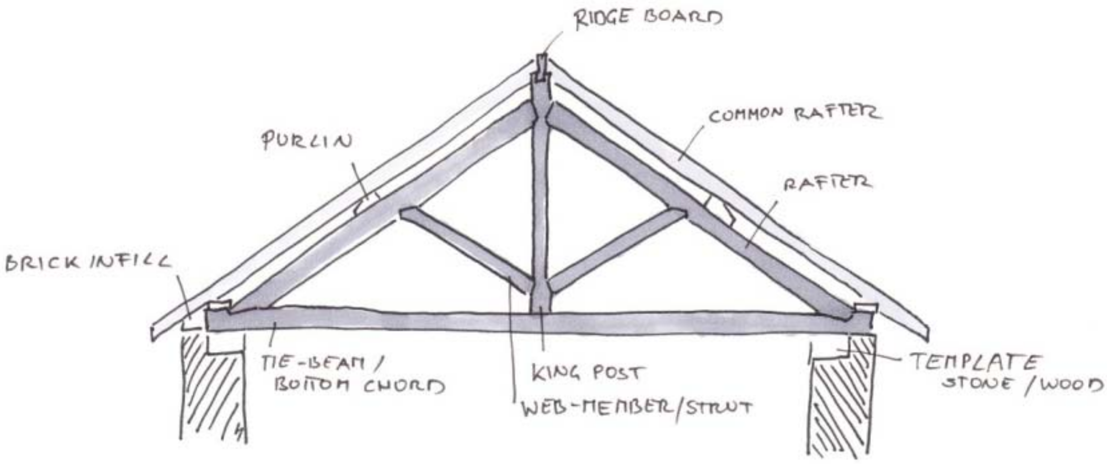
A huge historic building, like the Dome of Vercelli needs permanent maintenance and restoration. Therefore Arch. D. De Luca divided the interventions, according their urgency, into lots. This means that the most pressing intervention will be done first and when the project for the second lot has been developed and the economic situation has been resolved the second phase can be executed, than the third intervention will be planned and executed and so on.

1^{st} lot: Regards the restoration of the roof of the cathedral of San Eusebio is specified in chapter XX the workshop.
2^{nd} lot: Works to avoid the rising humidity and the adjustment of the green areas
3^{rd} lot: Revision of the electrical and heating system
4^{th} lot : Restoration of the mosaic (pavement)
5^{th} lot: Restoration of the inner part of the vaults
6^{th} lot: Restoration of the chapel of San Eusebio
7^{th} lot: Restoration of the chapel of B. Amedeo IX
8^{th} lot: Restoration of the main altar and the smaller ones in the side aisles
9^{th} lot: Timber elements of the choir (seats)
10^{th} lot: Restoration of the vaults and statues of the attic (outside)
11^{th} lot: Restoration of the gates
12^{th} lot: Restoration of the church square
13^{th} lot: Restoration of the wheels of the mobile altar

3. Roof structure

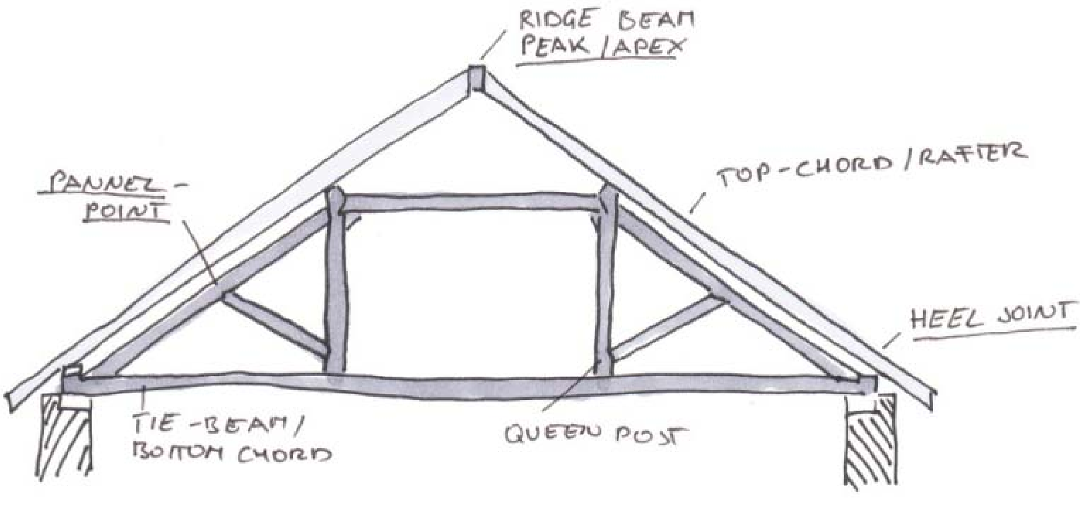
3.1. European roof trusses

The major structural elements of light frame structures which date back beyond the nineteenth century, before the industrial revolution brought the “new” materials like steel or iron, were made of timber. To cover roofs with a wide span the most common structure was the truss. A truss is a construction, consisting of one or more triangles, whose ends are connected at joints referred to as nodes. It is a structural element, which is designed to carry its own weight and added superimposed design loads. The height between the upper and lower chords (the height of the triangle), is the reason why a truss is such an efficient structural form. A solid beam for a given span of equal strength would have substantial weight and there for higher material cost compared to a truss. This triangular shape is such an efficient design, because it is the simplest geometric figure that will not change its shape if the connection points of all sides are fixed.
As trusses are exposed to wind forces, which are acting perpendicular to the gable, the triangle should be braced with diagonal, horizontal, and- or vertical braces connecting the truss members. To get a clearer idea of which elements such a truss can consist, the most common components are described below:
Every load carrying component of a roof Truss assembly is called **MEMBER**.
One of the elements which are in every truss is the **BOTTOM CHORD** or Tie beam. It is a horizontal or inclined member that establishes the bottom edge of a Truss, usually carrying combined tension and bending stresses. These bottom chords often work as ceiling joists. Together with the bottom chord the two **TOP CHORDs** built the basic triangle of a truss. These top chords are inclined or horizontal members that establish the top surface members of a Truss. These top cords are as well the RAFTERS of a pitched roof. The word rafter can be used for every sloping or pitched member in roof framing. To connect the single trusses on top exists the **RIDGE** beam, which lies on the horizontal roof line made by the top surfaces of two sloping roof surfaces. Further elements can be for example a **GIRDER,** which is a wooden beam used as the principal support of concentrated loads at points along its span.
To get the whole system stiffer to these basic elements **WEBS (**or the **WEBBING)** are added. They are the shorter members that join the top and bottom chords of a roof Truss, which form triangular patterns in that Truss, usually carrying. The webs are transmitting tension or compression stresses, and are designed to prevent bending and flexing.
A more specific expression is the term **LATERAL BRACING**, which is often used for timber members placed and connected at right angles to a chord or web member of a Truss. Another element which can be added to a truss is the **COLLAR BEAM**, which is a timber member connecting opposite roof rafters, often to resist lateral separation forces.



sketch 2

These timber elements connect at some points. The **PEAK** or **APEX** is the high point on the Truss where the sloped top chords meet and the **HEEL JOINT** is the point where the rafter and tie- beam chords intersect. A point at which one or more web members intersect the members of the main triangle is called a **PANEL POINT**. A special form is the **SPLICE POINT**, where two chord members are joined together to form a single member. It can occur at a panel point or between two panel points.

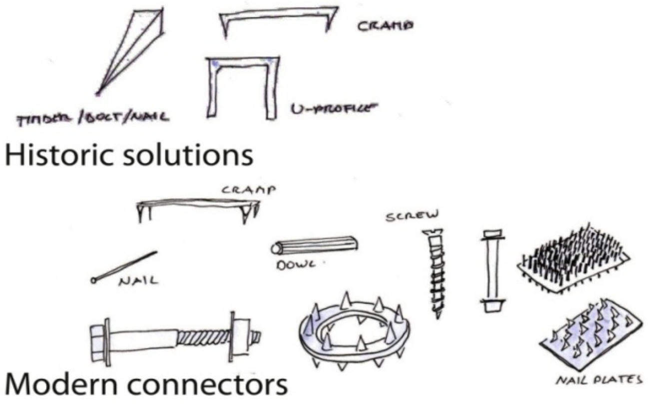


sketch 3

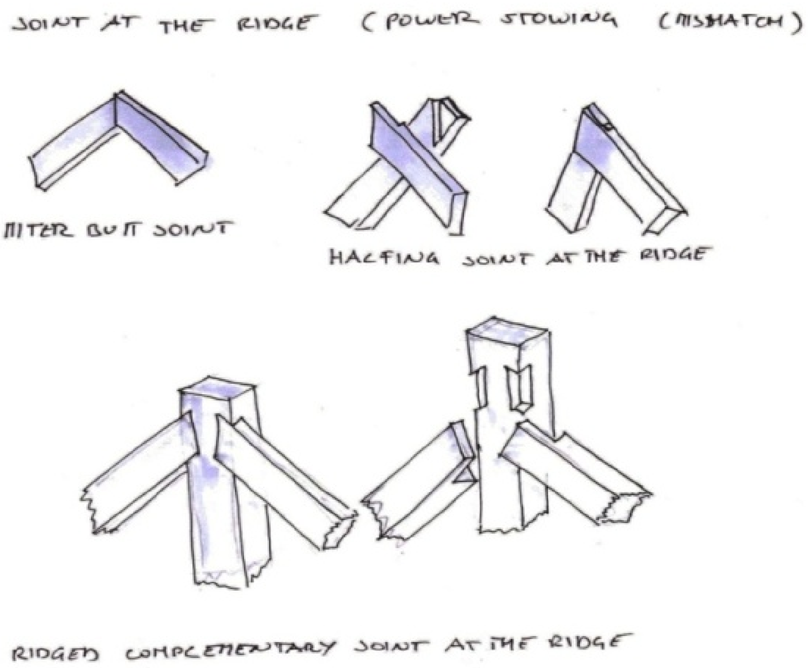
These connection points of trusses have to be joined in some way. This fore we have the C**ONNECTOR.** It is a mechanical device for securing two or more Trusses, components, pieces, parts, or members together. Also anchors, buckets, straps, wall ties, and fasteners are connectors. The most common joint is the **DIRECT**

NAIL, which is a nail driven perpendicular to the timber member, or the **TOE NAIL**, a nail nailed at an angle to fasten one member to another. In the same way DOWELs or BOLTs and SCREWs can be used. To get a stiffer connection a **NAIL-ON PLATE** can be applied. They are steel connector plates with or without pre-punched holes, through which nails are driven by hand or pneumatic means into the wood. According to its connection a member can be actually named. For example a **NAILER** (Scab) is a timber member fastened to another member by nails to reinforce the structure.

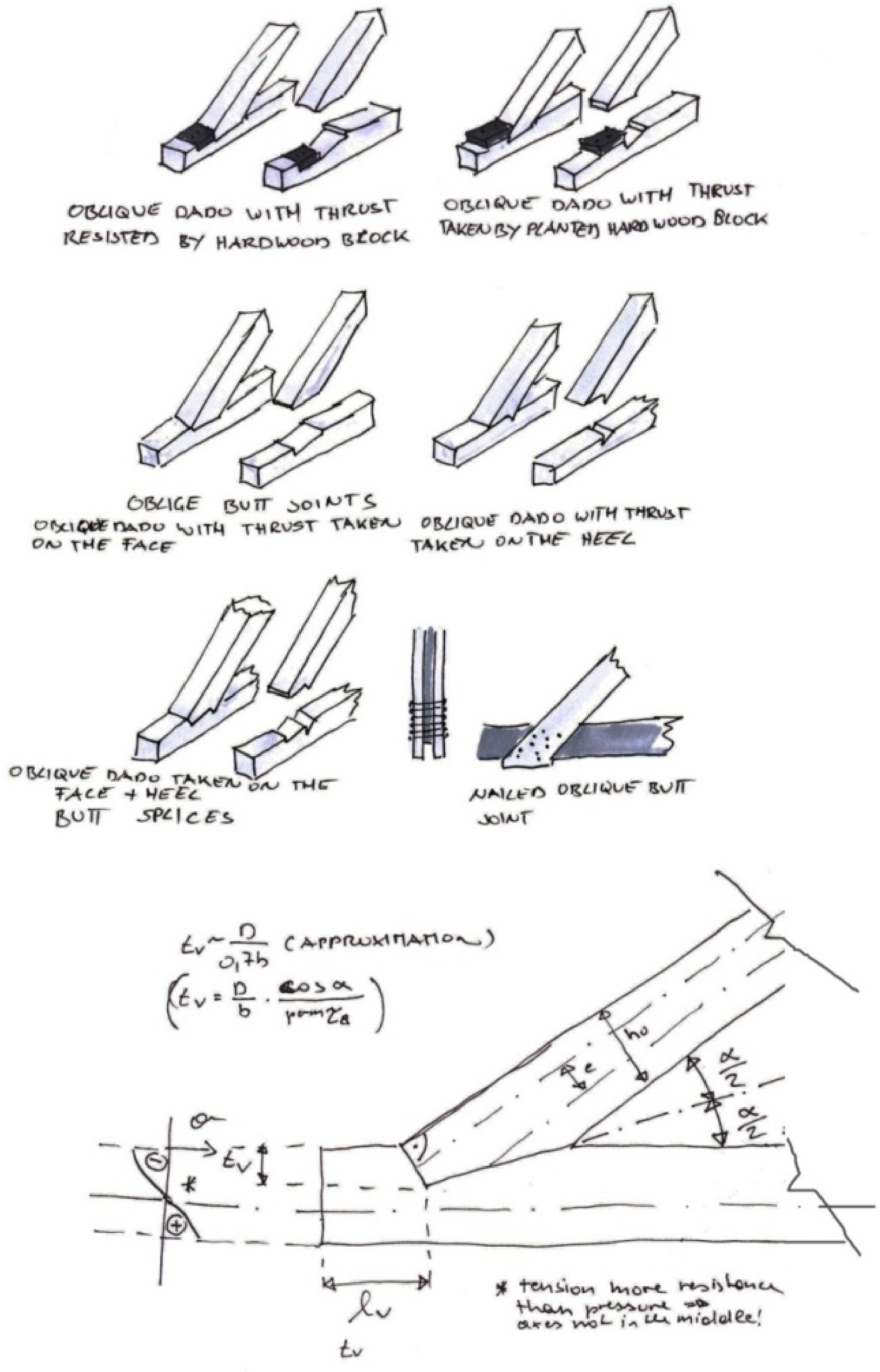
sketch 4



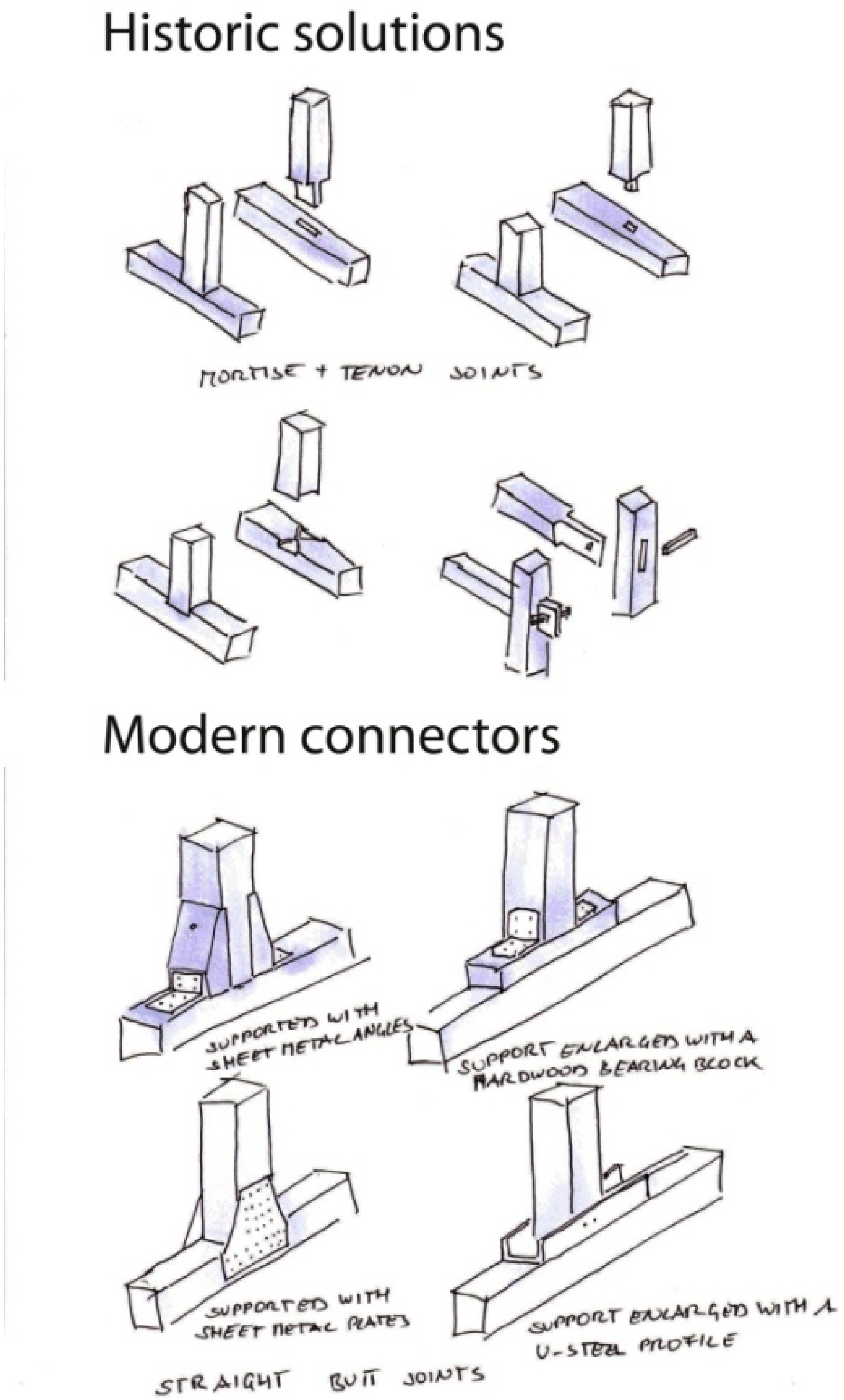
It gets more difficult and complicated if the members are connected by carpentry connections. There are various possibilities to join timber elements, but what they have mostly in common is that they are often wood on wood connections. Generally speaking the joints can be divided into BUT JOINTS, MORTISE and TENON JOINTS and POWER STOWING (MISSMATCH) JOINTS.



sketch 5


OBLIQUE DADO WITH THRUST RESISTED BY HARDWOOD BLOCK
OBLIQUE DADO WITH THRUST TAKEN BY PLANTED HARDWOOD BLOCK
OBLIGE BUTT JOINTS
OBLIQUE DADO WITH THRUST TAKEN ON THE FACE
OBLIQUE DADO WITH THRUST TAKEN ON THE HEEL
OBLIQUE DADO TAKEN ON THE FACE + HEEL
BUTT SPLICES
NAILED OBLIQUE BUTT JOINT
(APPROXIMATION)
* tension more resistance than pressure ⇒ axes not in the middle!

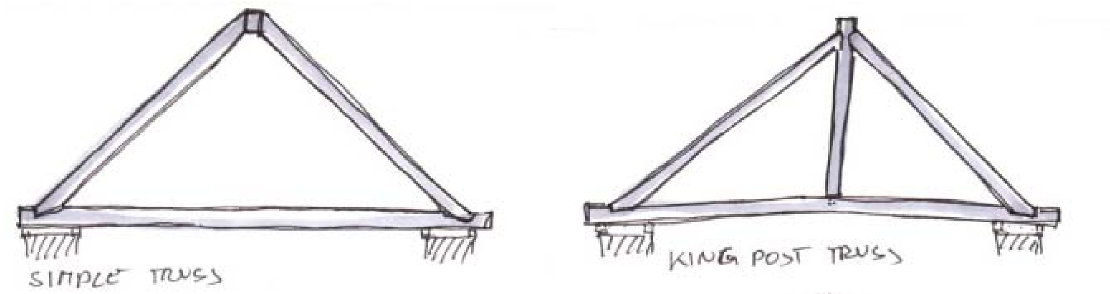
sketch 6



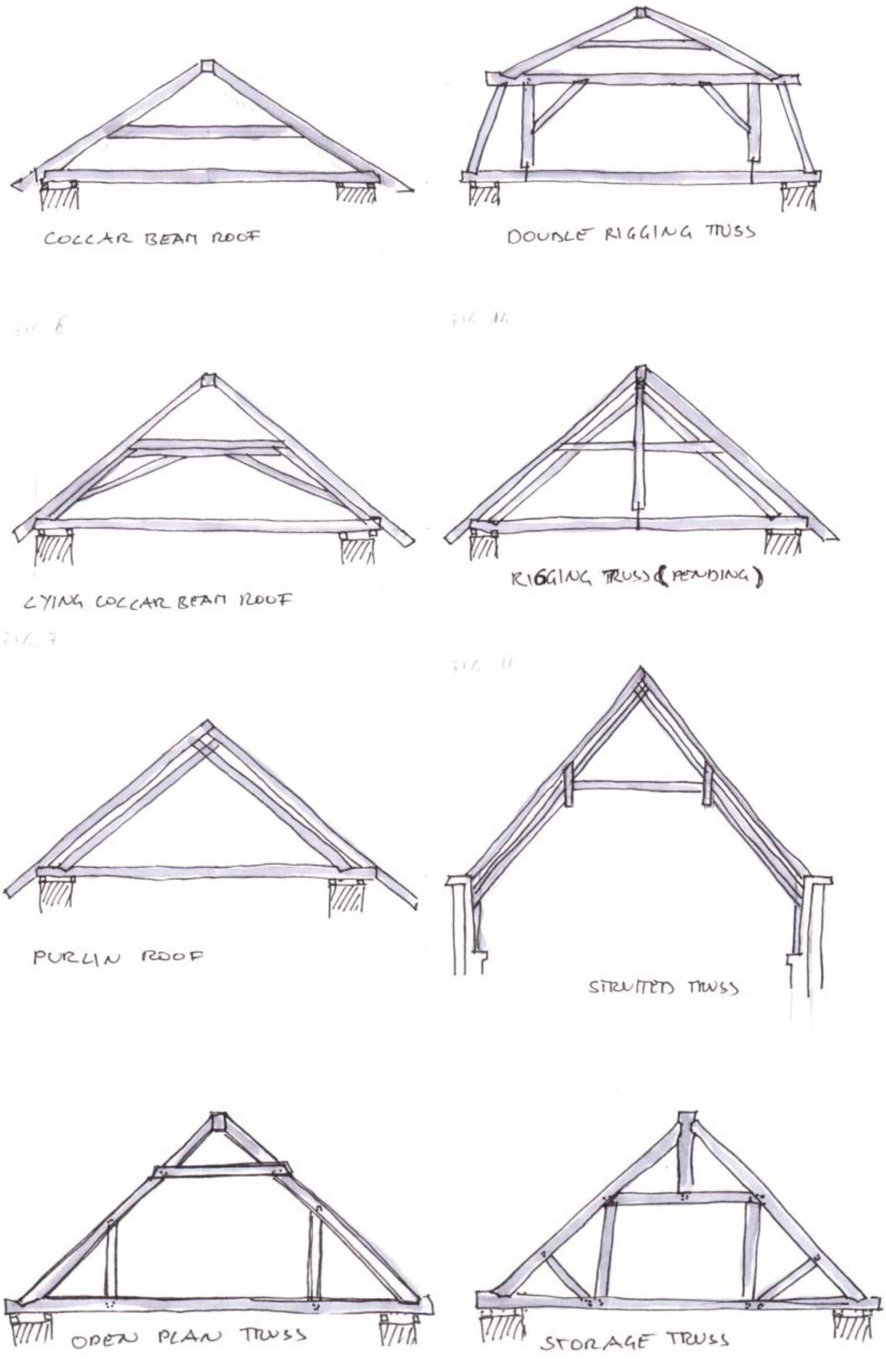
sketch 7

To get a quite complete list of possible joints the web side “www.modellbau-quendlinburg.de” can be very useful.

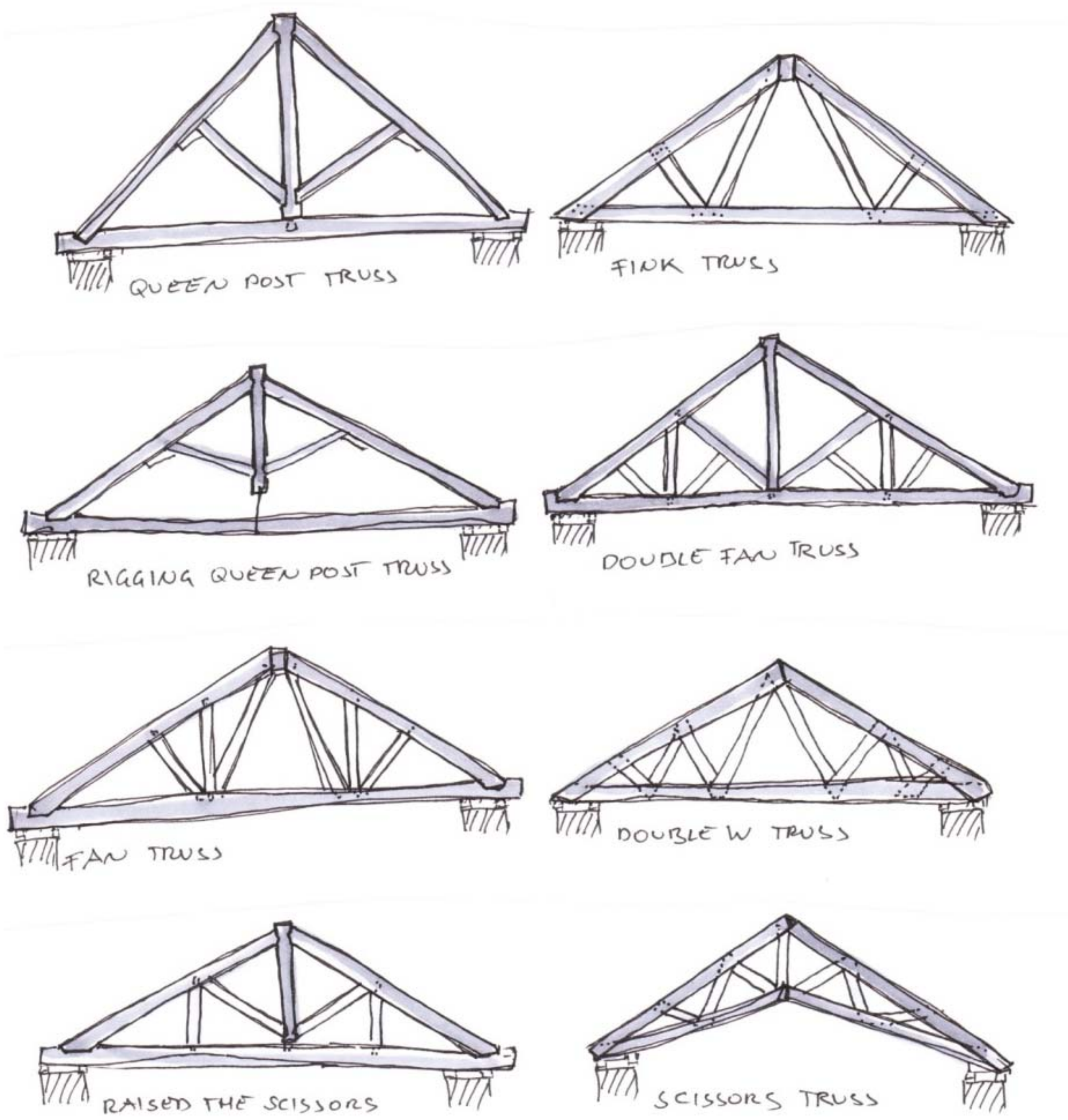
The size of the chords and the web configuration determine the span, load and spacing capacity of the structural element. In order how these elements are placed, different truss systems can occur. The most common truss systems, which are named according to their web configurations, are:
The simplest form of a truss, which consists only of one single triangle is known as the SIMPLE truss. It is shaped so as to have a near equal pitch on both sides of a centre peak. Another very common and simple truss is the KING POST truss which has additionally to the basic triangle one central vertical post dividing the equilateral triangle into two right- angled triangles. It is often combined with two angled struts.
A variation of this truss is known as the Italian King post truss, in which the king post (which is normally under tension and requires quite sophisticated joints with the tie beams and principal rafters), at his lower part (joint tie beam - king post) is replaced by a tension tie (metal element, usually rough iron).
Queen Post truss is a roof truss with two principal rafters and two vertical Queen posts with a restraining tie beam at the bottom and a straining beam at the top. The advantage of the Queen Post Truss is not only its ability to span greater distances than the King Post truss but mainly the box nature formed between the horizontal and vertical members allows access along the length of the building within the roof space.
Further types of trusses are for example the W-type or Fink Truss and the Scissors, or cathedral Truss, which allow even greater spans.



sketch 8


COLLAR BEAM ROOF
DOUBLE RIGGING TRUSS
LYING COLLAR BEAM ROOF
RIGGING TRUSS (PENDING)
PURLIN ROOF
STRUTTED TRUSS
OPEN PLAN TRUSS
STORAGE TRUSS

sketch 9



sketch 10

THE HISTORY of WOOD ROOF TRUSSES

According to *U. Barbisan* and *F. Laner*, the classical Greek structures, which look quite similar to the trusses we know now can´t be seen as a truss because the bottom chord (tie beam) bears on pilasters and is not working for himself. In Vitruvius writings “De architecturae”, first century before Christ no structures similar to a truss were mentioned. This means that the first trusses must have been constructed later, maybe the first trusses have been built with a roman technique around 300 to 500 after Christ. It is likely that they have been developed out of previous experiences with inclined beams used for roofs of churches or temples. It is difficult to prove because there is nearly no material (regarding trusses) left out of these centuries.
From this point on the trusses dispersed all over Europe and developed further on in different ways depending on the geographical and climatic conditions of the

area. Meanwhile in the Mediterranean Europe the trusses had a reduced inclination of the rafters (high wind loads), in the north of Europe the inclination augmented, because like this the high snow loads could fall of the roofs. These additional loads lead to very advanced, hyper – static constructions in these regions. In the septentrional regions tree dimensional structures with extremely high inclinations developed. As the roofs in these areas have often been used, the tie beams (bottom chord) of the trusses worked not only for the stability of the truss, but they are as well the structure of the floor.
In the renaissance *J. Mariano* proposes the first trusses without a tie-beam at the bottom. He compared his system with an arc. He also proposed a common system with a bottom chord, where the beam and the king post in the middle are strongly fixed, like all the antic truss systems.
Also the truss system Andrea Palladio, the Italian Renaissance architect, suggested has a rigged connection at the joint bottom chord- king post. He added to the common system some web members to get an even better and stiffer static system. He inserted these elements mainly for safety reasons. He wrote that in case of failure of a joint (for example Bottom chord-rafter) an added web member next to the connection point can overtake the forces and the whole structure is not necessarily in danger.
In the renaissance *Leonardo D. Vinci* made virtual experiments to optimise the equilibrium of a truss. He valuated the trusses according to their capacity meanwhile he stressed the tie beam under traction.
After the renaissance the truss systems changed into vary forms applications. The roof trusses stayed, but the triangles conquered also bridges. They started to construct truss systems substituting the arch structures (Of course not entirely!).
In the 18^{th} century *J. Leupold* has been one of the first, who considered the influence of different cross sections. He wrote about streaked timber beams, which have variable heights.
In 1729, *B. F. Belidor* wrote about the composition of the sloped rafters, based on structural analyses of the truss.
L. de Vegni proposed in the 18^{th} century a precise valuation how a truss works. He wrote that it has always been assumed that the (bottom chord) tie beam pushes directly against the walls. But everything working together is like a machine, which is dividing and guiding the loads in a way that the forces arrive in perpendicular direction on the bearing. Also *F. Milizia* wrote a similar theory in the same time period.
Jean-Baptiste Rondelet, the architect and architectural theorist of the late Enlightenment era, has been observing the deformations of and assumed that they occur mainly because of defects on the timber itself, or on too small dimensioned members. Further Rondelet said, that the truss system has to be triangular to be convenient.
The sience of the nineteenths century has been very interested in trellis-works and trusses, not seen as single elements but as a huge together. In 1847, the German mathematic A.F. Mobus said that a truss with pin-connected members must be entirely composed of triangles to be stable. He created a formula to achieve the condition of stability in a truss:

$$a = 2n - r$$

where *a* is the total number of truss members, *n* is the total number of joints and *r* is the number of reactions (equal to 3 generally) in a 2-dimensional structure. This was already a first step, but it was not sufficient. In a structure out of multiple members the arrangement of the timber elements has to be considered. Also new materials and ever larger structures made it necessary to think about increasingly sophisticated testing techniques and analytical methods.
In 1843, the English H. Moseley, thinking about the stability of the overturning of piers, analyzed the relations of a truss under various load combinations.

At the end of the nineteenth century it was necessary to design bridges with wide spans, which are able to carry high loads (railroads), major advances in design theory, graphic statics, and knowledge of material strengths were achieved. Bridges had to be precisely calculated. The levels of stresses in all bridge members had to be determined. Squire Whipple was the first, who proposed a design solution in 1847. His major breakthrough was that truss members could be analyzed as a system of forces in equilibrium. His system is known as the "method of joints". Some years later another American rethought the hypotheses of Whipple. H. Haupt generalised in its: General Theory of Bridge Construction" (NY, 1851) the thoughts of Whipple.
In 1850 the Russian scientist, Nikolai Yegorovich Zhukovsky, wrote about a method to reduce the forces, while J. Weisbach wrote the first manual in central Europe how to analyze the stresses in truss members. His formula is H=SG/h

$$H = S \cdot G / h$$

where *H* is the load arm, *G* is the load and *h* is the height of the truss. If S gets substituted by S=L/4 and G=qL/2 you get the correct formula of an arch with tree hinges:

$$H = (L/4) \cdot ((qL/2)/h)$$

In 1862 Wilhelm Ritter was the first one who said it is necessary to test a structures always with full scale load tests to receive valid results and he developed a further advance in design to calculate the forces in a truss: the "method of sections". He simplified the calculations of forces by developing a very simple formula. This allowed Ritter to determinate the forces in the members intersected by their cross-section. The two dimensional truss gets cut into two parts, in a way that maximal tree members are cut (two of them have to intersect in the same point). The members can be calculated according to the equilibrium conditions, because like this it is possible to create three linear independent equations.

$$\sum M = 0, \sum V = 0, \sum H = 0$$

In the three dimensional space it works in the same way only that six members have to be cut and six linear independent equations have to be created. On trusses with a parallel bottom and top chord the method of Ritter is not applicable.

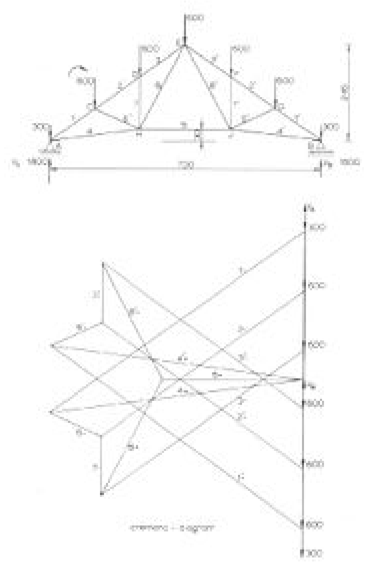


Illustration 26 Cremona diagram for a plane truss

To resolve this problem, the next try was a better method of graphical analysis, developed by a German structural engineer named **Karl Culmann**. According to him drawing is the way to communicate for an engineer. This is why Culmann was a pioneer of graphical methods in engineering, and published in 1865 his seminal book on the topic, Die graphische Statik (Graphic Statics).
Based on this method the Italian mathematician **Luigi Cremona** developed the Cremona diagram, which is a graphical method used in statics of trusses to determine the forces in members. The Cremona method can be translated to asymmetrical loads (wind loads) as well.
Another calculation method was developed by Alfred Clebsch, a German mathematician. He calculated the forces in the elements according to the displacements in the joints. James Clerk Maxwell, a Scottish theoretical physicist and mathematician mixed the graphical with the analytical method and developed a system to evaluate the displacements of the joints, in his book *Displacement Current, and Symmetry*

(1963). He worked together with O. Mohr, who specificities that the deformations of trusses are caused by displacements of the joints, which could have been caused by: external forces (snow wind), variations of the dimensions (too small cross section), different thermal conditions, material defects, or disconnections (joints).
Till the end of the nineteenth century these findings have been frequently applied on truss structures, especially in the Anglo Saxon area where the Maxwell diagram is still in use.
Two further methods to determine the deformations and displacements in trusses have been developed by M. Williot, in 1877 and H. F. B. Müller – Breslau, in 1887.
To obtain an approximate value for the displacement of a structure under a certain load, the graphical method Williot diagram can be used. In the diagram, a graph represents the structural system. The structure's fixed vertices are considered as a single, fixed starting point and from there sequentially adding the neighboring corner points' relative displacements due to forces.
With the Müller-Breslau principle influence lines can be determined. According to the principle, the influence lines of forces or moments can be assumed measuring the deflection that the structure displays after removing the restraint (on the point where the force acts) and applying a point that causes a unit displacement.
The Italian engineer, G. Colonetti studied the work of Müller - Breslau and wrote a volume about the same argument. The modern techniques to analyze trusses have been influenced a lot by his work.
In the second half of the twentieth century Odone Belluzzi, an Italian engineer, wrote two volumes about trusses in which he proposed some rules, how to calculate truss structures in a simplified way.
According to Belluzzi it can be assumed that:
-The connection points are hinges or pin-joints.
-The loads are applied only on the joints and not at intermediate points along the members.
-The live load of the members doesn’t have to be considered (exception: reinforced concrete).
-The elastic behaviour and the deformation of the members can be neglected (shear, bending moment, and other kinds of force are all practically zero).
-This means that every member of the truss is then in pure compression or pure tension.
Especially the last two arguments are the reason why trusses are such efficient structures, because most materials can hold a much larger load in tension and compression than in shear, bending, torsion, or other more complex stresses.
After Belluzzi, new software changed the way of calculating trusses completely (though especially the Ritter and Cremona method are still in use). The static programs, which are used for structural analysis of any type of trusses, can carry out all necessary calculations. The software uses matrix methods such as the direct stiffness method, the flexibility method or the finite element method (most common one).
Today with the prefabrication and the cross laminated timber, timber trusses get interesting again. The shape of trusses have not changed over the years but the make-up, spans possible and the safety has augmented, mainly because of the better possibilities to calculate these structures. Instead of pieces of logs now sawn lumber or laminated timber beams are used. The joints which were made by craftsmen, now are prefabricated using steel connector plates, nailed boards or plywood gusset plates.
For every use like multi-family residential, institutional, agricultural and commercial constructions trusses can be the most efficient solution, because they can be designed in almost any shape or size. Designing trusses however you have to be aware of the weak points of a truss structure. It is mostly not the structure

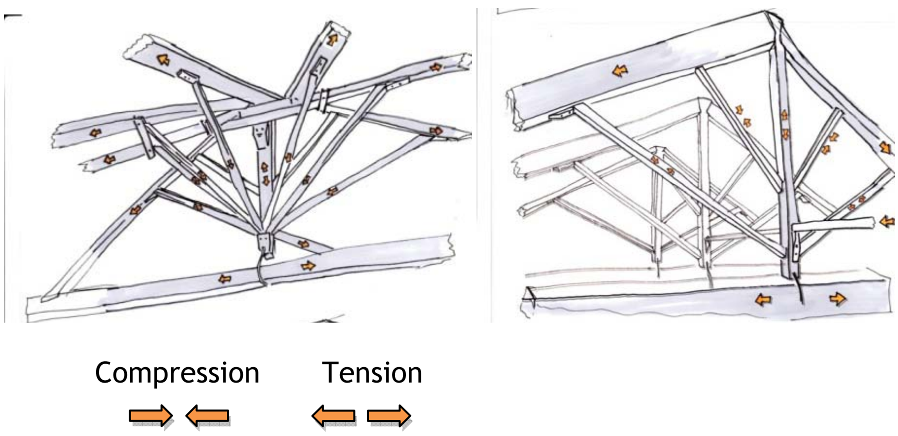
itself which may be inadequately designed for fire, windstorm and earthquake, which of course can cause major damage, but the most common failures are caused by overloading with roofing and re-roofing, inadequate repair, attic spaces used for storage and mechanical equipment, improper cutting or drilling for convenience and weather related influences, or simply improper use or lack of maintenance. It is anyway difficult to find evidence and therefore more often than not, the trusses are blamed.

3.2. Working group

Measurements:
Most of the measurements were taken out of the plans of Arch. D. De Luca.
Missing once taken by P. Panosch.
Plans:
Floor plans and sections of the choir and main aisle have been drawn by Arch. D. De Luca, modified by P. Panosch.
All other sections:
Drawn by P. Panosch
Hand drawings:
Drawn by P. Panosch
Static analyses:
Calculated by P. Panosch, controlled by Dr. Y. Amino

3.3. Characteristics of the timber structure

3.3.1. Choir



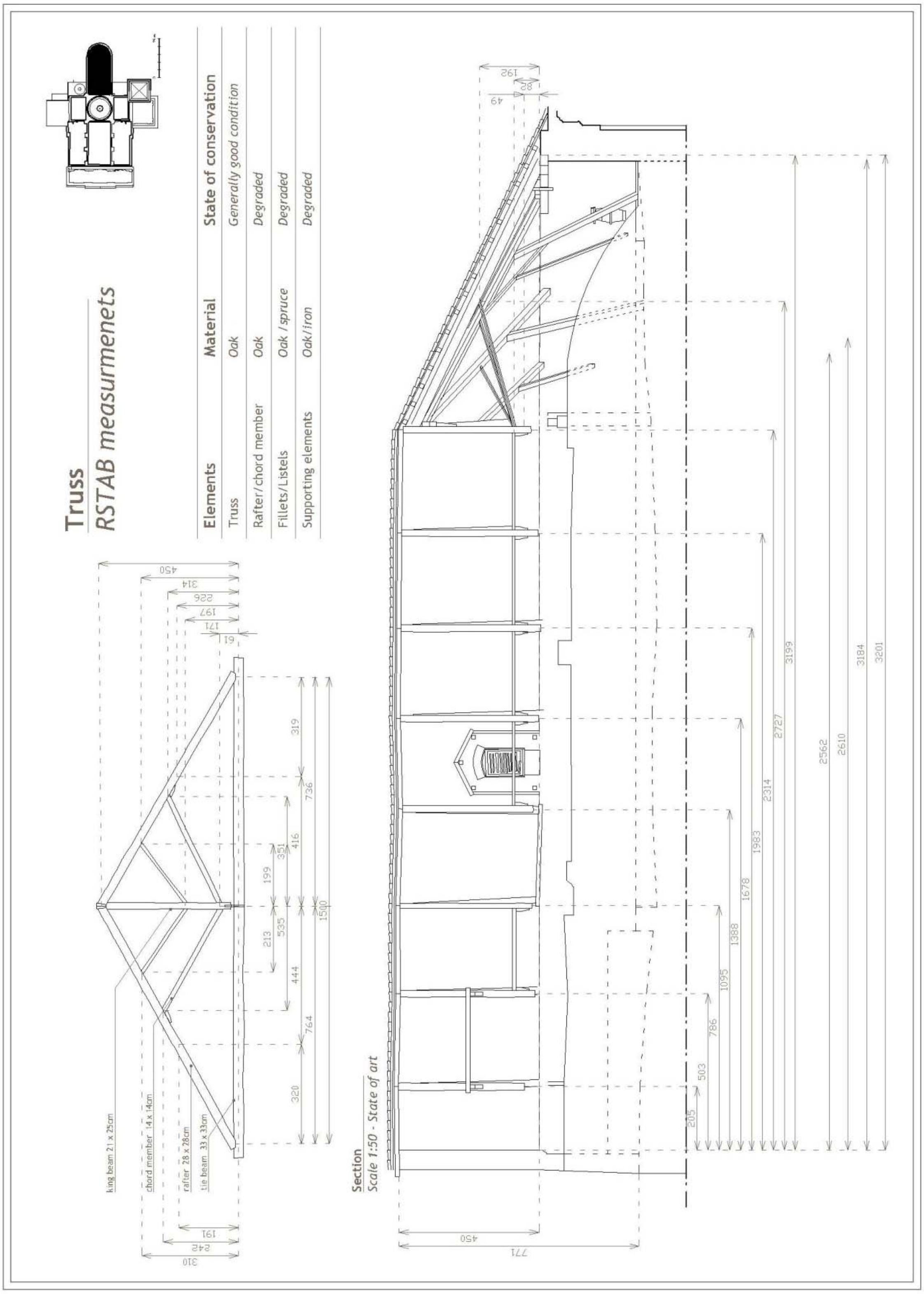
sketch 11

3.3.1.1. Static characteristics

The Choir consists of 8 Trusses (every 3 meters), with a span of 15 meters. Every Truss has a Bottom chord (Tie beam) and two top chords, which build the basic triangle. The top cords are also the rafters of the pitched roof. The trusses have in addition to the basic triangle one central vertical post dividing the equilateral triangle into two right- angle triangles. This is the king post; the post itself is interrupted at the joint with the bottom chord and at this point to support the tie beam and to avoid too big deformations in the middle of the chord a metal tension tile connects the two elements. However the main function of the king beam is to stiffen the joint on the ridge (rafters) and to carry the two angled struts (web members with an inclination), which are connected to the rafters. This system is very common in Italy, with the exception that instead of one strut on each side of the truss, there are two.
The ridge beam of the structure is missing. This means that all the little beams (third order) on top of the rafters have to transmit the loads in the longitudinal direction of the choir.
An "umbrella construction" on the east end of the structure also helps to distribute the forces. The loads which are taken by this structure are transmitted

over beams connecting the king posts. It is likely that these loads originally have been contributed over all 8 trusses, now some of these connecting elements are missing and only the first 5 trusses are connected. These forces caused high deformations. This umbrella construction is extremely interesting, because on the kingpost (truss apses) are arriving 9 struts, which is very uncommon!

3.3.1.2. Isometric drawing



Plan 2

3.3.1.3. Optimised static model RPLAN

In the thesis I limited the calculations to the trusses, as they are the most frequent element. Some calculations which have been done additionally (also 3D), regarding the apses and the loads perpendicular to the trusses are in the attachment (point Further calculations).
The load bearing capacity of the truss has been modelled assuming an optimal condition of every single timber element. Because the forces in each of its two main girders are essentially planar, a truss has been modelled as a two-dimensional plane frame.
A truss is a structure comprising a triangular unit constructed with straight members whose ends are connected at joints referred to as nodes. External forces and reactions to those forces are considered to act only at the nodes and result in forces in the timber elements which are either tensile or compressive forces. This means that torsional forces (moments) are excluded because, doing the calculations, all the joints in a truss are treated as revolutes.
The load cases which have been calculated are: the one for the permanent death load, a combination of death and snow load, death and wind load and for a combination of death, wind, snow and living load. As already mentioned, the connections are assumed as hinge joints.
To get detailed information about the assumed loads used for the model have a look at the attachment point Loads.
The values (max. stress, modulo of Elasticity…) for oak timber have been taken out of table (**Maximum stresses of on site timber of the load bearing system UNI 11119:2004/ see point Loads)**

If your table does not show the maximum stresses allowed in application of admissible stresses, the values can be adapted as follows:

$$X_d = \frac{K_{\text{mod}} \cdot X_k}{\gamma_m}$$

X_k the characteristic value of a strength property

$K_{\text{mod}} = 0.9$ the modification factor taking into account the effect of the duration of load and moister content(EN14081;EN 14080)

$\gamma_m = 1.3$ partial factor for a material property

Loads:
L= 23,06m (8 compartments)
Influence length 23.06/8 = 2.88 ~2.90m

Tile roof covering

$G_{k,tile} = 0.45 kN/sqm \cdot 2.9 = 1.305 kN/m$

$\gamma_G = 1.35$

Timber (Oak)

$G_{k,timber} = 8.00 kN/m^3$

$\gamma_G = 1.35$

The weight of the structural parts is considered in the model

Battens 4x4cm

$0.04 \cdot 0.04 \cdot 14 \cdot 2.9 \cdot 8 \cong 0.52 kN$

$\sqrt{(450)^2 + (1446/2)^2} = 851.60 cm$

$0.52/8.516 \cong 0.062 kN/m$

$G_{k,sum} = 1.305 + 0.062 = 1.367 kN/m$

Snow load (DM 14.01.2008: 3.4)

$G_{k,snow} = 1.24 kN/sqm \cdot 2.9 = 3.596 kN/m$

$\gamma_{Q,snow} = 1.5$

The program calculates the 30° roof automatically (depending how you let the forces act). For a manual calculation however the angle has to be considered:

$G_{k,snow} = 3.596 \cdot \cos 30° \cong 3.114 kN/m$

Wind load
Case D:

$Q_{k,above} = 0.704 kN/sqm \cdot 2.9 = 2.0416 kN/m$

$Q_{k,above} = 0.493 kN/sqm \cdot 2.9 = 1.4297 kN/m$

$Q_{k,above} = 0.211 kN/sqm \cdot 2.9 = 0.6119 kN/m$

Case D-C:

$Q_{k,above} = 0.704 kN/sqm \cdot 2.9 = 2.0416 kN/m$

$Q_{k,above} = 0.493 kN/sqm \cdot 2.9 = 1.4297 kN/m$

$Q_{k,below} = -0.070 kN/sqm \cdot 2.9 = -0.2030 kN/m$

$Q_{k,below} = -0.141 kN/sqm \cdot 2.9 = -0.4089 kN/m$

$\gamma \cdot \psi = 0.6 \cdot 1.5 = 0.9$

Live load

$Q_k = 0.5 kN/sqm \cdot 2.9 = 1.45 kN/m$

$\gamma \cdot \psi = 0.6 \cdot 1.5 = 0.9$

<u>Load combinations</u>
Stress analysis:

$\sum \gamma_{G,j} \cdot G_{k,j} + \gamma_{Q1} \cdot G_{k,1} + \sum_{i \geq 1} \gamma_{Q,i} \cdot \psi_{O,i} \cdot Q_{ki}$

Case D[5]:

$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.596 \cdot 1.5 + 2.0416 \cdot 0.9 + 1.45 \cdot 0.9 =$

$10.38189 \cong 10.38 kN/m$

[5] Inclination not considered

$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.596 \cdot 1.5 + 1.4297 \cdot 0.9 + 1.45 \cdot 0.9 =$
$9.83118 \cong 9.83 kN/m$
$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.596 \cdot 1.5 + 0.6119 \cdot 0.9 + 1.45 \cdot 0.9 =$
$9.09516 \cong 9.10 kN/m$

Case D-C[6]

$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.596 \cdot 1.5 + 2.0416 \cdot 0.9 + 1.45 \cdot 0.9 =$
$10.38189 \cong 10.38 kN/m$
$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.596 \cdot 1.5 + 1.4297 \cdot 0.9 + 1.45 \cdot 0.9 =$
$9.83118 \cong 9.83 kN/m$
$Q_{ges,wind,suck} = 1.367 \cdot 1.35 + 3.596 \cdot 1.5 - 0.203 \cdot 0.9 + 1.45 \cdot 0.9 =$
$8.36175 \cong 8.36 kN/m$
$Q_{ges,wind,suck} = 1.367 \cdot 1.35 + 3.596 \cdot 1.5 - 0.4089 \cdot 0.9 + 1.45 \cdot 0.9 =$
$8.17644 \cong 8.18 kN/m$

Case D (considering the inclination):

$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.114 \cdot 1.5 + 2.0416 \cdot 0.9 + 1.45 \cdot 0.9 = 9.65889 \cong 9.66 kN/m$

$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.114 \cdot 1.5 + 1.4297 \cdot 0.9 + 1.45 \cdot 0.9 = 9.10818 \cong 9.11 kN/m$
$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.114 \cdot 1.5 + 0.6119 \cdot 0.9 + 1.45 \cdot 0.9 = 8.37216 \cong 8.37 kN/m$

Case D-C[7]

$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.114 \cdot 1.5 + 2.0416 \cdot 0.9 + 1.45 \cdot 0.9 = 9.65889 \cong 9.66 kN/m$

$Q_{ges,wind,pressure} = 1.367 \cdot 1.35 + 3.114 \cdot 1.5 + 1.4297 \cdot 0.9 + 1.45 \cdot 0.9 = 9.10818 \cong 9.11 kN/m$

$Q_{ges,wind,suck} = 1.367 \cdot 1.35 + 3.114 \cdot 1.5 - 0.203 \cdot 0.9 + 1.45 \cdot 0.9 = 7.63875 \cong 7.64 kN/m$
$Q_{ges,wind,suck} = 1.367 \cdot 1.35 + 3.114 \cdot 1.5 - 0.4089 \cdot 0.9 + 1.45 \cdot 0.9 = 7.45344 \cong 7.45 kN/m$

According to the UNI 11119:2004 the Maximum Stresses (Tension or Compression parallel to the grain) for oak of the I[st] category have to be under 12 N/mm^{2}, for oak of the II[nd] category have to be under 10 N/mm^{2} and for oak of the III[rd] category have to be under 7,5 N/mm^{2}.
The highest load that occurs is $10.38 kN/m$ $9.66 kN/m$ devided by the width of the beam (0.21m) the load is $49.43\ kN/m^2$

Deformation:
$\sum 1 \cdot G_{k,j} + 1 \cdot G_{k,1} + \sum_{i \geq 1} \gamma_{Q,i} \cdot \psi_{O,i}$

[6] Inclination not considered
[7] Considering 30° inclination

Case D[8]:

$$Q_{ges,wind,pressure} = 1.367 + 3.114 + 2.0416 \cdot 0.5 + 1.45 \cdot 0.5 = 6.3368 \cong 6.34 kN/m$$

$$Q_{ges,wind,pressure} = 1.367 + 3.114 + 1.4297 \cdot 0.5 + 1.45 \cdot 0.5 = 5.92085 \cong 5.92 kN/m$$

$$Q_{ges,wind,pressure} = 1.367 + 3.114 + 0.6119 \cdot 0.5 + 1.45 \cdot 0.5 = 5.51195 \cong 5.51 kN/m$$

Case D-C

$$Q_{ges,wind,pressure} = 1.367 + 3.114 + 2.0416 \cdot 0.5 + 1.45 \cdot 0.5 = 6.3368 \cong 6.34 kN/m$$

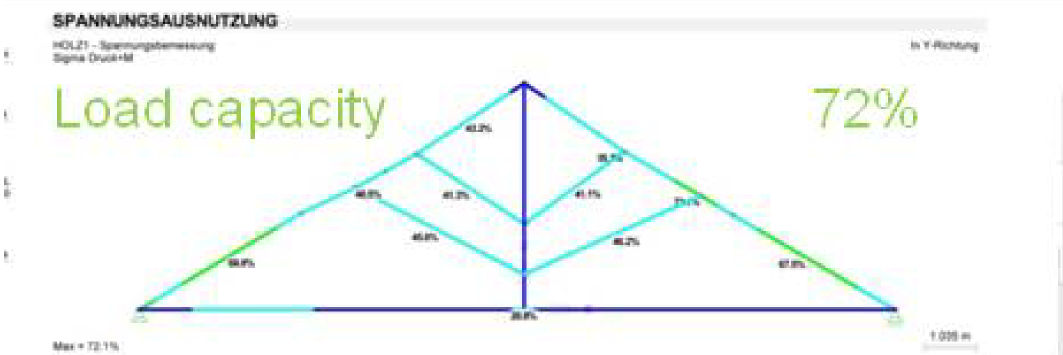
$$Q_{ges,wind,pressure} = 1.367 + 3.114 + 1.4297 \cdot 0.5 + 1.45 \cdot 0.5 = 5.92085 \cong 5.92 kN/m$$

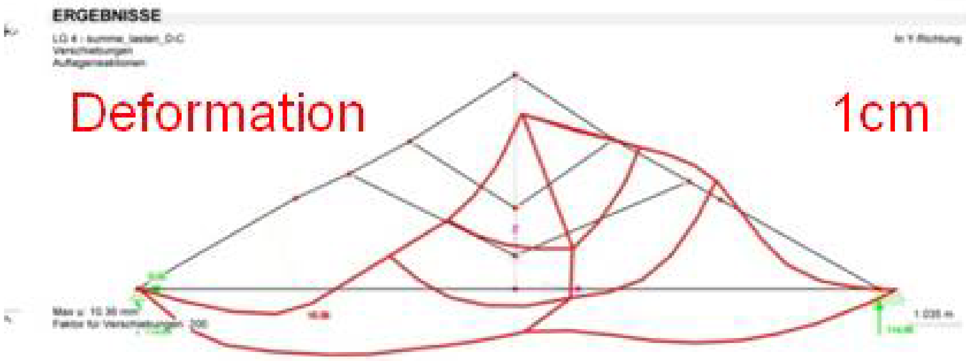
$$Q_{ges,wind,suck} = 1.367 + 3.114 - 0.203 \cdot 0.5 + 1.45 \cdot 0.5 = 5.1045 \cong 5.10 kN/m$$

$$Q_{ges,wind,suck} = 1.367 + 3.114 - 0.4089 \cdot 0.5 + 1.45 \cdot 0.5 = 5.00155 \cong 5.00 kN/m$$

$$\delta \leq 300$$

Results for the load case D-C (highest loads):

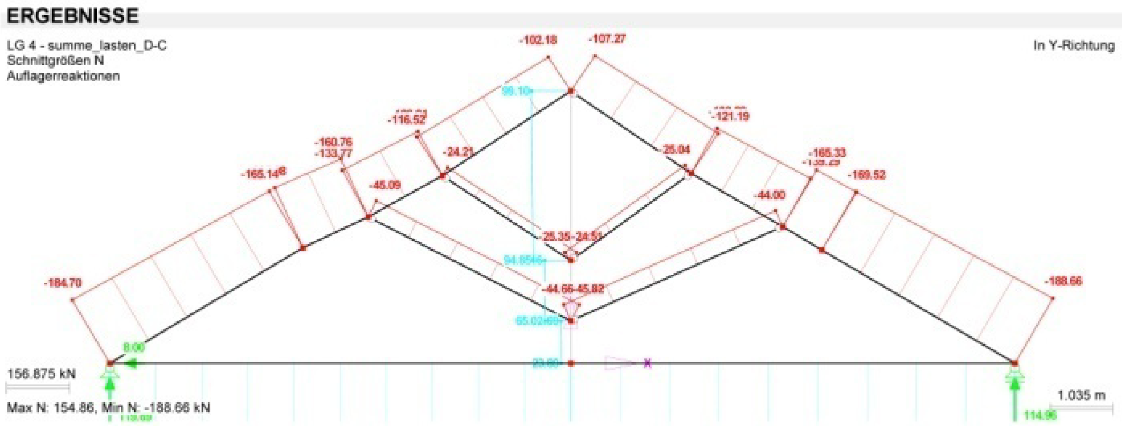




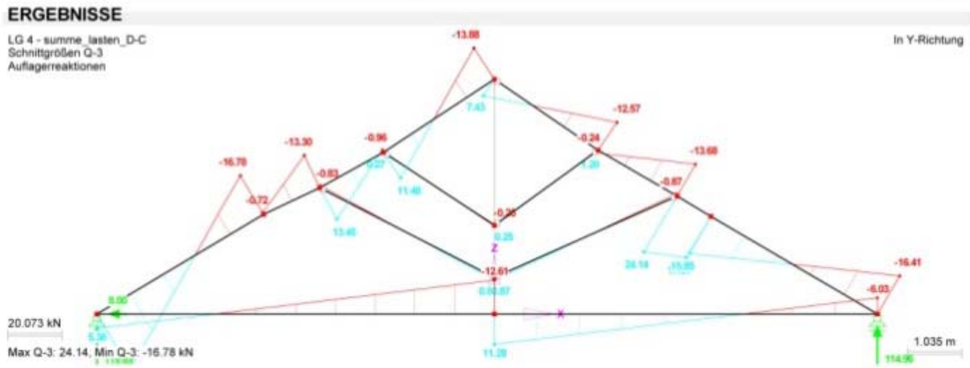
If the truss has no damaged areas at all, it is more than sufficient. The load capacity lies by 72% and the Deformation is 1 cm. considering that the truss has a span length of about 15.50m this is nearly no deformation.
The element which has the highest load to carry is the rafter.

The following picture shows the axial force working on the beams.

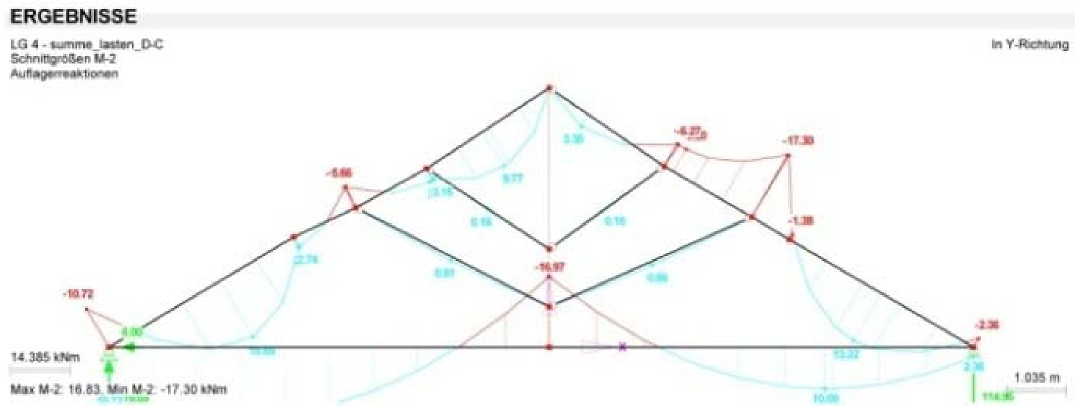
[8] Considering 30° inclination



The following picture shows the shear force working on the beams.



The following picture shows the axial force working on the beams.



Result: No problem found!
Further results (forces in the various beams and other load cases) can be found in the attachment (point RSTAB report).

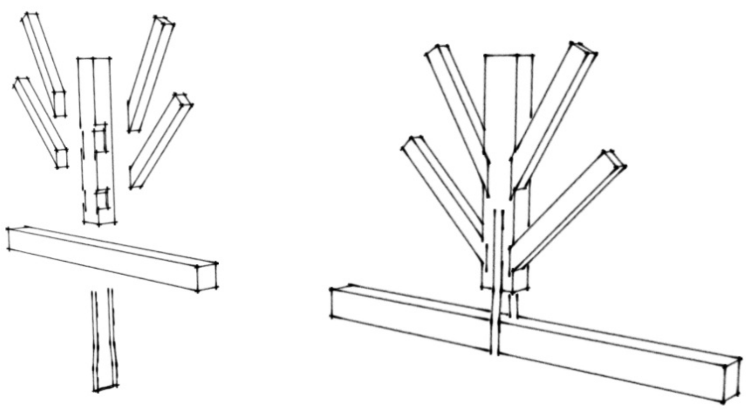
Further Parts of the cathedral (transepts, aisles,…)can be found in the Attachment.

3.4. Details

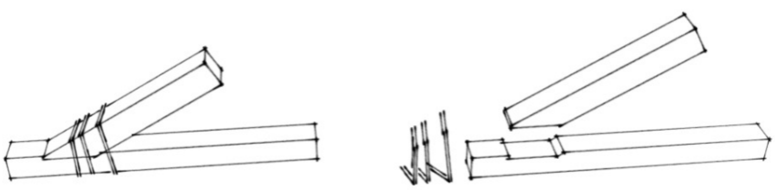
Nearly all of the joints are carpenter connections.
The most interesting joints we can find in the choir and the main aisle (very similar).
A very unusual and complicated detail is the point where the umbrella construction intersects with the king post. The difficulty is that 6 elements intersect in the same point. To increase the area of support for the 5 timber struts, a timber piece has been nailed on the king post.

The truss connections:
The points on the bearings of the wall where the rafter and the tie beam intersect is a face staggered joint and the connection between the two rafters and the king post is a kind of dove tail connection.
Most of the connections of the struts are joined with simple nails and where it was necessary some little timber elements have been added to ensure to maintain the position of the webs. In other cases some little "bird mouths" have been cut into the king post or the rafters to reinforce the connection.

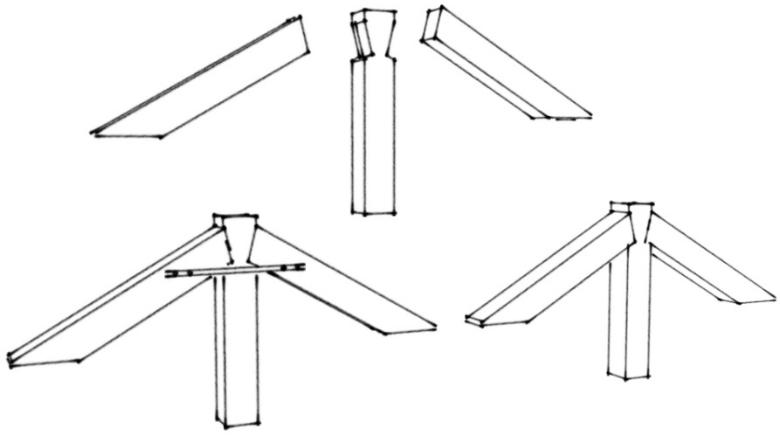
At the joint (main aisle) at the ridge of the truss (rafters-king post) a metal element has been added to reinforce the connection. Other details that differ a bit from the choir are the timber elements which have been added on the rafters. On the first view it seems as if all the timber elements have been doubled, but they do not continue and that means that they have no static influence (except higher loads). The only use for these timber pieces is to change the inclination (rafter slope) of the timber structure.



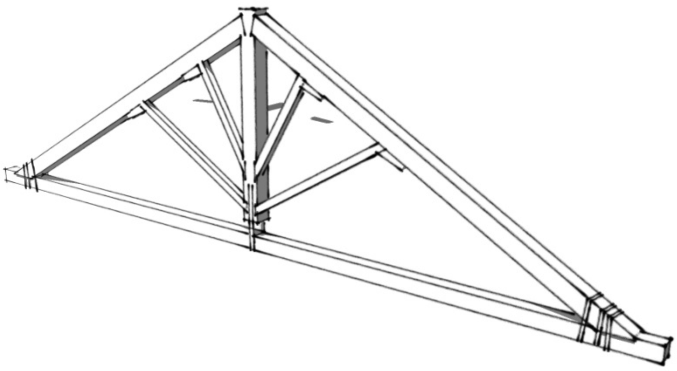
sketch 12 Connection tie beam - king post



sketch 13 Connection rafter – tie beam



sketch 14 Connection peak



sketch 15 truss

4 Diagnostics of the actual state

4.1. Basic inspection procedure

The definition of timber structure diagnosis according to the Italian standard UNI 11119:2004 is:
"assessment of the state of conservation and of the strength and stiffness characteristics of a structural timber member."

A diagnostic inspection is important because it gives detailed information of the conditions of a timber structure. Knowing the characteristics and critical zones of every single element helps to intervene only where it is necessary. The architect has the possibility to preserve the sane parts, and may even detect that the existing resistance section is still sufficient. Obviously it is important to know about the condition of the structure, because of safety reasons not only if the building is still in use, but also during works. An inspection allows planning interventions and site operations, which will save time and costs, compensating initial costs.

Before you start the inspection some conditions should be fulfilled to ensure the quality of the outcome. The structure must be accessible enough to perform the testing. The surface of the timber members must be clean and the lightning conditions must be sufficient to insure a correct visual examination.

The main objectives of the inspection are: to get information about the wood species of the timber members, the wood moisture content, the class of biological risk according to EN 335-1/2, the geometry and morphology of the elements including their position and the extension of main defects, decay or other possible damage, which means the position, shape and dimension of the critical zone and critical section. Finally a strength grading of every single timber member as a whole and/or in single critical zones has to be done.

4.1.1. Wood defects

The definition of wood defects according to the UNI 11119:2004 is:
"*wood feature which can negatively influence strength and stiffness, and/or on general structural behaviour (for example efficiency of joints) of timber members*."
(Italian Standard UNI 11119, 2004)

The standard describes further more important definitions:

Alteration: "*kind of modification to wood (biological, mechanical, chemical) or to metallic materials occurring after installation*."
(Italian Standard UNI 11119, 2004)

Mechanical damage: "*alteration of timber members or timber structures which appears as mechanical ruptures, caused by internal or external actions rather than by decay*."
(Italian Standard UNI 11119, 2004)

Decay: "*alteration from any kind of origin that always worsens the properties (in particular but not exclusively mechanical) of wooden material and metallic material. Biotic Decay: caused by biological agents (synonym: biodegradation); Abiotic Decay: caused by physical, chemical and mechanical agents*."
(Italian Standard UNI 11119, 2004)

Critical zone: "*part of a timber element with longitudinal axes no less than 150 mm, which is considered to be relevant for the diagnosis because of defects, position, state of conservation and also stress conditions which are determined by static analysis*."
(Italian Standard UNI 11119, 2004)

Critical Section: "*the cross section which is representative of a critical zone. All the defects, anomalies, alterations, damage and other characteristics that are present in the critical zone and have an influence on its strength are attributed to the critical section."*
(Italian Standard UNI 11119, 2004)

Efficient Section: "*The cross section of a timber member (including defects) which is determined excluding from the critical section all the areas where wood degradation and/or damage are eventually present*."
(Italian Standard UNI 11119, 2004)

State of conservation: "*State of a timber member in relation to alterations that are present*."
(Italian Standard UNI 11119, 2004)

It is important to know that generally wood doesn't decay only due to the passing of time (Manuale del Legno strutturale,Interventi sulle strutture, Vol IV, Chap. 3 Analisi e Verifica di Strutture di Legno Antiche, Torino 2004,A. Ceccotti) Theoretically the mechanical properties of a timber piece remain constant. But there are outer influences such as moisture or long time overloads, which make the wood vulnerable to biotic attacks (fungi, insects...), or weaken the wood itself. Therefore has every situation where wood is used as a structural element a favourable thermo – hydrometrical condition considering the timber biological decay.

<u>Water in wood</u>

Illustration 27wet beam

Wood is the product of the metabolic and physiological activity of woody plants. Because of its function in live plants, wood must be mechanically resistant (it sustains the weight of the crown, leaves, water, wind, snow etc.) and at the same time it must be porous: photosynthesis in the leaves requires water and inorganic substances (sap) to pass through the wood from the ground. Both these functions, mechanical support and sap conduction, are supplied by cells. Wood is composed of cells which are characterized by a solid wall surrounding a lumen. The wood cells are fusiform and about 90% of the cells in the wood have a vertical orientation. The cell wall has a good mechanical resistance to traction and compression, and the cell lumen can be covered by the sap. (Crivellaro 2007)
It is important to know that there are two types of water into the wood: in a living tree the sapwood cell lumen is full of liquid water, the so called free water. The water inside the macromolecules that compose the cell walls is called bound water (chemically bound to the cellulose).
There is an important value of wood moisture content, the fibre saturation point, that represents the wood moisture content in which the cells lumen are without free water and the walls are full of bound water. The wood moisture content of the fibre saturation point is generally indicated as 30%.
The moisture content is directly related to relative wetness and temperature of the surrounding air, because the timber tries to reach equilibrium with its environment. Arriving at this point it is no longer gaining or loosing water. In general wood without liquid water contact has a moisture content of about 15-18%.The table below helps to estimate the wood moisture content
To get detailed information about the moisture content in a timber piece portable electric meters can be used (see Inspection procedures).

Table 3–4. Moisture content of wood in equilibrium with stated temperature and relative humidity

Temperature		Moisture content (%) at various relative humidity values																		
(°C	(°F))	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
−1.1	(30)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
4.4	(40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0	(50)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
15.6	(60)	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
21.1	(70)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
26.7	(80)	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
32.2	(90)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
37.8	(100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3	(110)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
48.9	(120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
54.4	(130)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
60.0	(140)	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
65.6	(150)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4
71.1	(160)	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
76.7	(170)	0.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3
82.2	(180)	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7
87.8	(190)	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1
93.3	(200)	0.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5
98.9	(210)	0.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9
104.4	(220)	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.8	9.9			
110.0	(230)	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6.0	6.7						
115.6	(240)	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6								
121.1	(250)	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	2.9										
126.7	(260)	0.2	0.3	0.5	0.7	0.9	1.1	1.4												
132.2	(270)	0.1	0.1	0.2	0.3	0.4	0.4													

Table 1

Page 3.7 (tab 3.4) file www.fpl.fd.fed.us/documnts/fplgtr/fplgtr/ch03.pdf

Movements in the wood and its deformations
When the wood dries the bound water leaves the cell walls and is transmitted into the air in the form of vapour. The bound water leaves the cellulose and it comes closer together: the wood shrinks.

The shrinkage and swelling is not uniform. As e mean, the total wood shrinkage in the axial direction is 0.5 %, in the radial direction 5%, in the tangential direction 10% and the volumetric total shrinkage is around 15%. This difference in dimensions changes causes defects which weaken the timber piece. Deformations (cup, bow, twist, diamonding) and cracks will occur. This means that drying the wood causes stresses and the timber member hence a tendency to split. Even with a careful production these fissures in the solid timber cannot be ruled out.


Illustration 28 ring shake

Also ring shake can occur, which is the separation between two consecutive growth rings. The species chestnut, fir, larch, and elm show this technologically important defect more often.

It is possible to minimise the risk of splitting and distortion in case of replacement of an element in the timber member, if the difference between the moisture content of the wood upon installation and the equilibrium moisture content of the structure are similar. A to high moisture content also influences the properties of wood in a negative way. The strength, the module of elasticity and the shear of the timber decreases if the moisture content of the wood rises.(Kollmann and Coté, 1968)
This leads to mechanical weakening and increases the water absorption at the surface, which can cause bleaching and efflorescence.

Illustration 29 fungi

But these are not the only problems of a damp soil, damp air, splashing water, condensation water and so on in the surrounding of a wood piece. Where wood with a high moisture content can't dry rapidly or the moisture content in the timber is beyond 20% the risk of biotic decay by fungi is given. Infestations by fungi which can discolour or worse destroy the wood are a serious problem.
A wood moisture content under 20% on the other hand side can lead to attacks of timber boring insects (for example *Coleoptera* (most common insect class) and *Isoptera*). They can excavate tunnels for their nutrition, to construct a residence, or to build their shelter.

Animals

Illustration 30 animals

About 20.000 species "hollow out" the wood for different reasons (food, net, shelter). Wood consists out of starch and sugars which become a glucose chain (by

photosynthesis process). For insects this is very attractive food because it is easy to digest with enzymes.
These insects are dangerous, because they bore holes in the surface and the cross section of the timber. Doing this they reduce the wood fibre and this leads to a loss of strength and a weak load carrying capacity of the wood element.
Some examples of other wood destroying animals are insects, marine borer organism, bacteria, woodpecker and mammals.

Direct sunshine

As well as the wetness the Sunshine (long waves and the UV radiation) and especially temperature changes can harm the timber. High temperatures can dry the timber and cause stresses which lead to leaks, fissures, gaps, damage to coatings. Sunshine and high temperatures in combination with a high moisture content can cause fungi attacks which lead to rot and destruction of the timber. The sunshine in this case the short waves and the UV radiation can lead to photochemical attack and decomposition of the wood macromolecules. This can provoke further on discoloration of the wood surface.

Wind

Wind can be responsible for the erosion of wood surface which can create leaks, especially in early wood.

Chemicals

Chemicals can protect wood but can also cause damages, especially in the zones of connections. Plastic and meal pieces can corrode and this can lead to the destruction of the joint. But also the wood surface itself can be destroyed by adverse effects on coatings.

Metals

One big problem is the extreme thermal conduction in metals: the metal can be a point where condensation water can be collected.

Defects in the wood itself

Wood defects do not occur only because of damage that was caused after the timber was sawn and brought to the sight, but also in the wood itself. The tree is a living organism and therefore the wood can’t have the same characteristics all over. These natural irregularities are defects, when they can influence the load bearing capacity of a timber element.

Grain direction

Wood is an anisotropic material it has different properties in different directions. Especially parallel or perpendicular to the grain (grain direction) the properties of timber change dramatically. While in the direction of its fibres (longitudinal cells) wood can carry high loads, especially in tensile strength, timber has nearly no load bearing capacity perpendicular to the grain.

Illustration 31 grain direction

Knots

Every tree has branches and to fix the branches on the trunk there has to be something working like an anchor. The knots are these parts of the branch included in the trunk.

Knots have a similar structure compared with the wood, but they are horizontally oriented. In structural beams this is a big problem, because wood is an anisotropic material and has nearly no resistance perpendicular to the grain. This is why in a load bearing element knots are considered like holes. To know if a knot is a

Illustration 32(Picture: Hoadley (2002) understanding the wood. The Tauton press)

problem in a beam the position and the dimension of the knot has to be taken into consideration. (Not all parts of a structure have to carry the same amount of load!)

Illustration 33 knots

Structural damages

To high loads in a structure can cause lesions and tree injuries like the disconnection of a joint, deformations of the structural element, or even breakages.

Already during the production phase of timber elements structural damages can arrive. Especially in ancient structures wane can occur, because the structural elements have not been automatically sawn, but chopped by hand. These missing edges have to be considered in a load bearing element.

Illustration 34 fracture

Summary of the defects that can occur:
Slope of the grain direction
Width of annual rings
Knots
Fissures
- Shrinkage splits/cracks
- Ring shakes

Deformations
Cup
Bow
Twist
Diamonding
Biotic decay
Fungi attack
Discoloration / Rot
- Blue stain

Brown/white rot
Brown/ red streaks
Insect attacks
Structural damages
Disconnection
Breakage
Deformation
Wane

4.1.2. Inspection procedures

Generally an inspection procedure should identifying physical and mechanical properties of a piece of material without harming the structure in a way that the load bearing capacity (end use) is affected. It is a reliability check to ensure the safety; it shows if the structure suffered of any deterioration due to time dependent actions like corrosion or fatigue and it gives information about every other kind of structural damage. Like this the design working life of the structure can be extended.

Relevant definitions according to the UNI 11119:2004 are:

"*Non destructive test: a test that does not influence the load bearing function of a given element; non destructive testing methods commonly used for on site diagnosis can produce major or minor impact on the timber member.*"
(Italian Standard UNI 11119, 2004)

"*Impact (non destructive testing): influence of a non destructive test (...) on the timber members functions other than that of load bearing (for example aesthetic, historical and other visible markings).*"
(Italian Standard UNI 11119, 2004)

There are 2 integrated inspection procedures. One is the visual inspection, to determine the original characteristics of each structural element and the eventual damages caused by biotic decay and structural damages. Additional to the visual inspection there is the instrumented inspection to identify the decay in inner and hidden portions of the elements.

4.1.2.1. Visual inspection

According to visual features the load bearing capacity of a timber element can be estimated. A whole series of properties are relevant for the grading according to its appearance. Therefore the first step is the identification of the wood species. Then the structural visual grading to get information about the defectiveness of the timber can be started. Structural damages (as breakages, disconnections, deformations) and biological decay (like fungi and insect attacks) have to be considered.
The first step is to get information about the dimensions and the shape of every single timber element. Geometric features like deformations and wane, especially those which cause decrease in strength, have to be detected. An observation on all visible faces should give information growth particularities such as irregularities like fork and slashes, or knots with at least 5 mm diameter. Also any other eventual damage or decay has to be distinct. The position and the size of the main defects have to be marked in order to determinate the critical zones of the timber member.

4.1.2.2. Instrumented inspection

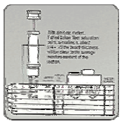
Tools

To get information about the moisture content if it is in between ~ 7-30% a electrical resistance moisture meter (pin-type meters) or a dielectric resistance moisture meter (non-pin meter) meter can be used. The instruments are portable and can be used directly on the sight. The instruments are suitable for square and round wood. To get a correct result the meter shall be equipped with settings for species and temperature and the measurements should be taken into the direction of the grain and in a certain distance to the edges. The area where the test takes place should be free from resin, bark, knots, or any other defect that can modify the outcome in order to receive a correct result. It is also important to know that both types of meters are not measuring the moisture content directly. They measure the electrical property of the timber piece; therefore some natural variation can occur.

Pin-type meters
Pins (needles) are driven (with a special hammer) into the wood. It is important that the needles achieve a certain depth, because

otherwise surface moisture can influence the result. These pins work like electrodes which measure the electrical resistance in between. Converting this information the meter can estimate the moisture content of the timber element.

Non-pin meter
It has a slightly bigger effective range then the Pin-type meter; it covers a range of about 5 to 28% moisture content. The non-pin or



dielectric meter doesn’t penetrate the timber, but uses a sensor plate. This metal plate is placed in direct contact with the wood surface and measures the dielectric constant or power-loss factor in order estimate the moisture content of the timber element.

Illustration 35 meters

Inspection according to the resistance

Illustration 36 resistograph

Additionally to the visual inspection an estimation of mechanical characteristics of ancient timber can be executed to detect the inner decay in hidden and non accessible zones of wood piece.

To measure the structural resistance of timber different methods can be used. The easiest way is Peering and poking with a common screw driver, or any other instrument able to penetrate the timber. A more sophisticated one is the exploratory drilling. In this case a dynamometric driller (Resistograph) measures the drilling resistance:
A needle with a diameter in between 1.5 - 3 mm enters the wood with a regular advance. The force that has been necessary to penetrate the timber element is recorded or directly printed out on a paper or wax paper strip (scale 1:1). The drill or rather the accrued hole harms the wood only insignificantly.

There are other dynamic techniques which measure the sound (Sounding) and ultrasound velocity (Ultrasound scanning) or the transversal/longitudinal vibrations. This can be very useful for timber pieces which are not accessible, because they are covered by another elements (for example floors).

On the following pictures describe some inspection procedures.

fibre inclination
(straight element)

cross section
(ruler)


resistance of the surface
(screwdriver)

(screwdriver and hammer)


sound (wood still alive?)

sample of weakened timber (hammer)


Sound test
(Hammer)

closer look
(Torch)

Illustration 37 visual inspection

Further basic instruments which are necessary for the inspection are: a pen and a piece of paper to document the defects, dimensions and other information, a light to make the inspection easier, different brushes to clean the wood surface, a measuring tape to get the dimensions, screwdrivers to see how deep you can penetrate the timber element in order to know how the condition of the outer parts of the structural elements are and an elastic stick to find out how deep a crack or an insect hole enters the wood, a drill to see how much resistance the timber has in the inner parts and a hammer to hear if the wood is still alive.

Summarised the aim of every inspection is to collect information to determinate the dimension, the position and the shape of the structural element including its defects (decay, fractures or other damages) to identify the critical zones, the wood species, the moisture content and the biological risk to start with the strength grading.

4.1.3. Grading (UNI 11119:2004)

The main aim of the grading is to find out if the wood is still sound, has enough resistance and if repair or strengthening is needed.

The definition of strength grading according to the (UNI 11119:2004) standard is: *"a procedure through which a single timber member can be classified into categories which define a level of mechanical performance "*
Performance: "physical and mechanical properties of a graded structural timber member."

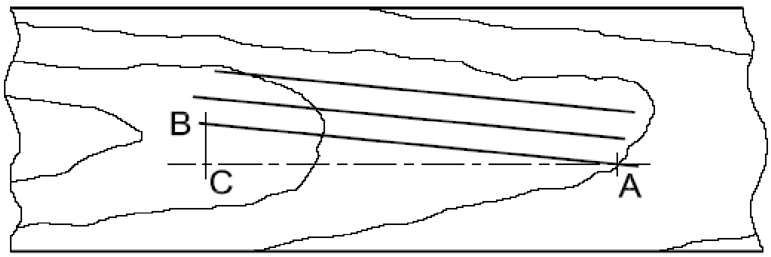
Grading a timber structure some rules have to be followed.
It is not enough to grade the whole system; every single element has to be classified separately and if necessary also every critical zone of the structural timber. The whole element has to be examined carefully and particular attention should be taken on the higher stressed parts of the element. The conditions under which the inspection has taken place have to be taken into consideration. It is important that at least 3 sides of the timber member have been checked. If there wasn't enough light or the surface of the timber wasn't clean this has to be mentions in order to get a better result. If the timber elements show areas of decay (alteration due to mechanical damage or biological attacks such as fungi or insects…), these parts have to be completely excluded from the efficient cross section. In the case that the whole element is affected for example by an insect attack the whole cross section can be taken into account, reducing the physical and mechanical properties of the timber.
It is not permitted to grade a piece in between two classes. The lower class has to be used. Species which are not mentioned by the standards can be graded referring to a species with similar characteristics (in wood anatomy and properties). The instrumented inspections should always be taken in the critical zones of the wooden member and must not weaken the load bearing capacity of the structural element.
Having all the necessary information the timber member can be graded according to table 2 (UNI 11119:2004).

Feature	On site grade		
	I	II	III
Wanes	1/8	1/5	1/3
Various damages (frost cracks; ring shakes)	absent	absent	admissible only if limited
Single knots	≤1/5	≤1/3	≤1/2
	≤50mm	≤70mm	
Group of knots	≤2/5	≤2/3	≤3/4
Slope of grain in radial section	≤1/14 (-7%)	≤1/8 (-12%)	≤1/5 (20%)
inclination% in tangential section	≤1/10 (10%)	≤1/5 (20%)	≤1/3 (-33%)
shrinkage	Admissible if not passing through the pith		

checks	

Table 2 (UNI 11119:2004)

This brings us to the next problem, how to measure the single defects:
crack
Because the slope grain determination is important for the strength of the element the fracture has to be measured from B to C and A to C separately.



Wanes	The two ratios between the cathetus and the length of its corresponding side of the efficient section must be calculated, and the lower value must be taken into account.
Single knots	The relationship between the minimum diameter of the knot and the dimension of the side where it appears on the efficient section.
Group of knots	The relationship between the sum of the minimum diameters of the knots found in a length equal to150 mm and the dimension of the side of the efficient section where the knots appear.
Slope of the grain	The inclination of the shrinkage splits with respect to the longitudinal axis of the element, measured on the surface of the members in areas that are distant from the knots or from other characteristics that can cause strong localized slope of the grain (for example: due to knots); in order to determine this parameter the minimum basis of measurement is equal to 150 mm, measured parallel to the axis of the timber member.

Table 3 (UNI 11119:2004)

Final report

Normally at the end of every inspection a report is required.
It should contain the date when the inspection was carried out, the name of the client, the name, qualification and the signature of the person responsible for the inspection.
The structure has to be characterised and the specific objectives of the inspection should be circumstantiated. The conditions of the whole structure and for every single element, included, dimensions of defects, decay and mechanical damages, moisture content in characteristic regions should be described in detail. The conditions at the site under which the analyses took place and also the methods used to perform the inspection should be mentioned, including eventually used instruments for non destructive testing. The parameters of testing have to be described as well as the number and position of the tests.

Note:
It shouldn't be forgotten however that the most important aspect is that the structure is secure! The engineer standards are changing frequently, but the structure should remain for a longer period.

Therefore it is important to analyze the structure carefully. Later regarding the structure it is not only important, that the beam has a knot, but also where. Statically it makes a great difference, if it is in the middle of the beam, or at the end. These aspects are not considered in the grading!

4.2. Expert survey

The main aim was to present the results of the classification of the timber elements according to their resistance, to ensure the safety of the roof and to maintain the ancient structure. All accessible areas have been visited to gain information about the general condition of the timber structure of the dome of Vercelli.
The two areas where the largest spans occur are the roofs of the choir and the main aisle, which have been inspected in particular. To get further information about the elements additionally to the visual inspection an instrumented inspection has been performed.

4.2.1. Working group

Prof. Clara Bertolini Cestari (Coordinatore)
Dott. Alan Crivellaro (University of Padua)
Luciana Cestari (restauratrice)
Arch. Gianoreste Biglione
Arch. Daniele De Luca
DI Pia Panosch

4.2.2. Date and place

The inspection has been carried out on the timber structure of the choir including its 8 trusses (400m²) and the false rafters over the apses (140m²), the structure of the right and the left transept (each with 175m²), the main aisle with its 7 trusses (440m²), the two side aisles(each with 365m²), the attic (400m²), the chapel on the right ("Capella del Crocifisso", 100m²) and the Cupola Chapel of S. Eusebio (320m²).
All in all 2880 m² of roof structure have been checked.

3rd , 4th ,12th December 2008
(Coro, Transept right, Main Aisle)
Prof. Clara Bertolini Cestari (Coordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (University of Padua), Luciana Cestari (restauratrice)

6th march 2009
(Coro, Transept right)
Prof. Clara Bertolini Cesari, Arch. Daniele De Luca, DI. Pia Panosch

9th march 2009
(Coro, Transept left, Transept right, Tower, Main Aisle, Aisle left, Aisle right, Chapel right "Capella del Crocifisso")
Arch. Daniele De Luca, Dott. Alan Crivellaro, DI. Pia Panosch

6th may 2009
(main Aisle, transept left, aisle left)
DI. Pia Panosch

12th may 2009
(Coro, Transept left, Transept right, Main Aisle, Aisle left, Aisle right, Chapel right “Capella del Crocifisso”)
DI. Pia Panosch

4.3. Climatic conditions under the roof

Generally speaking, if the temperature and the relative humidity of a room is known, the point where the wood reaches its equilibrium moisture content can be determinate (tab1).

In the case of the Dome in Vercelli the temperature of the analysed area (on the 3rd, 4th and 12th December 2008) was about 4° C and the relative humidity of the air about 80%.
The relative high humidity measured on the surrounding air explains the damaged roof covering. It is obvious that the moisture content in the wood can increase if the roof isn’t tight and water can penetrate the structure (rain). An inspection of the sight on a rainy day could give further information.

Anyway under these conditions wood achieves its moisture content equilibrium with a moisture content of about 16%.

4.4. Biological Risk (EN 335, 2005)

As mentioned above the timber elements have a moisture content of about 16%. But during the inspections active fungi has been found. This means that at least occasionally the value of 20% has been achieved. Therefore the structure can be classified in second category. This means that the structure can be attacked by carries, discolouration and insects.
Improving the ventilation of the timber roof, risk class 1 (no risk of fungi attack) can be achieved.

4.5. Species Identification

4.5.1. Characteristics of wood

All woods are mainly made out of carbon, oxygen and hydrogen. Going more into details the deep the molecular components are cellulose, hemicelluloses, lignin and about 10% of the wood is out of other substances including pigments, tanning, oils, resins.
Further on every kind of is composed by cells and these cells are composed by a cell wall surrounding a cell lumen. The density of the cell wall substance is always about 1.53 g/cm^3 for all species of wood.
So considering, that all timber elements are mainly made out of the same elements, the main question is why do we have to identify the timber species?

4.5.1.1. Why is the wood identification important?

The first point to care about starting with the inspection is the identification of the wood species. To know what timber species you are working with is useful because every single timber piece has different physical and mechanical properties, and a different natural durability.
So wood should be used according to its specific species characteristics!
This is how we come to our next question:

4.5.1.2. How can a material (wood) have so different characteristics?

One of the factors that make a difference is the different form of the cell walls according to their functions (support, conduction or storage) in the living tree. Most of the cells (about 90%) have a longish form. But there are also horizontal cells and these form the rays (storage structures). Going into detail there are the fibres which have support function, vessels for the conduction, tracheids for both support and conduction and parenchyma cells for the storage.
The distinctive features of a timber species depend on the orientation, position and quantity of these different cells with respect to each other.
Simplifying the wood structure, we have a bundle of tubes offset from each other in the longitudinal direction. This explains also a part of the anisotropic behaviour of wood (very strong in the longitude direction (parallel to the grain) and inefficient perpendicular to the fibres). The different way of organising the cells causes a variability in wood structure (anatomical identification in so possible) and density.
As already mentioned the density of the cell wall substance is about 1.53 g/cm^3. The density of the wood depends on the thickness of the cell walls and the cell cavity volume which varies mainly, but not only from species to species but also within a species. Balsa wood for example has a porosity of about 96% and a density of about 0.2 g/cm^3. On the other hand side guaiaco has a porosity of about 10% and a density of about 1.2 g/cm^3.

4.5.2. What kind of wood was used?

To identify the wood species it is in few cases possible to see the characteristics with the naked eye as much as necessary. In most cases a small timber piece must be removed for the anatomical identification using an optical microscope.
Starting the observation of the timber structure of the dome of Vercelli it was obvious, that all examined pieces of the structure have the same characteristics:

The growth-rings are easily distinguishable with the naked eye. They are very distinct and decorative.
The brown colour of the heartwood differs from the colour of the sap wood (darkening from light gray-yellow to dark brown).
The timber vessels are particularly big and have a ring porous distortion.

Conclusion: There for all carrying trusses are the same wood species: oak wood (Quercus sp.p.).

4.5.3. Characteristics of oak wood

The Oak tree (*Quercus* petraea (Mattuschka) Liebl. and *Quercus* robur L.) is the most common broad leaved species in temperate Europe. The diameter of oak tress lies in between 40 to 80 cm and the thickness of the sapwood is in a range from 1 to 4 cm.
For oak wood with a moisture content of 12-15% the average density lies between 0.65 and 0.76 g/cm^3. According to a moisture change of 1% the theoretical amount of differential shrinkage lies by 0.18 to 0.22 % (radial) and 0.28 to 0.35 % (tangential). Special care has to be taken drying oak timber. The drying rate has to be slow, because there is a high risk of distortion, checking and even collapse.

Oak wood has a moderate dimensional and form stability. The resistance of the sapwood according its natural durability and treatability is as for nearly all species

considered as low. The resistance of its heartwood to fungal (according to EN 335 standards: class 2 durable) and insect attack (dry wood borers: risk limited to sapwood, termites: moderate durable) is high.
The Use class according to the standard: EN 350-2: Oak can be used for internal and external applications (not in ground contact). The wood colour varies from gray to yellow and dark brown to light brown. According to the colour changes the sapwood is easily distinguishable from the heartwood. That means that the growth rings are very distinct and the texture of the wood is very decorative. Looking at the wood under the microscope you will find large porous rings in early wood. Oak is easily peel and sliceable for veneer applications, especially if it has been steamed before slicing. According to its properties, you can find this species mainly in highly stressed structures, parquet flooring, storage barrels and for high quality veneers.

4.6. Choir

Illustration 38 choir trusses

Illustration 39 choir apsis

4.6.1. What was analysed?

The free span between the external walls is about 15.50 m and the cross section of the primary structural elements is mainly 30 x 30 cm or smaller. Often the size of the cross section varies over the length of the structural elements.
The supporting elements of the roof of the choir are trusses.
In general, the inspected trusses have the function to carry the protecting roof of the religious building. The trusses are composed out of a tie beam (bottom chord), two rafters (side beams), a king post in the middle and 4 chord members, always two of them are connecting each rafter with the king post. These chord members have not been classified, because some of them miss entirely, others have been substituted recently and a visual inspection seemed to be sufficient.
All of these elements are made of an entire tree trunk, which has been brought into their square form with an axe. The king post has been done with less attention than the other construction elements. Maybe because the element has relatively big dimensions and was therefore done by a student or with less attention.

4.6.2. Used methods

The standard: UNI 11119: 2004 (*Beni culturali – Manufatti lignei – Strutture portanti degli edifici – Ispezioni in situ per la valutazione dello stato di conservazione e la stima delle prestazioni degli elementi in opera*) includes the operative methods to inspect a timber structure and was used for visual strength classification of the roof structure of the Dome of Vercelli.

Additionally to a visual inspection on the 3rd, 4th, 12th December 2008, special tools were used. The instrumental inspection to estimate the presence of decay of the internal part of the beams was accomplished by a Resistograph. To receive accurate information about the climatic conditions of the surrounding air, but also

to measure the wood moisture content itself, a Pin-type meter was used. The following inspections 2009 were only visual inspections often under bad lighting conditions. Regarding the results the view surveys have to be considered. To get detailed information about the conditions further expert's surveys are necessary. The wood species has been identified according to the Italian standard:
UNI 11118: 2004 (*Beni culturali - Manufatti lignei - Criteri per l'identificazione delle specie legnose*).

4.6.3. General state of conservation

Looking at the entire visible structure it is generally in good conditions. Some timber elements show fungi and insect (Xylophages) attacks limited to the sapwood. Anyway now there are no insects active. The attack must have occurred in an earlier period.

Generally the top chords are less degraded than the bottom chords. It is likely that the difference of the conditions occur because of the joint wall - bottom chord, where different materials get together. When the space between the wall and the bottom chord is filled (cement, bricks...) the water can't flow away and the moisture content of the wood rises. This makes the timber vulnerable for fungi and insect attacks.

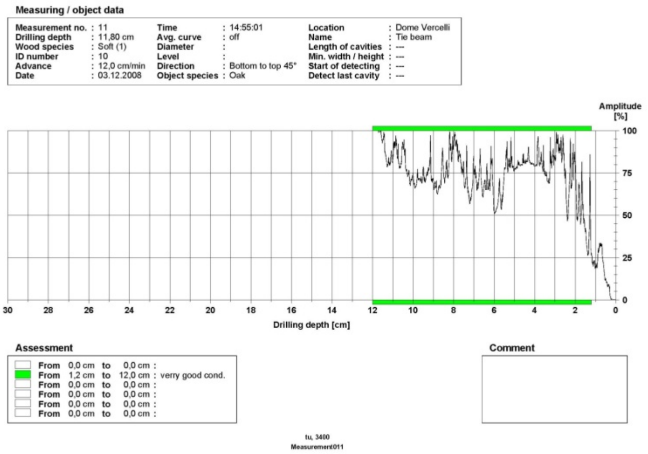
4.6.4. Description of every single element

Diagnosis of the timber joints rafter/ tie-beam /chord member

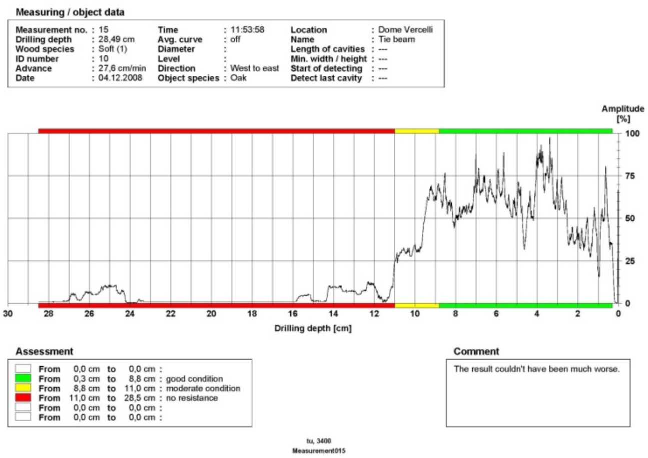
IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	N. 8		Choir		
Tie-beam					
Biological decay	From fungi		Nothing visible		
	From insects		Absent		
Defects	Joints		See rafter		
	Ring-shakes		Nothing observed		
	Twist				
Wooden species	Oak				
Humidity	According to the surrounding air about 16%				
Average dimensions of the element	27 x 30 cm				
	Section		Rectangular		
	Geometric peculiarity		Wane	Absent	
			Deformations	Absent	
Other characteristics	There is a problem at the joint tie beam- rafter, because of the heavy degrade, the tie beam seemed to be flattened (crushed) by the weight of the slightly moved and curved rafter. A group of knots is visible.				
Resistographic profiles					
Data	Profile N°	from	Direction	Observations	

3.12.08	R 11	front end north side	underside to top side inclination 45° (ref. exterior wall)	- Drill 11 (executed on soft timber): the test was taken on the truss 8.



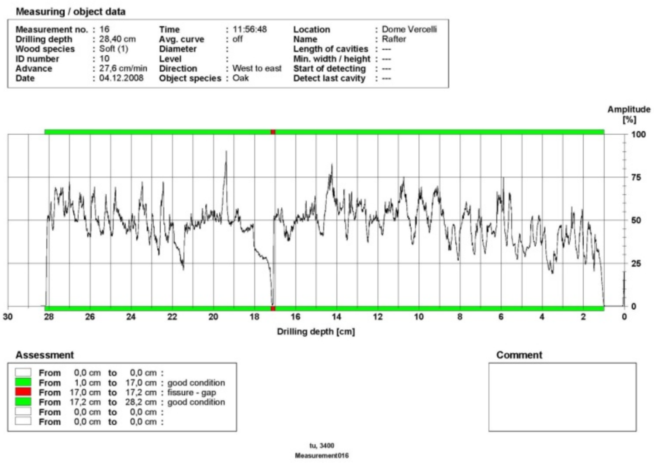
3.12.08	R 15	front end south side	perpendicular to grain	Drill 15 (executed on soft timber): the test has been taken perpendicular to grain on the tie beam. There are only 6cm of good timber, after that there is nearly no resistance. The result couldn't have been much worse.



Rafter	North Side		
Biological decay	From fungi	Nothing visible	
	From insects	Absent	
Defects	Joints	The joint (bottom cord - top chord) on north side is supported by a wooden "barotto" placed vertically and braced next to the external wall, which suffered immediately bacteria attack.	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Humidity	According to the surrounding air about 16%		
Average dimensions of the element	28 x 25 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing visible
		Deformations	
Other characteristics	Some knots are visible. The rafter is in a moderate condition.		

Rafter	South Side	
Biological decay	From fungi	Nothing visible
	From insects	Absent
Defects	Joints	The joint (tie beam – rafter) on the south side is heavily degraded.
	Ring-shakes	Nothing observed

	Twist			
Wooden species	Oak			
Humidity	According to the surrounding air about 16%			
Average dimensions of the element	26 x 29 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Nothing visible	
		Deformations		
Other characteristics	The beam is in a moderate condition. A single knot is visible.			
Resistographic profiles				
Data	Profile N°	from	Direction	Observations
3.12.08	R 16	front end south side	perpendicular to grain	Drill 16 (executed on soft timber): the test has been taken in perpendicular direction on the rafter next to the joint tie beam-rafter. The graph falls at a point due to a crack.



King Post			
Biological decay	From fungi	Absent	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a good condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam (no tension forces can be transmitted).	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Humidity	According to the surrounding air about 16%		
Average dimensions of the element	-		
	Section	Rectangular	
	Geometric peculiarity	Wane	Absent
		Deformations	
Other characteristics	The king post is in an extremely weak condition (water infiltrations). Element not valuated.		
PHOTO			
n. Photo	IMG_7034 Truss 8	IMG_7344 Knot (king post – rafter)	

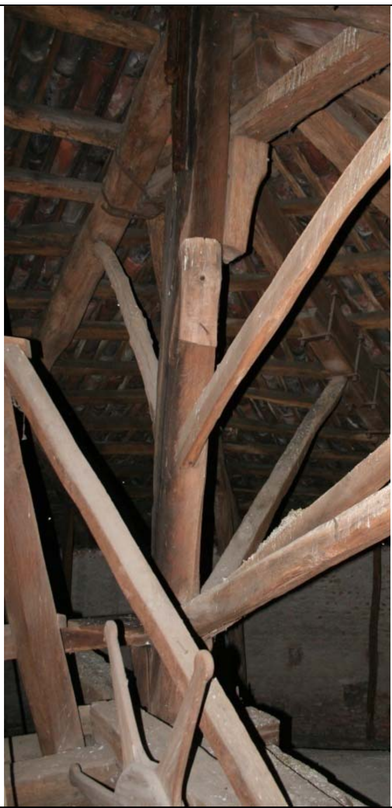
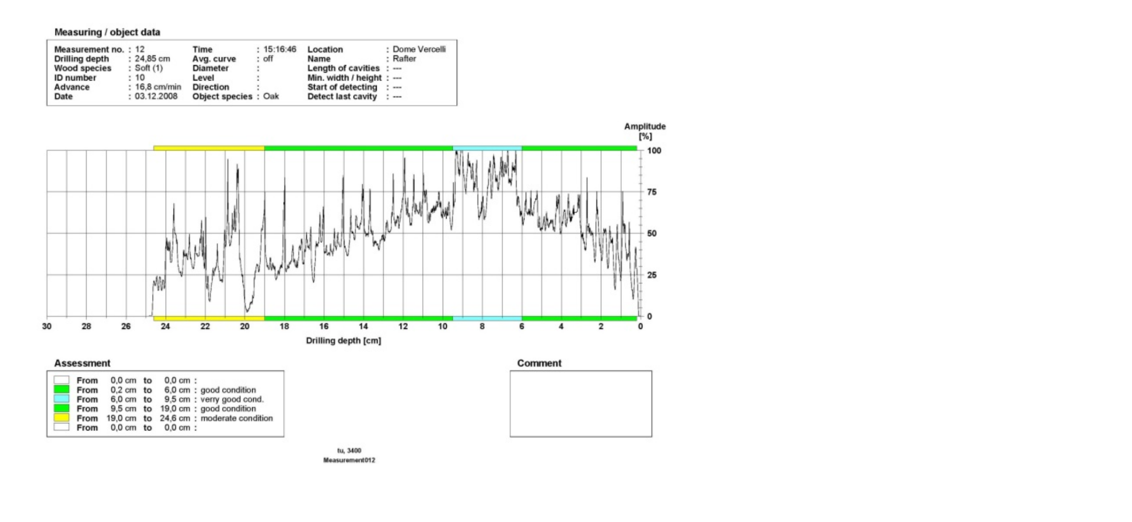
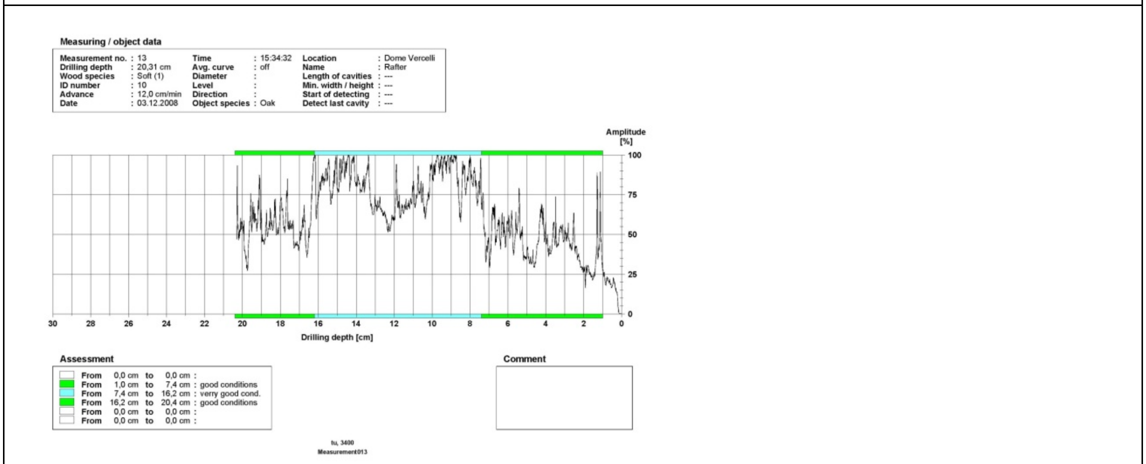
PHOTO		
n. Photo	IMG_7023 Knot (king post – chord member)	IMG_0609/ IMG_0610 Knot (rafter – chord member)

PHOTO		
n. Photo	IMG_0631 / IMG_0630 Knot (rafter – tie beam) South side	IMG_0612 / IMG_0658 Knot (rafter – tie beam) Nord side

Rafter Abside			
Biological decay	From fungi	Absent	
	From insects	Absent	
Defects	Joints	Nothing visible	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Humidity	According to the surrounding air about 16%		
Average dimensions of the element	22 x 22 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing visible
		Deformations	
Other characteristics	All the beams of the apse are in a perfect condition, because they have been placed on top of the wall. This means that they are perfectly ventilated.		

Resistographic profiles				
Data	Profile N°	from	Direction	Observations
3.12.08	R 12, 13 and 14	near the bearing	-	- Drill 12, 13 and 14 (executed on soft timber): the bores have been taken near the bearing on the wall (rafter). All tests showed good results and some even had to be interrupted, because the timber was too strong.





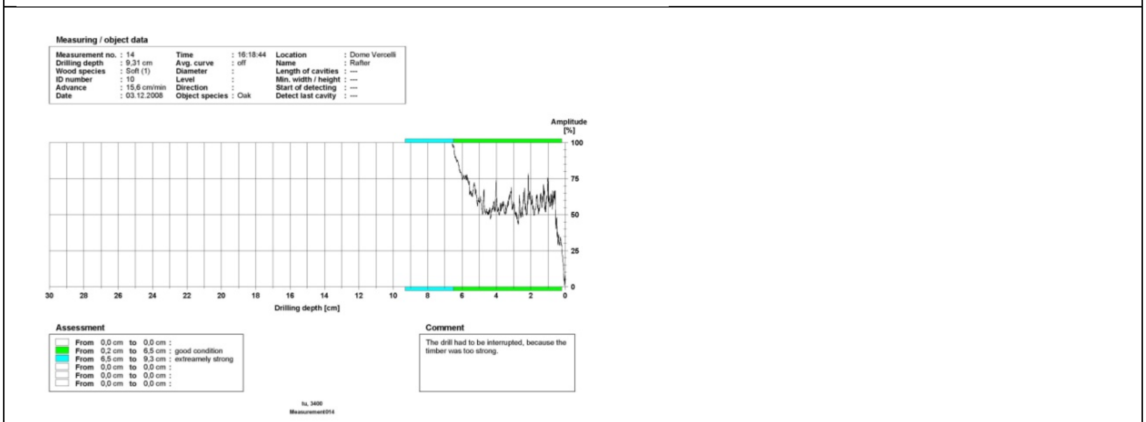


Table 4

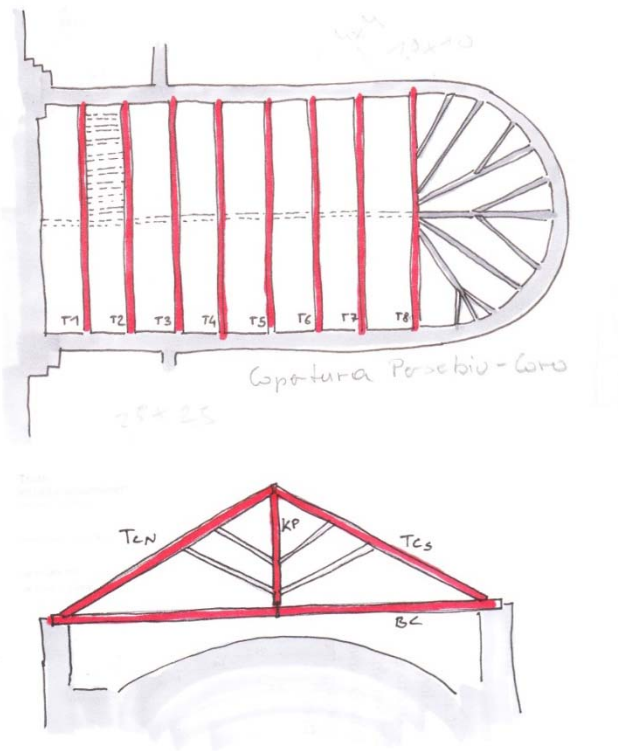
The further descriptions are in the attachment (description of every single element).

4.6.5. Grading table

The results of the classification of the single elements can be seen in the following table (Tab.5). Every element is listed with its characteristics and according to the standard (UNI 11119) ((**Maximum stresses of on site timber of the load bearing system (**maximal tensile force of oak) **UNI 11119:2004/ see point Loads Appendix)** categorised.

For the classification only the visible parts were taken into consideration. The hidden areas (wall- bottom chord, top chord) have not been analysed.

None of the points of support have been visible during the inspection. The bottom chord has been examined on 4 sides. The top cords have been inspected on 3 sides. The upper part of the beam hasn't been taken into consideration, because it was not directly visible. The king post has been checked on 4 sides.



sketch 16

Table 5. Results of the resistance qualification for the examined timber elements of the trusses.

Identification		Minimum measured cs b x h [cm]	Average humidity of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Efficient Cross-section b x h [cm]	Category according UNI 11119
T1*	Bc1	33 x 33 N 26 X 24 S	18% N side	Wane and deviation of the grain direction	Water infiltration visible N and S side	32 x 33 N 26 X 24 S	*III*
	Tc N-1	27 x 21	\	Knot	\	=	II
	Tc S-1	27 x 27	\	Wane	Water infiltration visible	=	III
	KP -1	22 x 25	\	Knot and Wane	\	=	III
T2*	Bc -2	37 x 31 N 27 x 27 S	15% N side	Single deviation of the grain direction	Sapwood: fungi attack	22 x 27 S	*II*

	Tc N-2	28 x 28	\	Single deviation of the grain direction	\	=	//
	Tc S-2	25 x 23	\	Single deviation of the grain direction	\	20 x 23	//
	KP -2	22 x 23	\	Knot and wane	\	=	///
T3*	Bc -3	28 x 28 N 35 x 33 S	15% N side	Single knot	Sapwood: fungi attack	23 x 26	III
	Tc N-3	28 x 28	21%	Knots	\	=	II
	Tc S-3	24 x 29	\	Injuries on the living tree	\	=	III
	KP -3	26 x 20	\	Knot and wane	\	=	III
T4*	Bc -4	30 x 30 N \ S	> 30% N	Single knot and injuries caused by insects	See notes	Not determinable	III
	Tc N-4	27 x 27	> 30%	Knot and wane	Liquid water	=	III
	Tc S-4	28 x 28	\	Knot and wane	\	=	III
	KP -4	24 x 26	\	Wane	\	=	III
T5*	Bc -5	26 x 30 N 24 x 26 S	\	Single knot	Bottom chord degrade S side	24 x 24	III
	Tc N-5	20 x 28	\	Knot and wane	\	=	III
	Tc S-5	21 x 27		Single knot	\	=	III
	KP -5	23 x 21	\	knots	\	21 x 19	III
T6*	Bc -6	26 x 26 N 32 x 30 N	\	Single knot	\	26 x 25	III
	Tc N-6	22 x 27	\	Knot and wane	\	=	III
	Tc S-6	23 x 27	\	knot	\	=	II
	KP -6	20 x 26	\	Knot and wane	\	=	III
T7*	Bc -7	31 x 36 N 27 x 27 N	\	Single group of small knots	\	26 x 26	III
	Tc N-7	28 x 26	\	knots	\	=	III
	Tc S-7	26 x 26	\	Single knot	\	=	III
	KP -7	22 x 20	\	Knots	\	=	III
T8*	Bc -8	26 x 27 N 29 x 30 S	\	Single group of knots	\	23 x 27	III
	Tc N-8	28 x 25	\	Knot	\	\	III
	Tc S-8	26 x 29	\	Single knot	\	\	III
	KP-8	\	\	\	Element not valuated	\	\

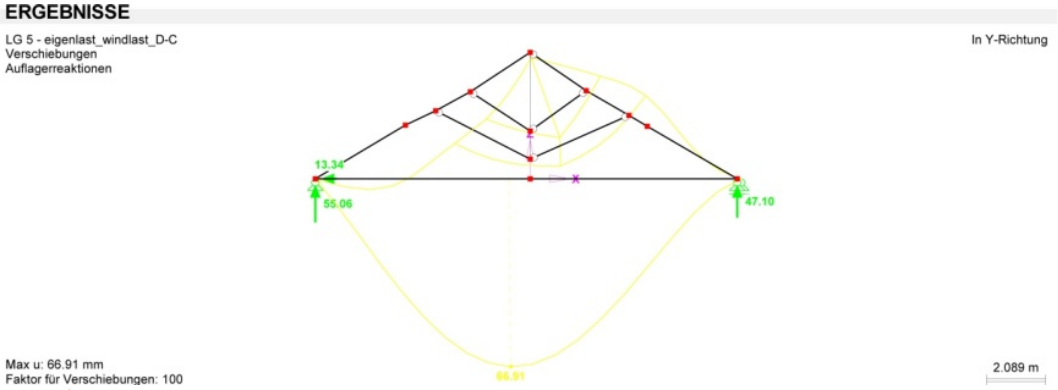
Table 5

T= Truss; Bc = bottom chord; Tc = top chord; N = north; S = south; KP=King post; W= web member; FR= False rafter;
B=Battens; CB=Contra-battens.
N. I. = not qualified (adequate); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

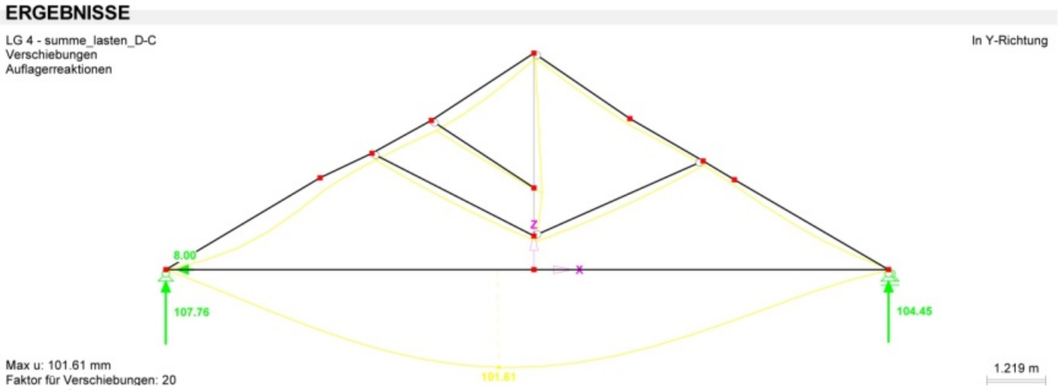
4.6.6. Static model RPLAN defects

Deformations

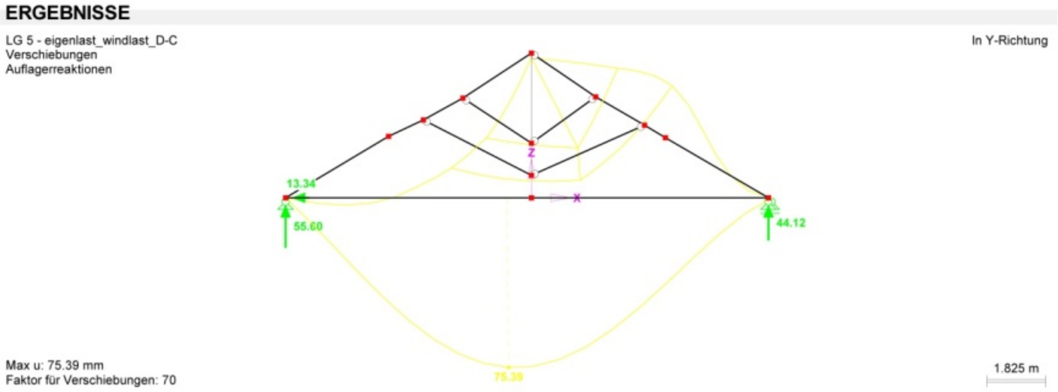
Truss 1



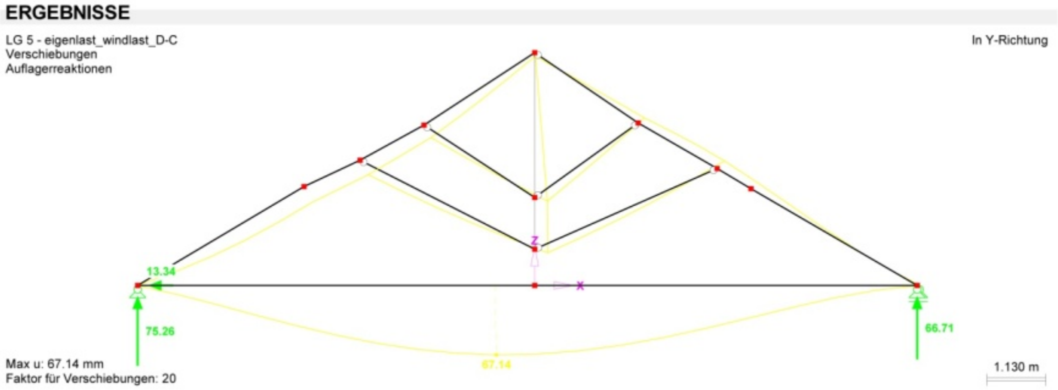
Truss2



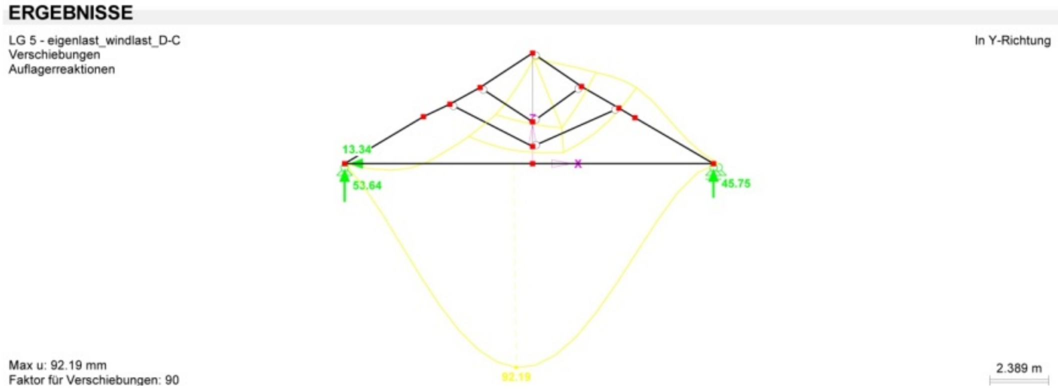
Truss3



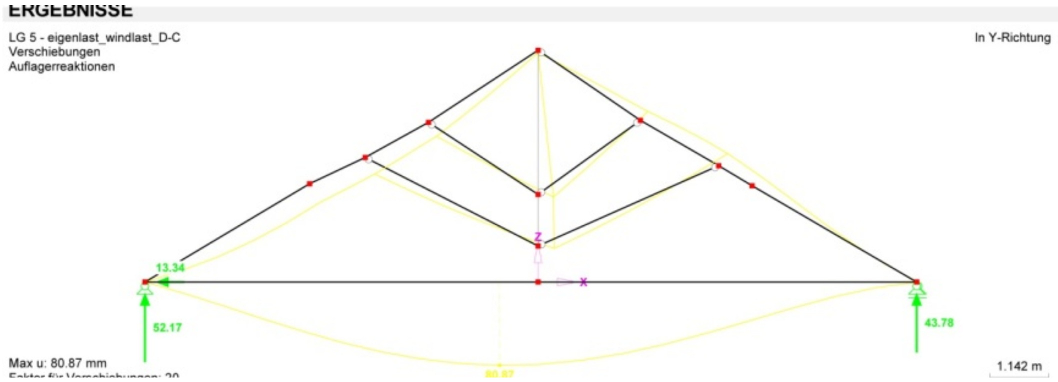
Truss4



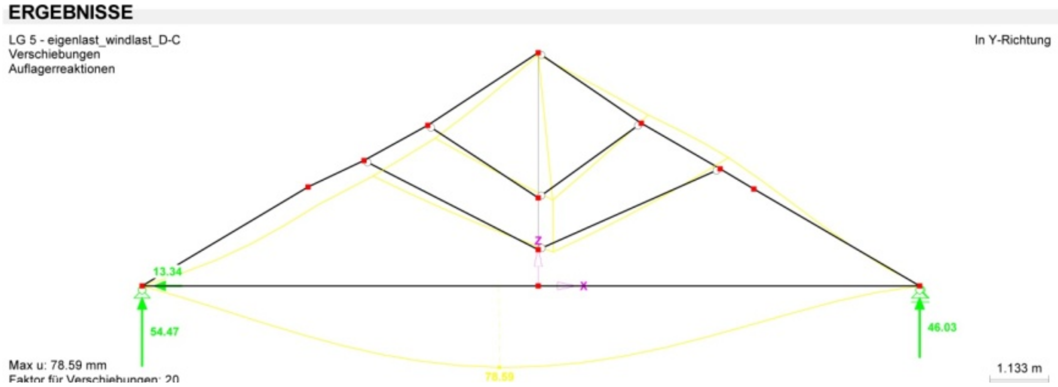
Truss5



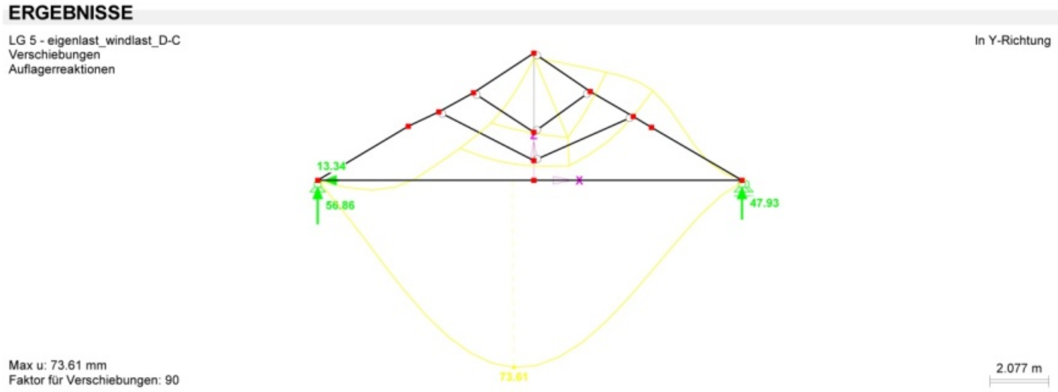
Tuss6



Truss7



Truss8

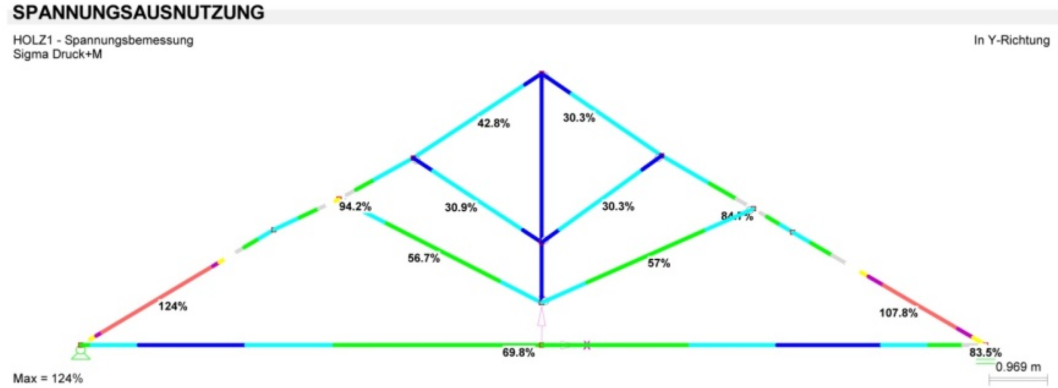


Deformation: 15000mm/300 = 50mm (l/300)
The worsted point is the midpoint of the tie beam. The deformations lay in between 60 to 100 mm!

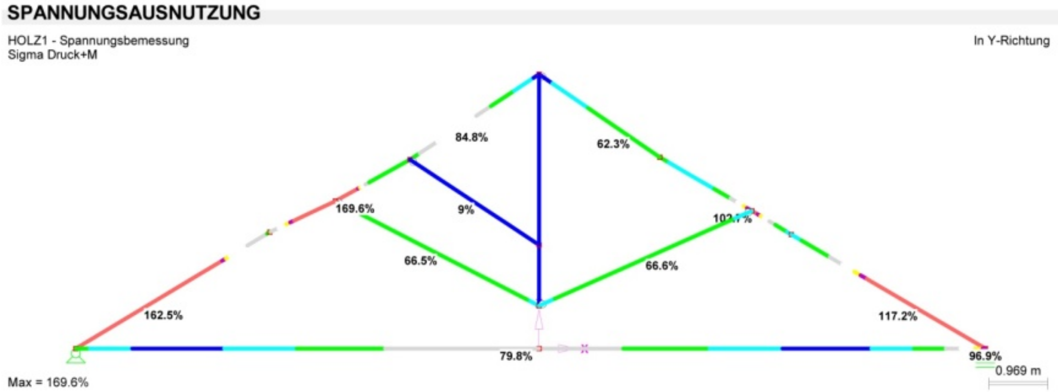
This is too high. Reason: The metal tension elements connecting the tie beam with the king post do not work anymore. They have to be substituted.

Stress:

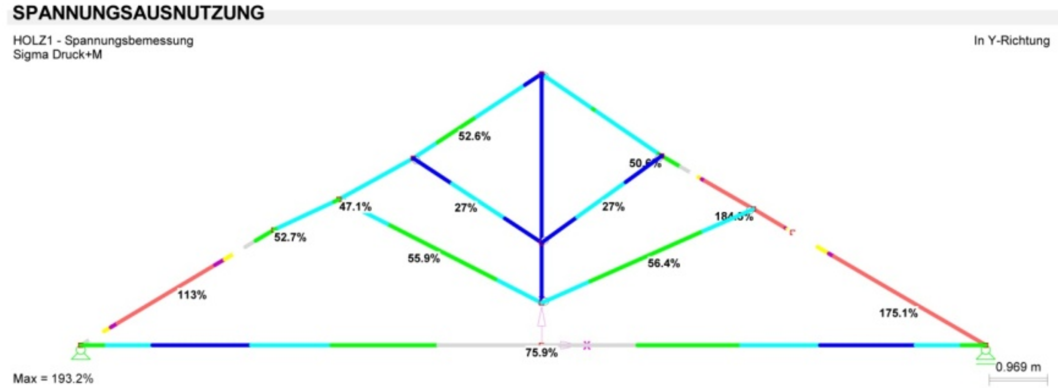
Truss1



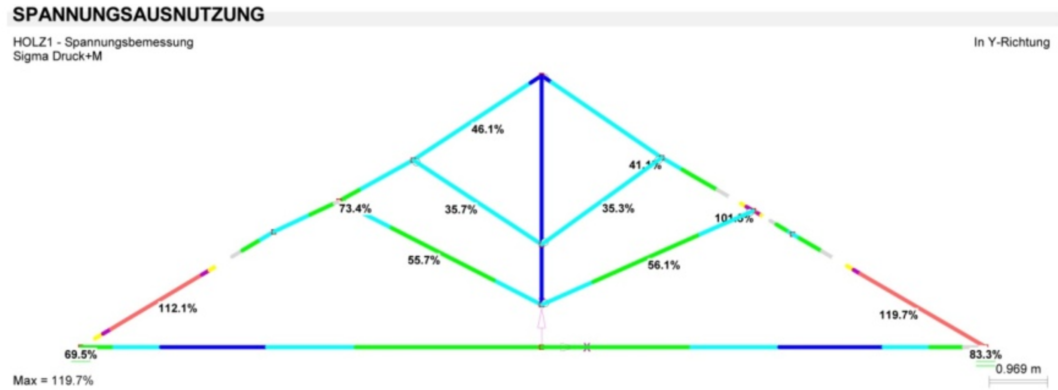
Truss2



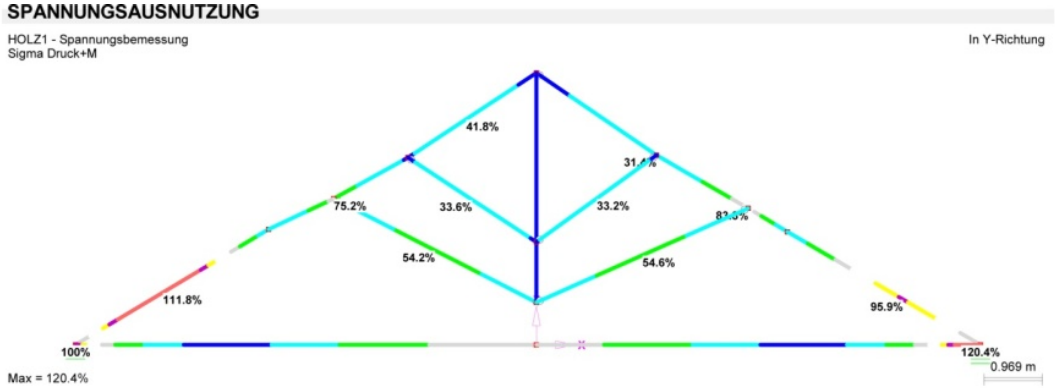
Truss3



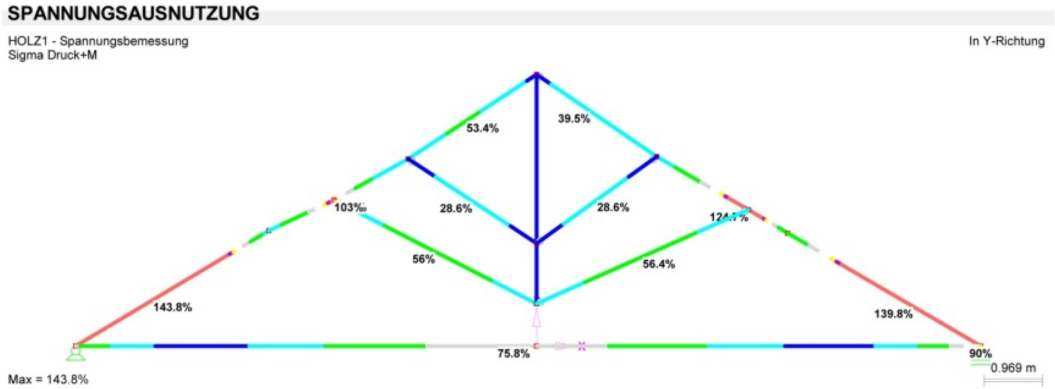
Truss4



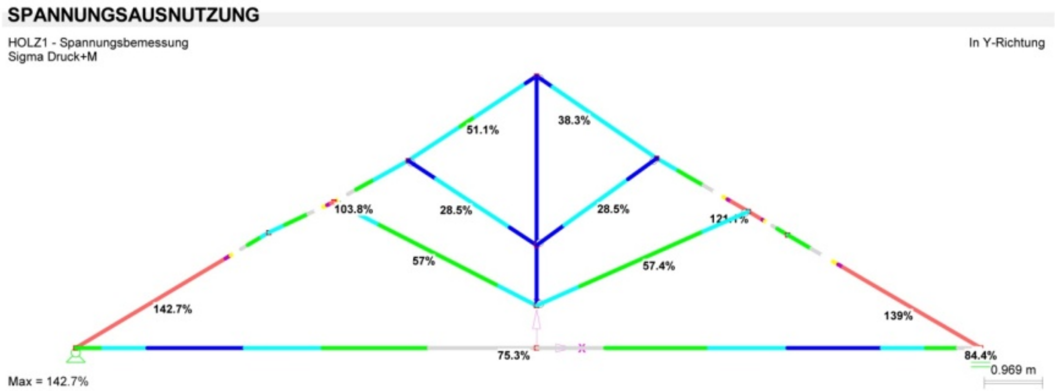
Truss5



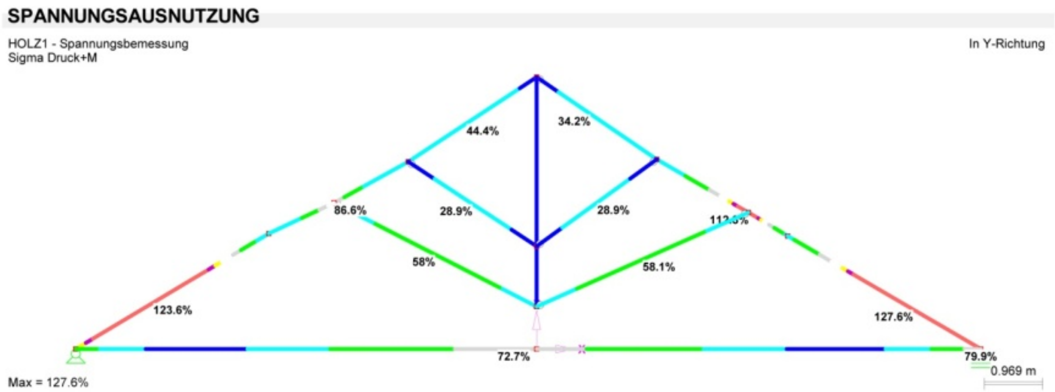
Truss6



Truss7



Truss8

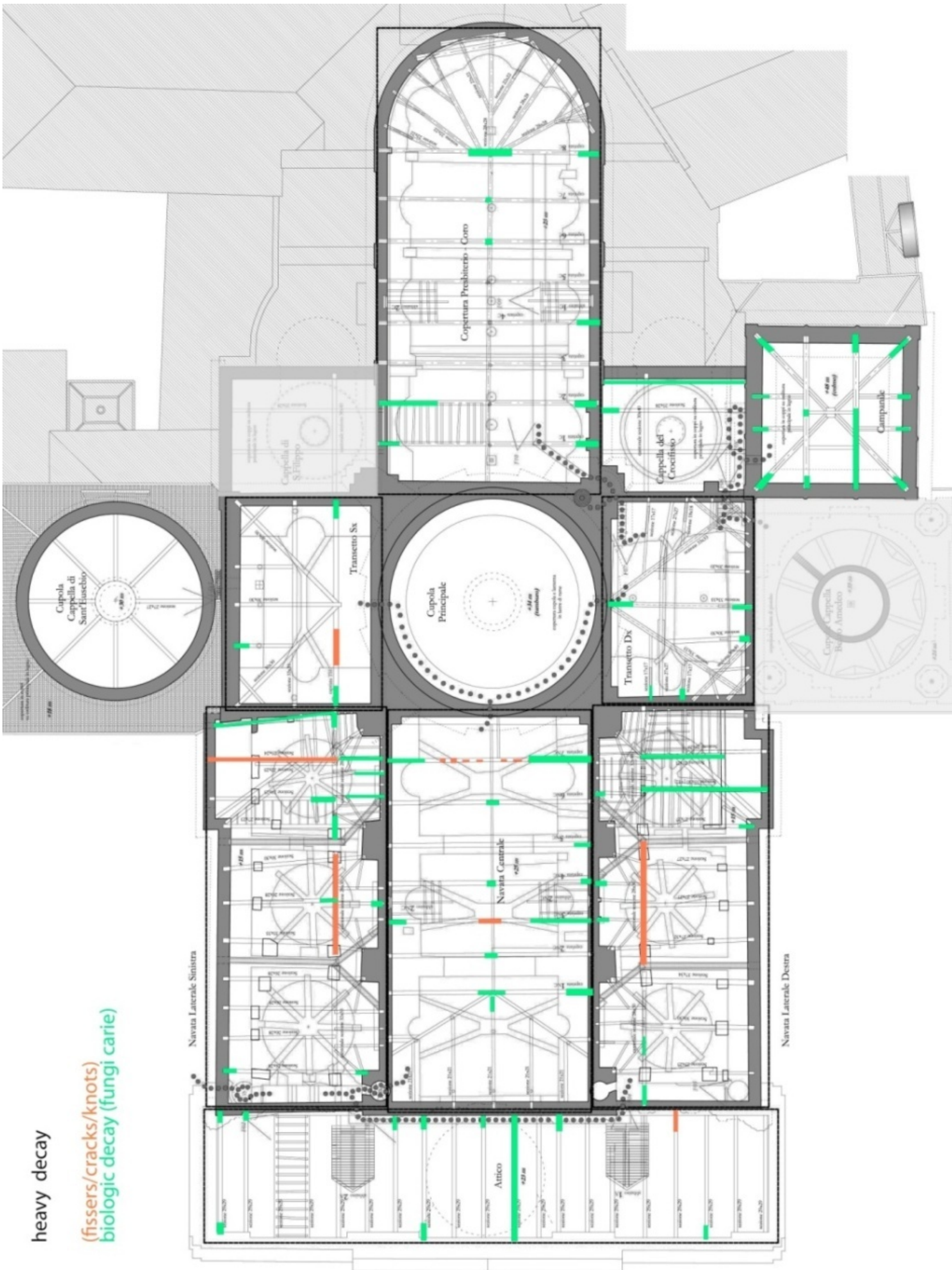


The stress in the lower part of the rafters is generally a too high (Values between 110%-175% of the load capacity).
Further results can be found in the attachment.

5 Critical points of the structure

Of course the roof has to be checked frequently, as it is the most exposed part of the cathedral to the outer influences like rain or wind. This means also that it gets easily damaged and has to be repaired frequently. Additionally to the natural defects of the timber structure, some points especially at the joints, where the wood is in contact with metal elements or the external walls are weakened.
To find out where the critical points are, is necessary, to find out where an intervention will be necessary. After the diagnostic phase all necessary information should be available.
Critical areas can be found asking the following questions:
How good is the structure maintained?
Is the timber sound?
Is its resistance sufficient?
Can it resist for further years?
How much of the cross- section is sound?
In which sorting class can the element be assigned?

The following plan shows the areas where the structure has suffered most. The signed points are in a dangerous condition. It has to be considered, that most of the bearings of the structure have been covered (stones /dirt and in some cases also concrete). Therefore it is difficult be certain, that all damaged areas have been discovered. It is recommended to have a closer look at the elements, when they are freed.
Elements of third order or smaller (battens,..) have not been considered in the map. Nearly all of them have to be replaced. They are often heavily degraded, because they are the first elements, which suffer from the leaky tiles (because of they are next to them). Furthermore they are not always out of oak wood, but spruce, which degrades much easier and they have smaller cross sections. (If they lose 1mm, it is a much bigger problem)


Copertura Presbiterio - Coro
Cappella del Crocifisso
Campanile
Transetto Sx
Cupola Principale
Transetto Dx
Cupola Cappella di Sant'Eusebio
Navata Centrale
Navata Laterale Sinistra
Navata Laterale Destra
Attico
heavy decay
(fissers/cracks/knots)
biologic decay (fungi carie)

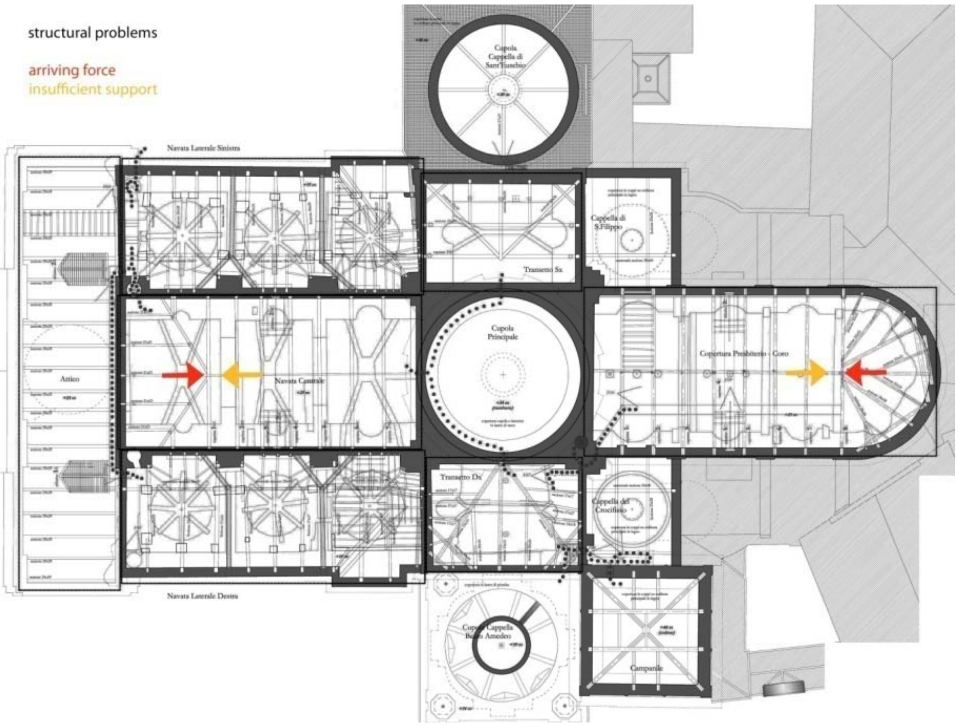
Plan 3

The points where the timber structure has suffered most are on the ridge and the eaves of the roof. These points are difficult to get dense and where water can penetrate the structure it gets easily damaged.

Illustration 40 Water infiltrations on the peak

Illustration 41 Damaged tie beam

The trusses:
Some joints of the trusses bearing on the external walls are heavily degraded (see pic. damaged tie beam) Especially the heads of the tie-beams seem to be problematical in some points. The unreliable components should be replaced or reinforced.
Also some of the king posts are drenched with water and therefore not in perfect conditions, but as their main duty is to ensure e more rigid connection on the top of the truss this is not always a dangerous situation and if the elements can dry out there shouldn't be any problem. It is important however that the roofing especially above these elements is dense and that no new water infiltrations are and will be possible.
In some points too heavy loads caused overcharge and therefore displacements.
A huge problem of the structure is the umbrella construction in the choir and the main aisle. The forces in the east – west direction cannot be transported easily and created already displacements (king posts of the trusses).


structural problems
arriving force
insufficient support
Navata Laterale Sinistra
Cupola Principale
Navata Centrale
Copertura Presbiterio - Coro
Transetto Sx
Transetto Dx
Campanile
Navata Laterale Destra
Attico

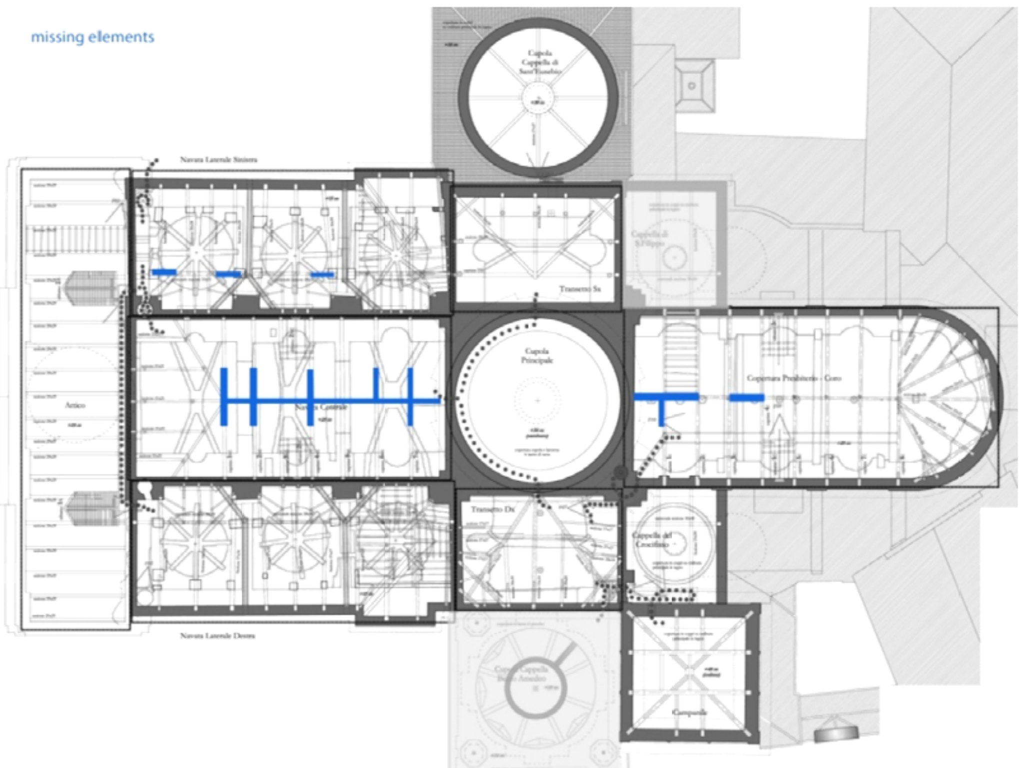
Plan 4


displacements
Navata Laterale Sinistra
Cupola Principale
Navata Centrale
Copertura Presbiterio - Coro
Transetto Sx
Transetto Dx
Campanile
Navata Laterale Destra

Plan 5

Illustration 42 displacement

Illustration 43 Missing elements



Plan 6

Some elements are missing completely it is unlikely that the structure has been designed non symmetrical therefore these elements must have been removed because of their weak condition.

6. Interventions of the roof

The scope is to plan an intervention after the preliminary evaluation of the state of conservation. The efficiency of the intervention will have to be considered as well as the techniques in the execution of the intervention.
The interventions regard mainly the elements of second and third order as well as the tile roofing. The primary structure should be maintained if possible. The project should be done with a lot of care and accuracy with the newest techniques to ensure a maximum efficiency and stability (therefore also safety) of the historic building.
This chapter contains the criteria that should be followed in the planning of conservation and execution, the restoration and also the maintenance of the load bearing wooden structure of the dome of Vercelli. The works executed on the actual construction site (till February 2010) of the dome of Vercelli will be described, comments (how it could be improved), and alternative proposals will be made.

6.1. Interventions out of the literature

General rules:
Timber is a living material, therefore it can swell, shrink… (Leave the timber the necessary space to work) Furthermore every species has its own characteristics. If the environmental impact changes, the timber may change its properties. This has to be considered designing the restoration project. For example: If a wood on wood connection is foreseen the new timber element should be the same species and have the same humidity content like the one it is connected with. Like this future damages can be prevented.
Be careful of the long term deformation.
It is important that the way the structure works has been understood before starting to plan an intervention! You can cause major damage to the structure intervening in the wrong way (added loads, changed angles because of deformations, new direction of the force …)
The timber structure may have influence on the rest of the structure: Be careful dismantling it!
Think about the material properties: For example the fibre direction makes a huge difference concerning timber.
Think about indirect influences: If the water can drain off, or is it enclosed in the wall and will it harm the timber element. This should be considered especially at the bearings and joints. Though also the humidity of the air, the absorbency ability of the surrounding elements and so on are important. Some materials can influence the conditions of the timber structure in positive way.
The interventions must not affect the seismic, or fire behaviour in a negative way.
The intervention has to be feasible.

Possibilities to intervene:

- Strengthening of existing timber beams:

Old structures often need to be strengthened because of more demanding requirements (changes in the code), rotted elements (smaller cross-section than the original element), or also higher loads (changed use).

One of the most effective and common methods is, to increase the bending, shear strength and therefore the load capacity, using a wood-wood compound. The existing beam and a new additional section made from solid timber or laminated veneer can be fixed mechanically or can be glued together. Metal tension bars can be mounted at the intrados and, or beams (steel, solid wood, laminar) on the extrados of the element. Recent developments suggest to T- beam type compound

sections, where existing floor joists are strengthened by the addition of plywood or LVL boards.
In some cases this will not be possible because of esthetical issues or lack of space.
In this case the lamination of the timber sections is the best way to reinforce the existing structure. Steel elements, glass or carbon fibre fabrics, laminates and bars (FRP) are retrofitted in the existing timber elements to allow higher load bearing capacities.
Bending tests (according to the paper Strengthening of wooden beams with FRP Materials, 15 July 2009, (Politecnico di Torino, Italy) by C. Bernardini, L. Credali, G. Pistone) showed the most effective way is gluing the strengthening device over the whole length into the existing timber elements to compensate the defects of the original beam. The experiments showed that the reinforcement works in the points where the timber is insufficient. To prevent de-bonding and splitting phenomena in the share zone bandings in carbon fibre fabric or special carbon connectors are recommended.

Another method is the timber-concrete composite (anchors connect the timber elements to a concrete plate) which is very effective for ceilings and floors because of the thigh stiffness, the good acoustic performance and the high fire resistance. But in the case of trusses (like in the dome of Vercelli) it is not very useful and therefore not further considered in this paper.

Illustration 44 interventions manuale legno strutturale

-Replacing timber elements
If a timber element is so damaged that is has to be completely replaced a fully interlocked mechanical connection can be created between the new and the old timber section using bonded - in rods. These prostheses can be done with metal casings; they can be glued (glulam) or they elements can get strengthened by restoring the deteriorated timber by inserting thin metal sheets.
In case it is not possible to remove and substitute the damaged parts an according to the Timber manual (.....) approved method, two- part epoxy resin mortar reinforcement with glass or carbon fibre, can be used to repair the damaged parts of the structure.
Generally it is to say that such interventions (what ever material has been used (timber steel, glue..) the connecters should always be orientated into fibre connection.

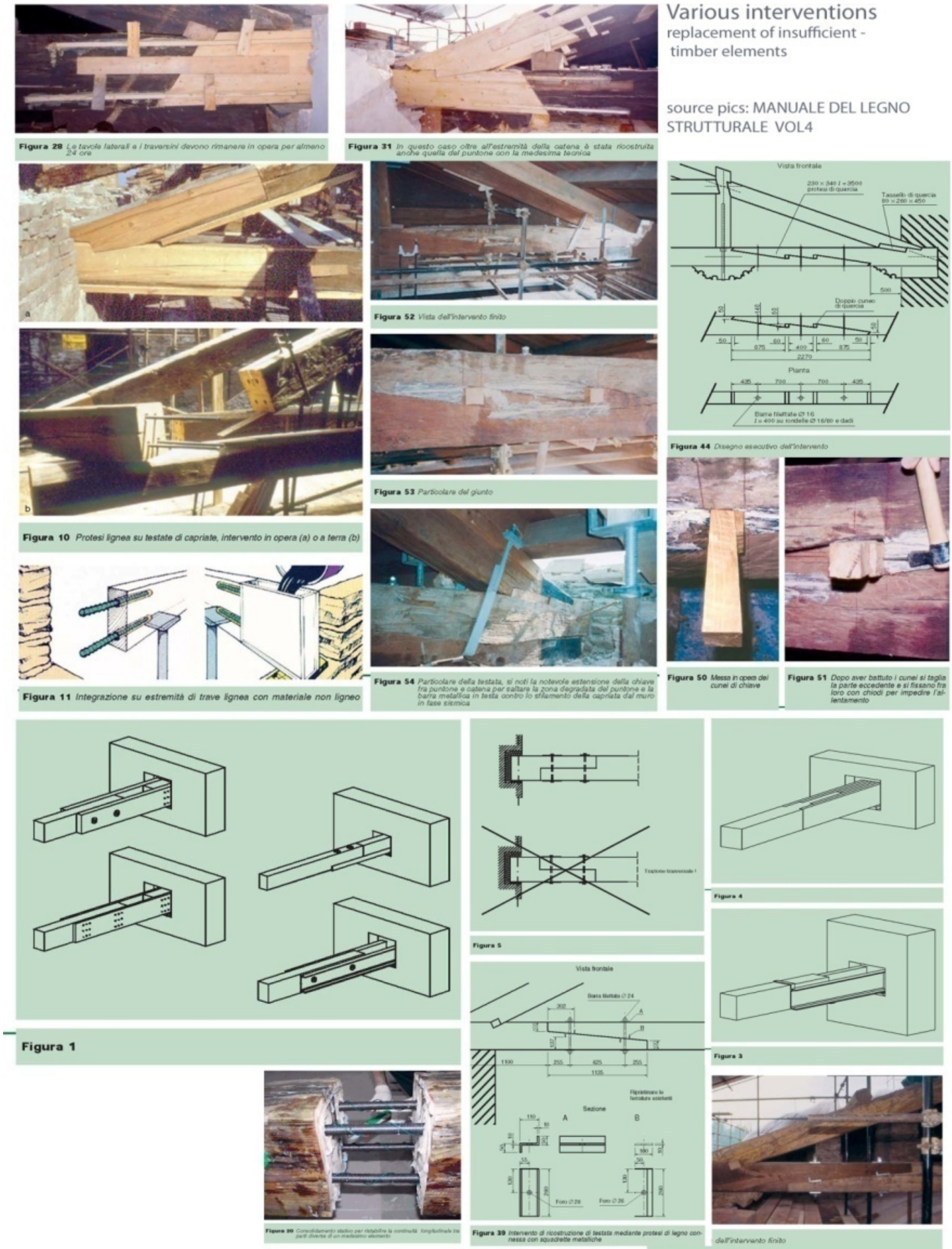


Illustration 45 interventions manuale legno strutturale

Historical solutions:

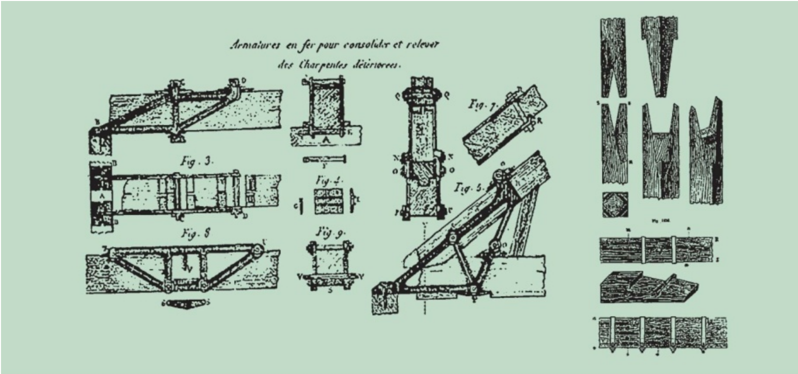


Figura 7 *A sinistra, sistemi di rinforzo nei nodi trave muratura e puntone-catena (Rondelli, op. cit.); a destra, giunti di continuità (da Pareo, Sacher, op. cit.)*

Illustration 46 interventions manuale legno strutturale

In case of smaller injuries or fissures (Fissures up to 5 mm are allowed to be sealed) caused by weather, thermal or moister influences, but also design errors, lack of care during the erection, transport ect. can be closed with a pressure injection with epoxy resin. In order to achieve a completely locked mechanical connection the resin has to be mixed with suitable fillers (according to the building authority). It has to be said that, often however it is not necessary to close such small fissures. As wood is a living material it shrinks and swells, closed fissures can cause more damage than good in some cases. (If the wood wants to shrink back and is blocked by the resin it will crack in another maybe more dangerous point.)

6.2. Interventions which have been performed in the dome in former times

The roof of the cathedral has been restored various times. Some of these refurbishments are documented on the beams or exterior walls. (see pic. Former refurbishment)

Illustration 47 Former refurbishment

To get an overview of the various interventions which have been executed on the roof of the dome of Vercelli, some examples have been chosen.
These interventions have been more or less efficient. There are timber or metal elements supporting the structure perfectly, but some have lost their efficiency during the years.
Some intervention may have been performed directly after, or during the erection of the roof, others later.

The elements which seem to be doubled beams, for example in the main aisle, turn out to be inserted only to get a sufficient inclination. Of course not all added elements work like this, for example the doubled elements in the chapels and the side aisles augment the load bearing capacity of the beams.
A less efficient intervention are the metal ties, most of them have warren out. They got so big that they cannot support the structure at all.
Other interventions support beams having to wide spans (especially the tie beams of the trusses in the main aisle and the choir). The supporting elements are often posts bearing directly on the vaults. This is for sure not the best way to intervene, because punctual forces are difficult to distribute and therefore dangerous for vaults.
The most extreme case is a post in the main aisle, which overtakes all forces coming from west. It is placed directly after the umbrella construction on the west end and substitutes the connection which most likely once connected all trusses till the wall on the east side of the aisle. The forces coming from west may have caused the displacements of the king posts of the trusses (which are also visible on the choir). It is likely that this post bearing on the vault has been added to get rid of the forces perpendicular to the truss systems and therefore the movements of the king posts.
It is difficult to decide what to do with such interventions, as it is very complicated to ascertain how the structure actually works. It is always very risky to remove former interventions; therefore I would recommend leaving them the way they are, or replacing them with adequate secure modern interventions.


Support tie beam   original bearings and bearings which have been closed with concrete


Closed bearing truss   support tie beam (struts bearing on the vault)

Strut bearing on vault

connection rafter tie beam

Support king post

strut to overtake the forces
coming from the umbrella structure
(bearing on the vault)

Support connection of
the truss on the peak

support tie beam

Strut supporting rafter

connection rafter - tie beam

timber element to ensure the inclination of the roof

Metal elements connection king post – rafters

Timber element to avoid displacements

strut to overtake the forces coming from the umbrella structure

Support joist (doubled)

Illustration 48 Former refurbishments

6.3. Workshop

To maintain a huge historic building, like the Dome of Vercelli it is nearly always necessary to refurbish the cathedral.

The first lot regards the restoration of the roof of the cathedral of San Eusebio, because one of the weakest points of a building is the roof. It is in direct contact with outer influences like rain, wind and sunshine and of course an un- tight roof cover leads to further damage in the cathedral.

The whole roof covering has to be redone (tiles). The timber elements (frames and beaming) of third or smaller order have to be replaced, as well as the strongly weakened ones of primary and secondary order.
It is foreseen to finish the work of the first lot until January 2010.

6.3.1. Costumer

Archbishop S.E.R. Mons. Enrico Masseroni
Deputy General of the diocese Cristiano Bodo
Archdiocese Vercelli
13100 Vercelli

6.3.2. Who is working on this project?

It is not always easy especially for not qualified people but also for experts to interpret situations and conditions of the structure and react in an adequate (if possible best) way.
This means:
For every restoration and conservation site especially if they are timber structures it is absolutely necessary that qualified experts out of various fields work together to maintain a satisfying result.

Illustration 49 team

Design and leading architect:
Prof. Arch. Daniele De Luca
Ufficio Beni Culturali
Curia A
Piazza Sant' Eusebio 10
13100 Vercelli

Collaborators:
Arch. Germana Corradino
Arch. Riccardo Pasquino

Office construction management:
Direction

Prof. Arch. Daniele De Luca
Ufficio Beni Culturali

Responsible for the execution
Arch. Germana Corradino
Via Prarolo 38
13100 Vercelli
Arch. Riccardo Pasquino
Vicolo Savoia 1
27030 Palestro

Safety officer (D.Lgs. 81 / 2008)
Arch. Germana Corradino
Arch. Riccardo Pasquino

Building inspection
Arch. Mario Bona

Company
Temporary association of companies

Principal Company, Group leader

Abitat S.p.A.
Construzioni Edili Civili e Industriali
Corso Milano 9
27029 Vigevano
Task: Building Enterprise
Responsible engineer Giuseppe Massino (R.S.P.P.)

Further principal Company

Bona 1858
Piazza Roma 6
13100 Vercelli
Task: Building Enterprise
Responsible Person: Mario Bona

Further principal Company

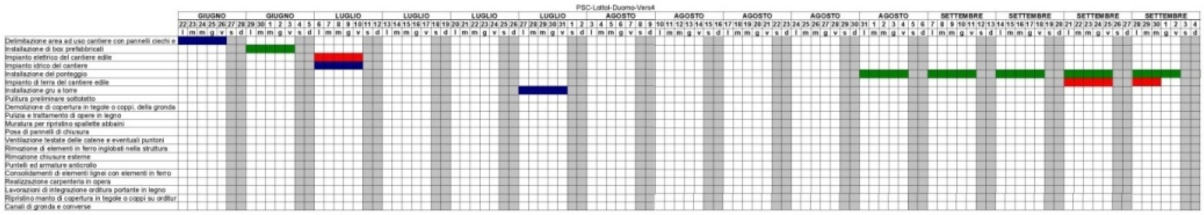
Dremar ASM Srl
Ambiente Servizi Montaggi
Via Resega
28021 Borgomanero
Task: Environmental services and assembly
Responsible Person: Giovani Maria Marazza

Further Company

Ecologica
Via Parini 3
13048 Santhia Verceil
Task: De ratting and disinfestations
Responsible Person: Vaudagana Pier Antonio

6.3.3. Date and place

The time-plan by Arch. Daniele De Luca and Arch. Riccardo Pasquino
(Translation of the table see next point: Steps 1-24)



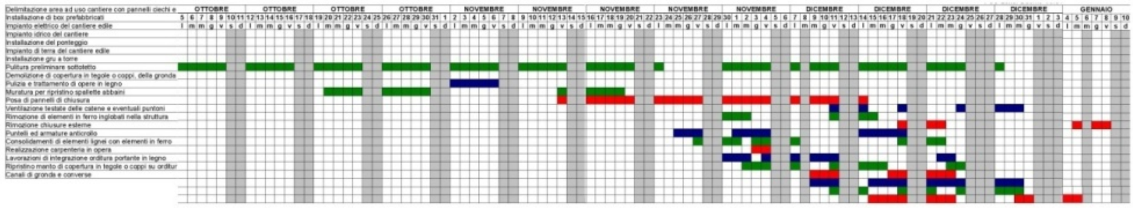


Table 6

To get a good idea about the work that has been done on the construction site it was necessary to visit the workshop, whenever a new phase begun.
Site inspections Pia Panosch:

Illustration 50 Pia on site

14.09.09	building site equipment
21.09.09	meeting executing companies
5.10.09	scaffold
22.10.09	cleaning
5.11.09	inner scaffold
26.11.09	safety net
14.12.09	free joints at the bearings on the wall

29.01.10 intervention choir

6.3.4. Steps

-1 The security of the existing structure has to be evaluated
-2 Delimitation of the workshop area with opaque panels
-3 Installation of a prefabricated box
-4 Electrical and hydraulical support for the workshop
-5 Scaffold
-6 Earthen system of the workshop
-7 Installation of the tower crane
-8 Preliminary cleaning of the attic
-9 Removal of the tiles and gutter
-10 Removal of the timber elements (small order)
-11 Verification of every single element (reuse)
-12 Total or partial removal of the timber structure
-13 Cleaning and treatment of the timber elements
-14 Restoration of the walls and the dormer window
-15 Pose closing panels
-16 Ventilation of the head of the tie beams and eventually the rafters
-17 Removal of the metal elements (timber trusses and frames)
-18 Removal of the external panels
-19 Support against failure
-20 Strengthening of the timber beams with metal elements
-21 Realisation of the carpentry (reconstruction of weakened timber elements)
-22 Integration of the new reinforcing elements in the existing structure
-23 Reinstatement of the tails
-24 Gutters and valley gutters

Notes:
1. Tile covering
- Put in order the misplaced tiles
- Substitution of the damaged elements

2. Gutter in copper
- Rearrangement of the gutter
- Complete or partial substitution of the gutter

3. Exposed timber elements (frames and trusses)
- Spreading of protective oils
- Re-varnishing of the timber elements

6.3.4.1. Security on site

The scope is to make the workshop in a secure way “easily” accessible.
Situations which have to be resolved:
-Access to the workshop
-Security of the workshop
-System to transport and distribute the loads
-Displacement of the materials
-Movement of the tools

-Hygienic conditions
-Protection of third people

Protective measurements which have to be taken to secure the workshop:

The scaffold The crane



How he scaffold is bearing on the roof signs next to the entrance

Security hooks


Illustration 51 security on site

The first step is to ensure that the existing structure is able to carry the loads which will be added meanwhile the construction site is open and later on.
It has to be assured that only authorised people have access to the construction site.
Every person entering has to be dresses adequately (security shoes and helmet).
As it is too dangerous to excess the cathedral from the common staircases, the company Dremar got the task to built an exterior aluminium gangway and the scaffold out of metal tubes. The cathedral had to be accessible from all sides. The scaffold has to have two emergency exits. Considering the Slope in the horizontal direction people working on the top of the roof have to be anchored on an anchorage post, which has to be fixed on the roof.
Additionally to security hooks, on the last floor of the scaffold, a security net has to be installed to catch people working on top of the roof (removing replacing tiles…) falling from the roof. Also in the inner part of the cathedral a scaffold had to be erected to simplify the work on site. A net in the inner part of the cathedral has to catch people and elements breaking through the roof.
The whole interior situation had to be lightened. The lightning system has to be chosen in a way that the structure is in no danger. Lights which get hot producing light can cause an inflammation.

Attached plans (arch. De Luca)
To get further information about the measurements which have been taken to secure the construction site see Appendix (Plans Manuale di siccurezza).

6.3.4.2. Principal interventions of consolidation

Before starting with the work some preliminary actions have to be taken to secure the work and ensure that the right actions will be taken.
-timbering and bracing the dangerous zones of the timber structure with appropriate adjustable piers
- removing the gutters, antennas, the chimney pot, the flashing and all the other elements which have been mounted on the roof.
- verification of the stability of the cornices and if they are insufficient and directly in contact with the timber structure they have to be braced.
-The covering tiles have to be removed and stored in a secure place for eventual reuse.
- Every single timber element has to be checked and classified. (Possible reuse?)
- Total or partial removal of the structure.

6.3.4.3. Cleaning

To be able to work in hygienic conditions and to evaluate the real state of the structure the whole attic of the dome of Vercelli has to be cleaned. This preliminary cleaning has been done with conventional brooms and brushes.
Not even a week after the cleaning took place the whole workshop has been full of dove dirt again. Therefore it is necessary to protect the roof against animals entering and soiling the whole attic.

Illustration 52 Company Ecologica cleaning the roof

In a later phase, before the interventions on the timber elements will take place (connecting new timber elements with old ones and the treatment with chemical products to augment the resistance against outer influences) a sandblasting with a controlled pressure or a further brushing too remove the dirt is foreseen.

6.3.4.4. The walls

Thinking always about the timber structure it shouldn't be forgotten, that the wood is only a part of the structure. The load capacity of the walls has to be considered as well. The wall can have suffered water infiltrations and mortar and plaster may be missing in some points. The weakened elements have to be replaced without dismantling the whole wall.

The method to restore the walls is called "cuci and scuci" which means stitch and unstitch.

After the repair the walls can be treated with substances to avoid damage in future. In points were the structure is too weak to endure the restoration temporary elements can replace the structure.

Illustration 53 cuci and scuci

6.3.4.5. Connections of the timber structure

The timber elements of 2nd and 3rd order can be connected with zinced discs. Only the beams of the ridge should be connected with shoulder bolts or stainless steel nails to ensure a stiffer connection. Of course if the discs during the construction turn out to be insufficient, they should be fixed with bolts or nails. The rafters and their counter pieces can be fixed with always two anchors with a hexagonal nut and a washer out of zinced steel.

6.3.4.6. Restoration of the salvageable components and integration of the missing points linked with the timber elements "uso Trieste" or typical laminated timber

After the elements have been accurately cleaned (most likely sandblasting) the interventions can start. It is preferable to use timber elements "use Trieste" to substitute the bearing incapable elements. Only if a traditional technique is not applicable laminated timber should be used. The direction of work (Arch. D. De

Luca) has to be informed of every single laminated element that will be used and he has to approve that the application of this element is necessary.
As far as possible every original element should be preserved and reused. In the points where the existing connection is insufficient
Where the cross section of the element is insufficient it can be either doubled or (in points where this is possible) interrupted with a post to reduce the span.

6.3.4.7. Regeneration of the head of the beam of the roof truss

These points are in a quite weak condition and most of these connections will have to be redone. The concrete project has to be done on site, when the areas are freed from all elements (stones, dirt, but also tiles) and better visible.
Two by two trusses get uncovered and then recovered with a plastic foil to refurbish each element one by one. To make an intervention possible, the truss has to be lifted. In the case of Vercelli this has been done with a figuring machine[9]. To avoid that rising damp coming from the walls can penetrate the timber element a bituminous film has been inserted under the tie beam.

Illustration 54 uncovered roof

Illustration 55 Figuring machine

Comment: normally the machine shouldn't bear on the scaffold.

According to the state of the degradation the most effective restoration method has and will be applied.
So far only the first three trusses of the choir have been dismantled and three different methods have been chosen.
Truss one, which has been in the weakest condition:
The heads of the tie beam have been substituted completely. The beam got two prostheses, which are fixed with two metal plates, one on each side. To ensure the connection between tie beam and it has been fixed with two screws at the end (position where two nails connected the original structure) and a metal tie. Additionally to the screws, the two timber elements have been glued (MAPE wood primer 100 / MAPE wood gel 120 and MAPE wood paste 140).

[9] Lifting a truss is a quite complicated procedure, because it changes the load conditions.

Illustration 56 Element, which had been substituted

Illustration 57 Elements to substitute

Illustration 58 Truss 1 south end

Illustration 59 Truss 1 south end

Truss two, which is in a slightly better condition:
This tie beam doesn't had to be substituted, but reinforced with two timber elements, fixing the head of the beam from each side. The outer part of the original tie beam has been hardened with resin.

Illustration 60 Truss 2 south end

Illustration 61 Truss2 north end

Truss 3 has been in a moderate condition no intervention has been necessary.

Illustration 62 Truss3 south end

After the trusses have been refurbished the three degraded timber beams on top of the roof, which connect the structure vertically (instead of a bigger ridge beam), will be substituted.

Illustration 63 Three beams at the ridge (elements of third and fourth order)

After the stabilisation of the structure has been restored, the other elements of third and fourth order will be substituted and the roof gets covered with new tiles.

6.3.4.8. Preservative choices

All timber elements will be treated with anti fungi products.

6.3.4.9. Presetting for future interventions of maintenance

Apparatuses to monitor the situation are foreseen.
Comment: Of course they cannot replace frequent inspections.

6.4. Proposals for interventions/ comments to the actual workshop

The goal is not just to cover the cathedral with a structure as stable as possible because with a new glue laminated structure this can be achieved with much less planning effort.
Therefore the first question has to be:

What is the best conservation strategy to preserve as much of the original structure as possible and to ensure the stabilisation of the heavy timber roof trusses and frames, the dormers and the reroofing maintaining their original appearance?

The foreseen project should prevent further damage and reinforce the structure in the inefficient parts. Like this the cathedral can be maintained, without losing the historical value. This means that the minimum intervention is the philosophy which should be followed on the restoration or further more conservation site.
The criteria that have been followed for design choices:
- The interventions should regard the current and the future use
    - In our case the use doesn't change.
- The historical formal and structural value of the building (this is why a conservative method has been chosen)
-The interventions should leave a “trace” which shouldn't be hidden.

- These “traces” have to be (as far as possible) harmonized with the existing structure.
- The intervention should be reversible.
- The removing of past interventions should be avoided.
Complicated Timber structures are even today difficult to calculate (especially because you never know how strong the wooden element really is) and therefore it is unwise to remove elements which may work in an unexpected way. The element may be without forces during the summer and in winter with additional loads and higher humidity it may have an important influence on the structure. At the dome of Vercelli lots of previous interventions have been performed, but it is recommended even if the beams are bearing on the vaults or the interventions seem useless on the first sight before touching or removing an element it has to be checked very - very carefully and if there is any doubt that the intervention may support the load bearing system the timber or metal elements have to remain.

-The overall performance of the existing static model should be maintained.
The first rough calculations seam to show that the existing structure of the dome is capable to carry the forces (reinforcing it in the wittered or weakened points) so there is no need at all to change the existing static overall performance of the roof structure. The stiffness of the single knots and the arrangement of the single timber elements should be maintained.

- A decision has to be taken if it is better to execute the repairs on site or if the whole structure has to be dismantled to get a satisfying result in the end. The problem with dismantling is that an enormous logistic coordination is needed. Every single piece has to be categorised and marked to re-find his original place after being repaired. But the advantage of dismantling is that the work can be done more easily in a more adequate ambience than on the roof of a cathedral. The initial plan was to remove the structure completely but at the moment a temporally support by a steel beam grid system seems more likely.
In the case of Vercelli I would recommend to do the repairs on site. So if it is possible it will save a lot of time and money to stay on site. However the decision will be it is important to work systematically.

6.4.1. Stuff decisions

After the accurate diagnostic phase the refurbishment project has to be made. It is important whatever the philosophy of the restoration side may be that the people working on timber structures are experts. Collaboration between operative specialists of various fields is necessary to obtain a satisfying result. The interventions often require a high knowledge of the material timber itself as well as craftsmanship.
The engineer has to proof the structure, the wood technologist has to classify the single elements, the chemist has to think about formulations to preserve the timber, and the historian has to know about techniques used in the period when the building has been erected and so on. The architect has to collect all these informations and bring them into the project.
Comment: The companies and experts working on the restoration site of the dome of Vercelli are carefully chosen and have already experience in the field.

6.4.2. Preliminary Actions

Generally the first step is to look at the compability of the use and other building conditions, like heat, humidity etc., which may influence the intervention. The preliminary research may influence the type of a conservative intervention and / or can aid to avoid incompatible adjustments (See point 6.2. Interventions which

have been performed in the dome in former times). For example: If the timber structure is damaged because of water infiltrations (as the structure of the Dome of Vercelli) the first step is to get the roof dense. It would be completely useless repairing the structure and not eliminating the source of the damage.
Workshop: In the case of the roof of the cathedral of Vercelli, the use will not change.
Comment: I would recommend a slight change of use. See chapter 7 Open the roof to the public.

6.4.2.1. Security on site

Before starting to work some primary actions have to be taken to secure the work.
-One important aspect is to think about at this stage is access to all parts of the structure. In the case of the Dome of Vercelli it will be necessary to use ladders and scaffolding. The ladders and scaffolds need to rest on something firm. Thinking about the costs it has to be considered, because scaffolding is expensive to hire and difficult to transport to remote locations. By law it has to be independently inspected frequently.
-Then the timbering, underpinning and or bracing with appropriate adjustable upright elements for the construction site.
-The gutter and the chimney flue, the antenna, the flashings and all the other elements which are on top of the roof have to be removed.
-The stability of the cornice has to be checked and eventually supported (propping).
-The roof tiles have to be removed.
-Every single element has to be analysed regarding the safety of and the reusability. To do this, it is necessary to clear and free the elements from eventual contamination and herbal infestations.
All the battens and contra battens have to be removed partially or if all the elements are heavily degraded also entirely.
Comment: Regarding the workshop, all of these points have been thought about and are written in the “Manuale di siccurezza”. Whenever I have visited the construction site, these security measurements have been controlled and executed. Therefore the security standard at the conservation site of the cathedral is very high. Regarding the cost point I assume that it may have been cheaper scaffolding always only a part of the church finishing this part and then move to the next one instead of making everything together.

6.4.2.2. Cleaning

The structure of the Dome of Vercelli which has not been subjected to any recent stabilisation treatments is largely covered in dirt and rotted wood. Cleaning down is not absolutely necessary, but surface accumulations make it difficult to determine the whole damage of the structure and it can prevent eventually later used preservative chemicals from penetrating to sound wood. This means also that fewer amounts of chemical products will be needed and you can discover previously unsuspected areas of rot and other structural weaknesses.

One possibility to clean timber down to moderately sound wood is the water blasting. The two most important characteristics of a water blaster are the water pressure, and the volume per minute delivered. It is important to control how powerful the water jet is. In general a pressure of
500-1500 psi will remove dirt and completely rotten wood, but higher pressures are likely to weaken the fabric of sound wood.
At a minimum the operator needs warm clothing and PVC parka and over trousers. Wet suits are ideal for protracted operations.

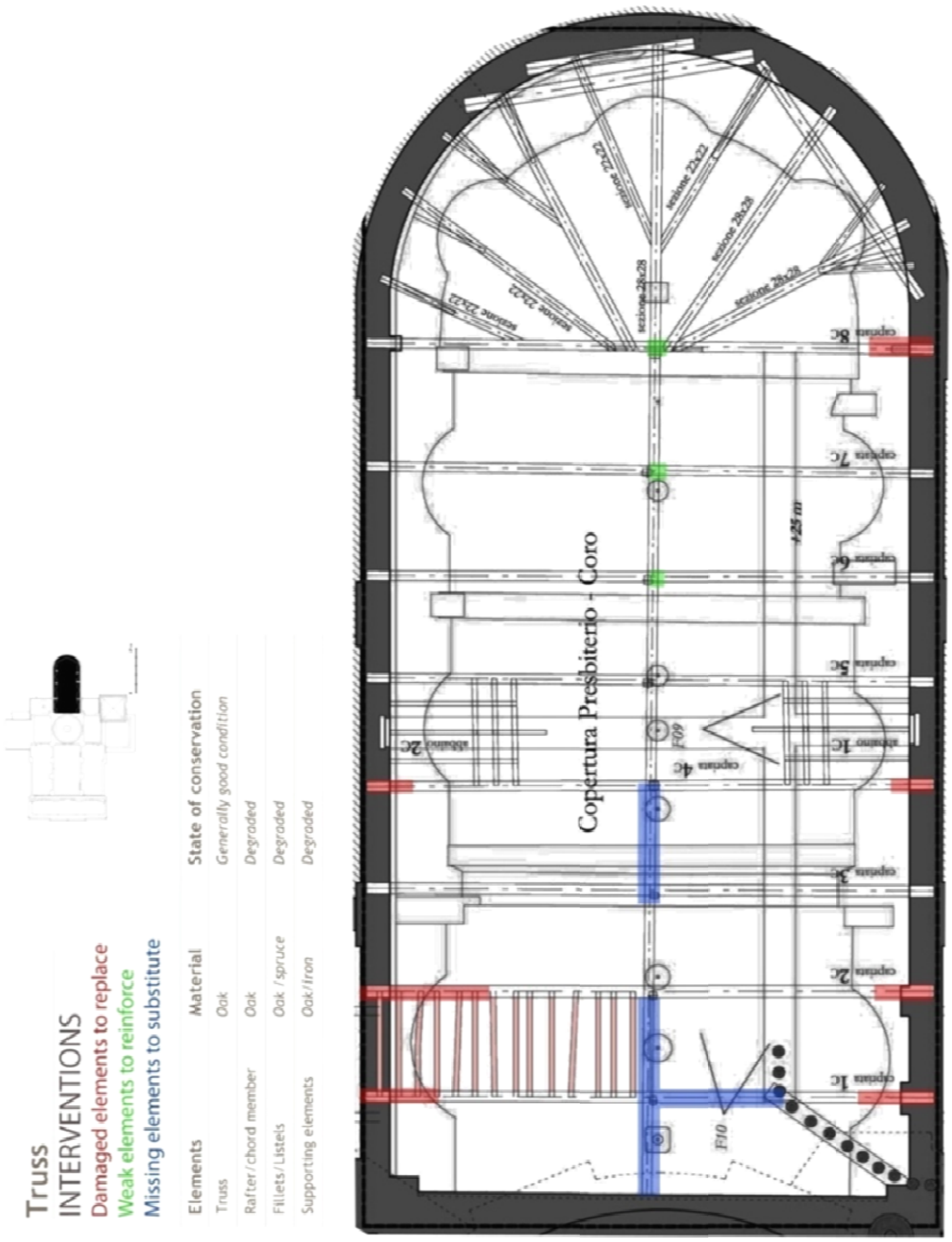
Most water blasters have provision for adding detergents or other chemicals to the water, but there is little advantage in doing so, and considering the large amount of water passing through the water blaster, any chemicals added at this stage are a potential cause of environmental pollution.
The one big disadvantage of water blasting is that it injects a substantial amount of water into the fabric of what might otherwise be a reasonably dry structure. Therefore this method can only be used when the timber structure can dry out easily. Another disadvantage is that the structure's appearance will be changed forever once water blasting, some components may be so thoroughly rotted that they will not survive it. Therefore at least so take lots of photos beforehand.
This is why for the dome of Vercelli laborious dry cleaning techniques are more adequate, in particular by brushing down with hard-bristled (often long-handled) brooms. Some brooms clean amazingly easy mushy rotten wood. Wire brushes may be useful, but are even more prone to clogging.
Another possibility, particularly for removing dirt and completely rotten wood from fissures is a workshop air compressor, or sandblasting with controlled pressure.

As these dry methods of cleaning produce clouds of dust it is important to wear respirators with particulate filters to avoid bereaving the dirt in.
If there is concern about metals (such as lead), chemicals or other dusts contaminating the environment an ordinary vacuum cleaner can be used.

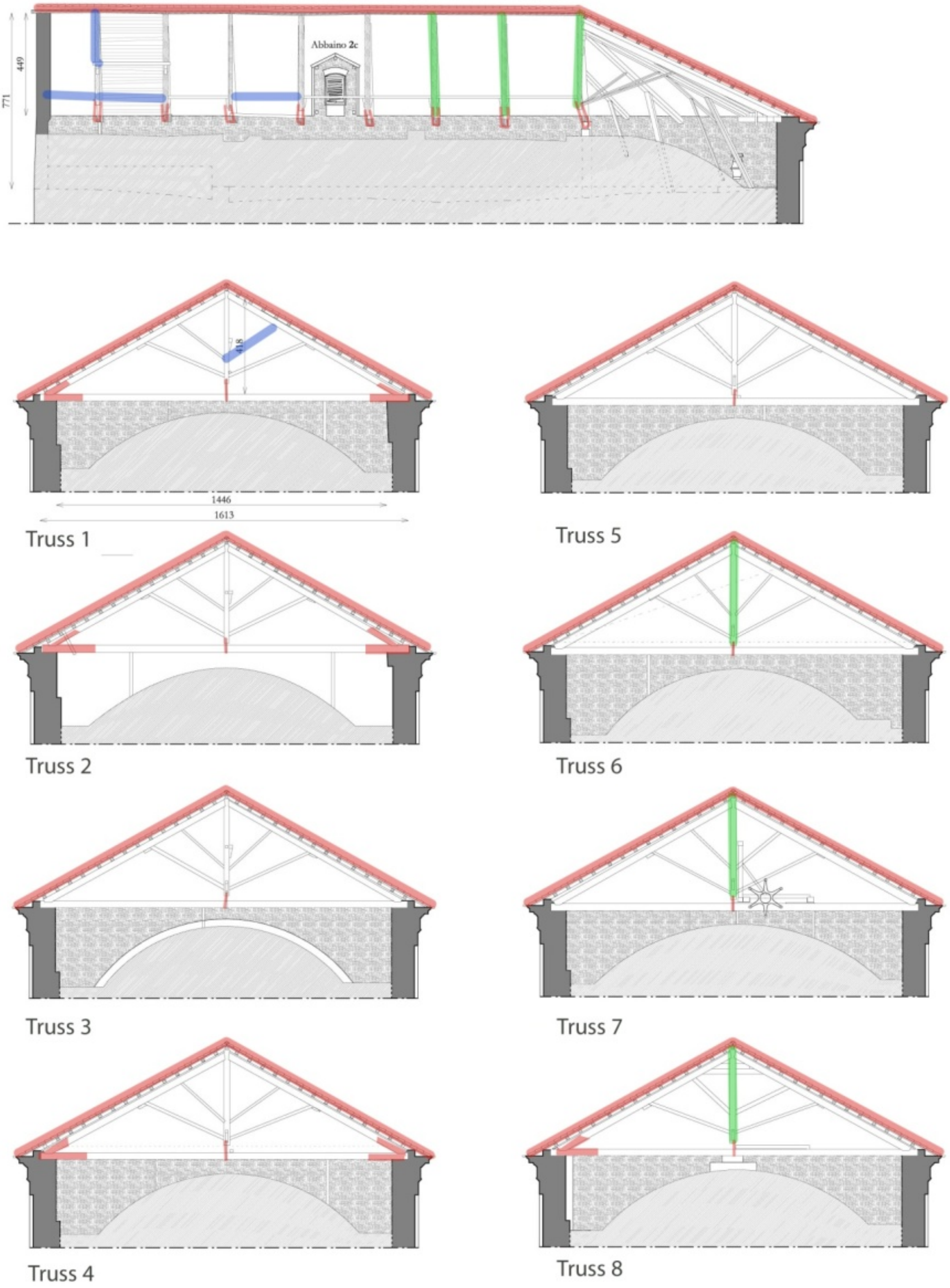
Comment: I would take the same decision, which has been taken on the workshop: I would recommend a dry cleaning technique. Maybe sandblasting or an air compressor would have been quicker, but if the brushing is done accurately it leads to the same result. There is something else I would change; on the workshop has been made a mistake: It is necessary that doves and other animals cannot re-enter the attic after the cleaning has been done! In the case of the Dome of Vercelli this has been possible and it is unbelievable how much dirt doves can produce in only one day. Already a week after the cleaning the roof has been dirty again and probably the structure will have to be cleaned again.

6.4.3. Proposal how and where to intervene

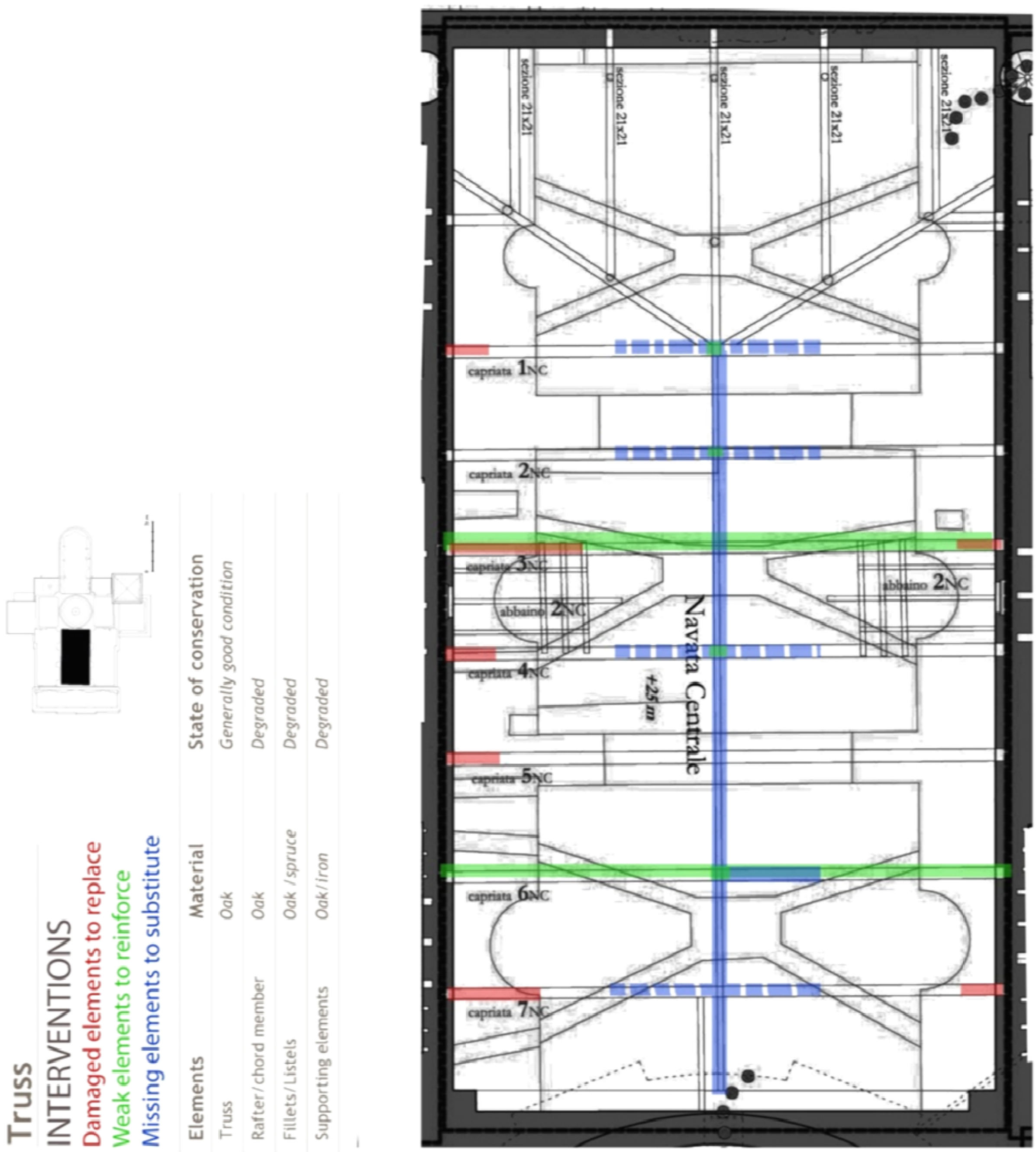
6.4.3.1. Plans of interventions



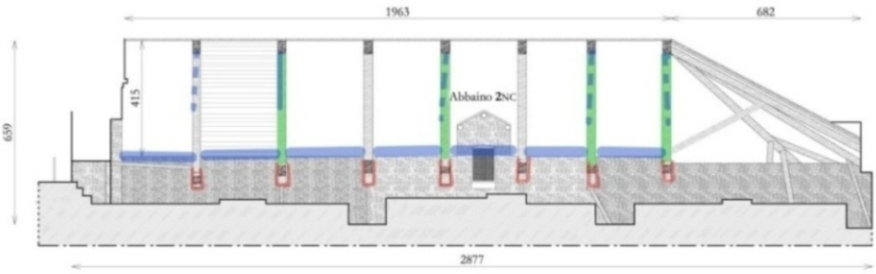
Plan 7

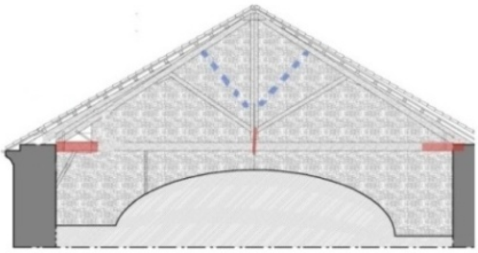

Abbaino 2c
449
771
418
1446
1613
Truss 1
Truss 5
Truss 2
Truss 6
Truss 3
Truss 7
Truss 4
Truss 8

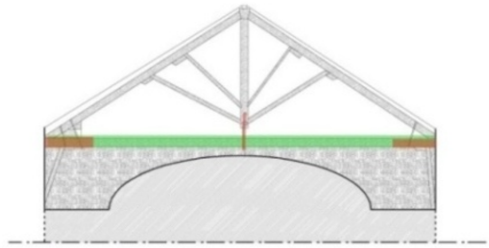
Plan 8

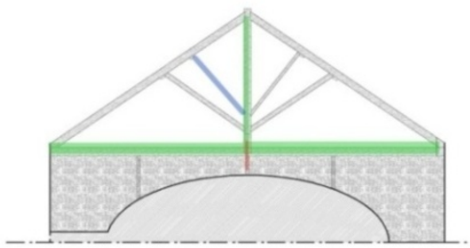

Truss
INTERVENTIONS
Damaged elements to replace
Weak elements to reinforce
Missing elements to substitute
Elements | Material | State of conservation
Truss | Oak | Generally good condition
Rafter/chord member | Oak | Degraded
Fillets/Listels | Oak / spruce | Degraded
Supporting elements | Oak/Iron | Degraded
sezione 21x21
capriata 1NC
capriata 2NC
capriata 3NC
abbaino 2NC
capriata 4NC
Navata Centrale
+25m
capriata 5NC
capriata 6NC
capriata 7NC

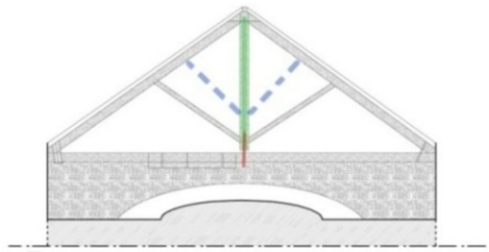
Plan 9

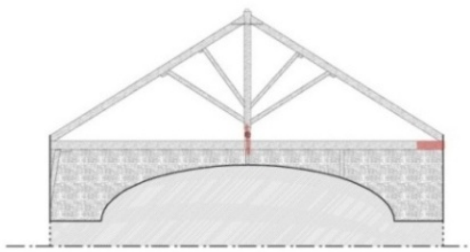


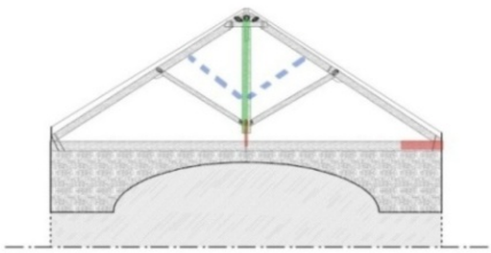

Truss 7

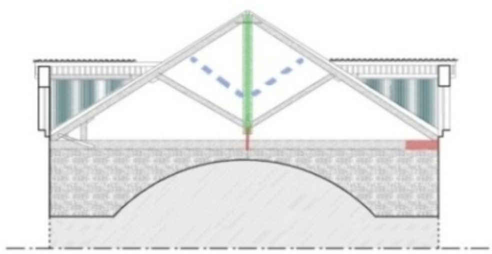

Truss 3


Truss 6

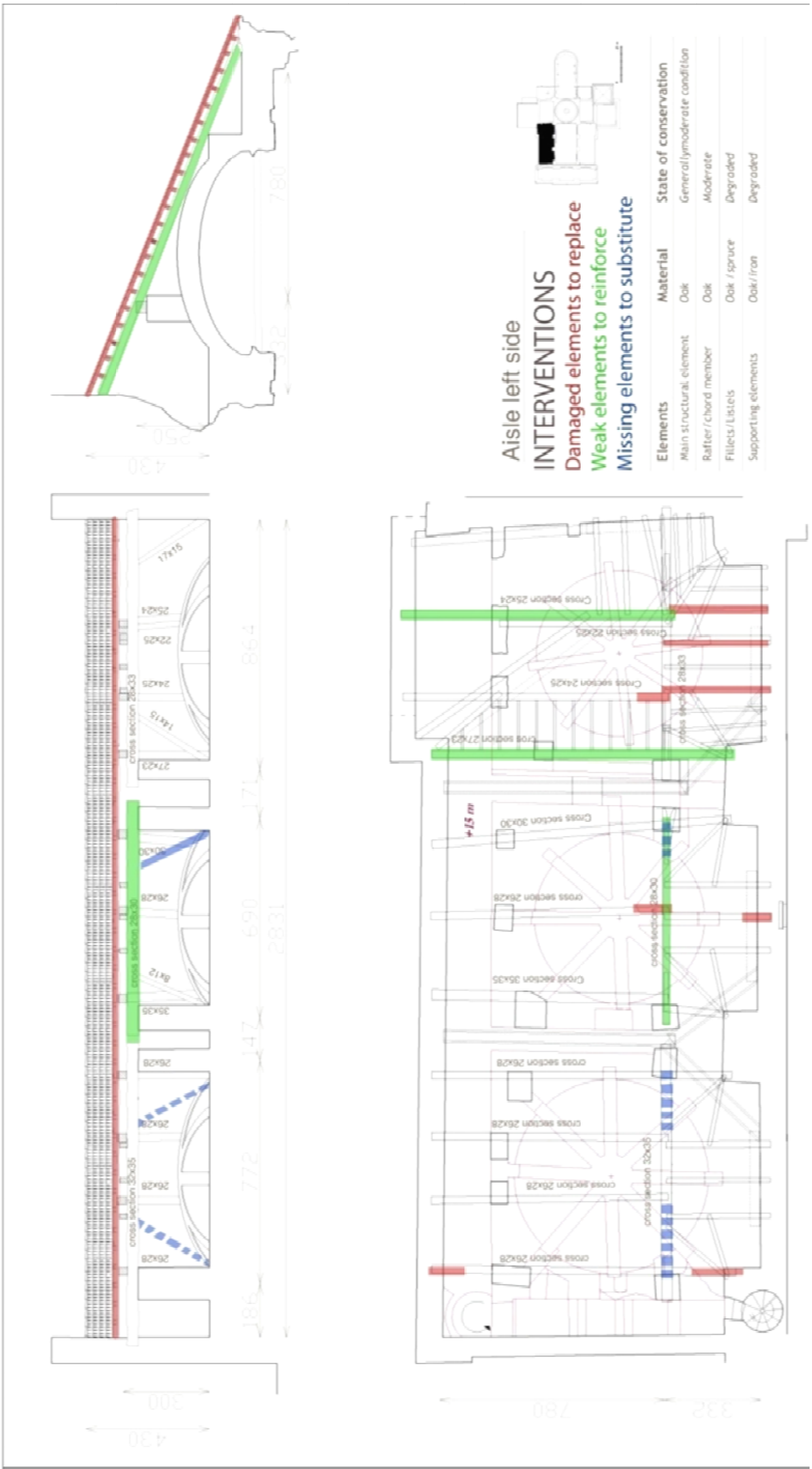

Truss 2


Truss 5


Truss 1


Truss 4

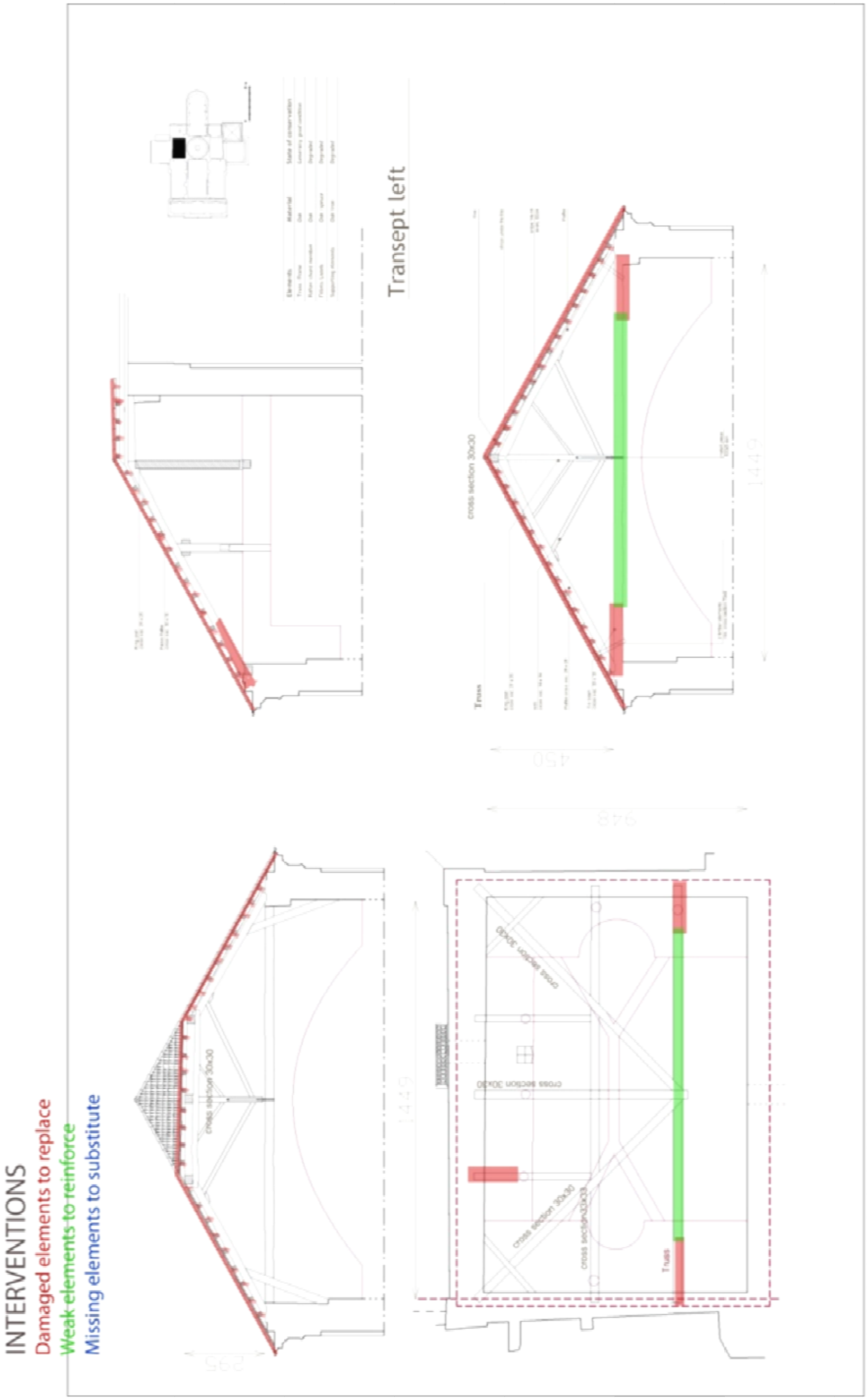
Plan 10


Aisle left side
INTERVENTIONS
Damaged elements to replace
Weak elements to reinforce
Missing elements to substitute
Elements
Material
State of conservation
Main structural element
Oak
Rafter/chord member
Oak
Moderate
Fillets/Listels
Oak/spruce
Degraded
Supporting elements
Oak/Iron
Degraded

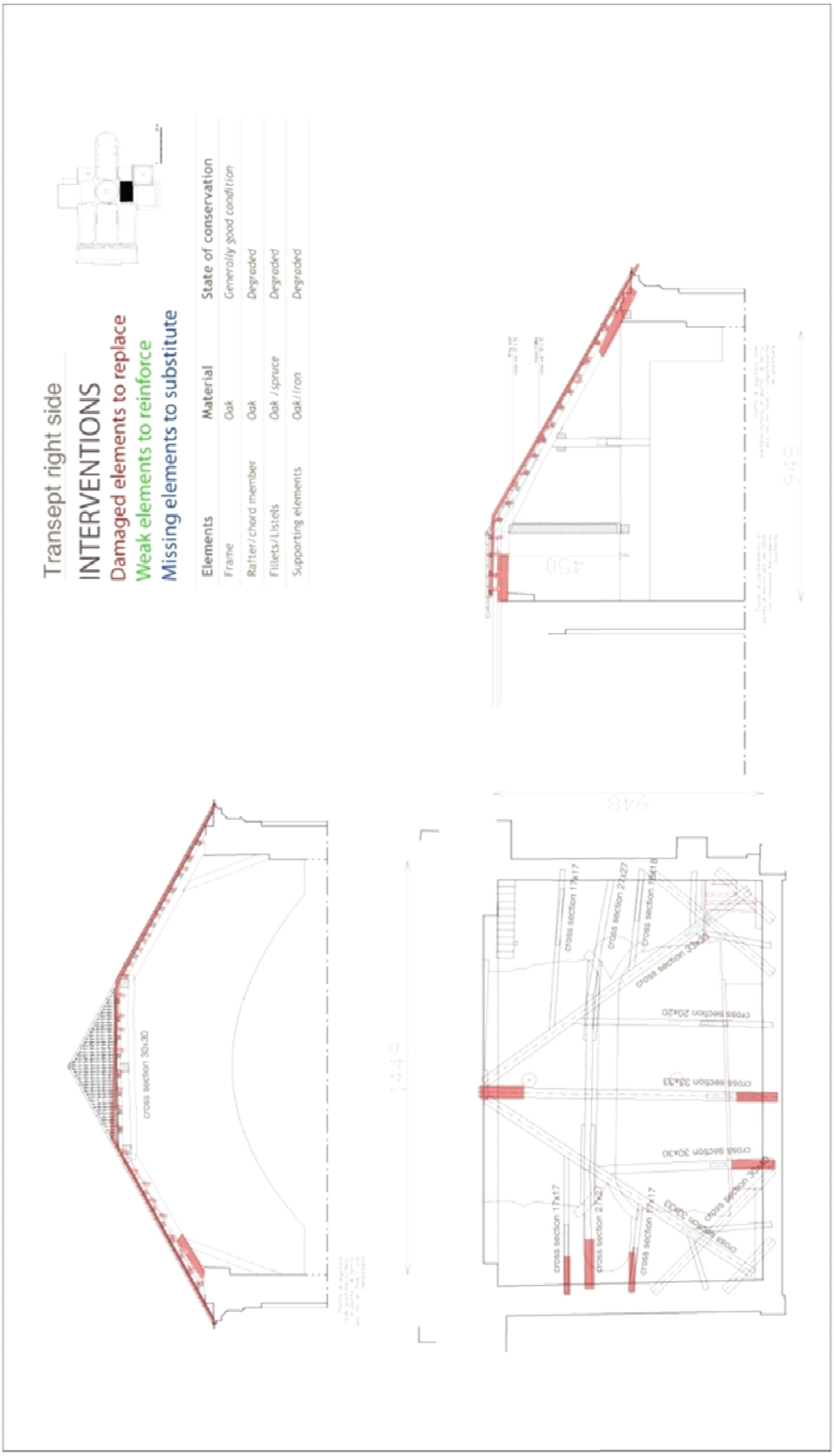
Plan 11


Aisle right side
INTERVENTIONS
Damaged elements to replace
Weak elements to reinforce
Missing elements to substitute
Elements
Material
State of conservation
Main structural element
Oak
Generally moderate condition
Rafter/chord member
Oak
Moderate
Fillets/Listels
Oak / spruce
Degraded
Supporting elements
Oak/iron
Degraded

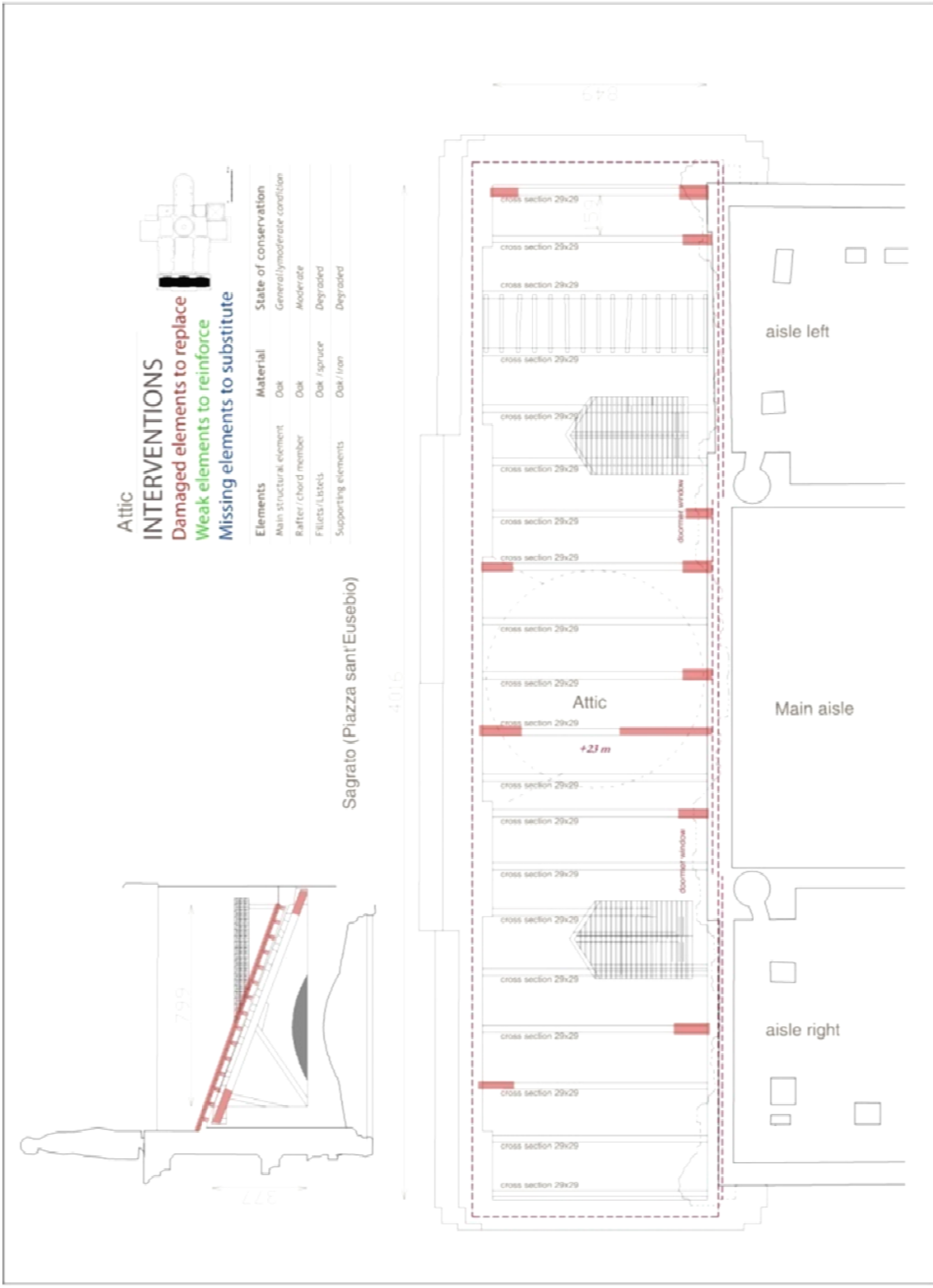
Plan 12


INTERVENTIONS
Damaged elements to replace
Weak elements to reinforce
Missing elements to substitute
Transept left
cross section 30x30
Truss

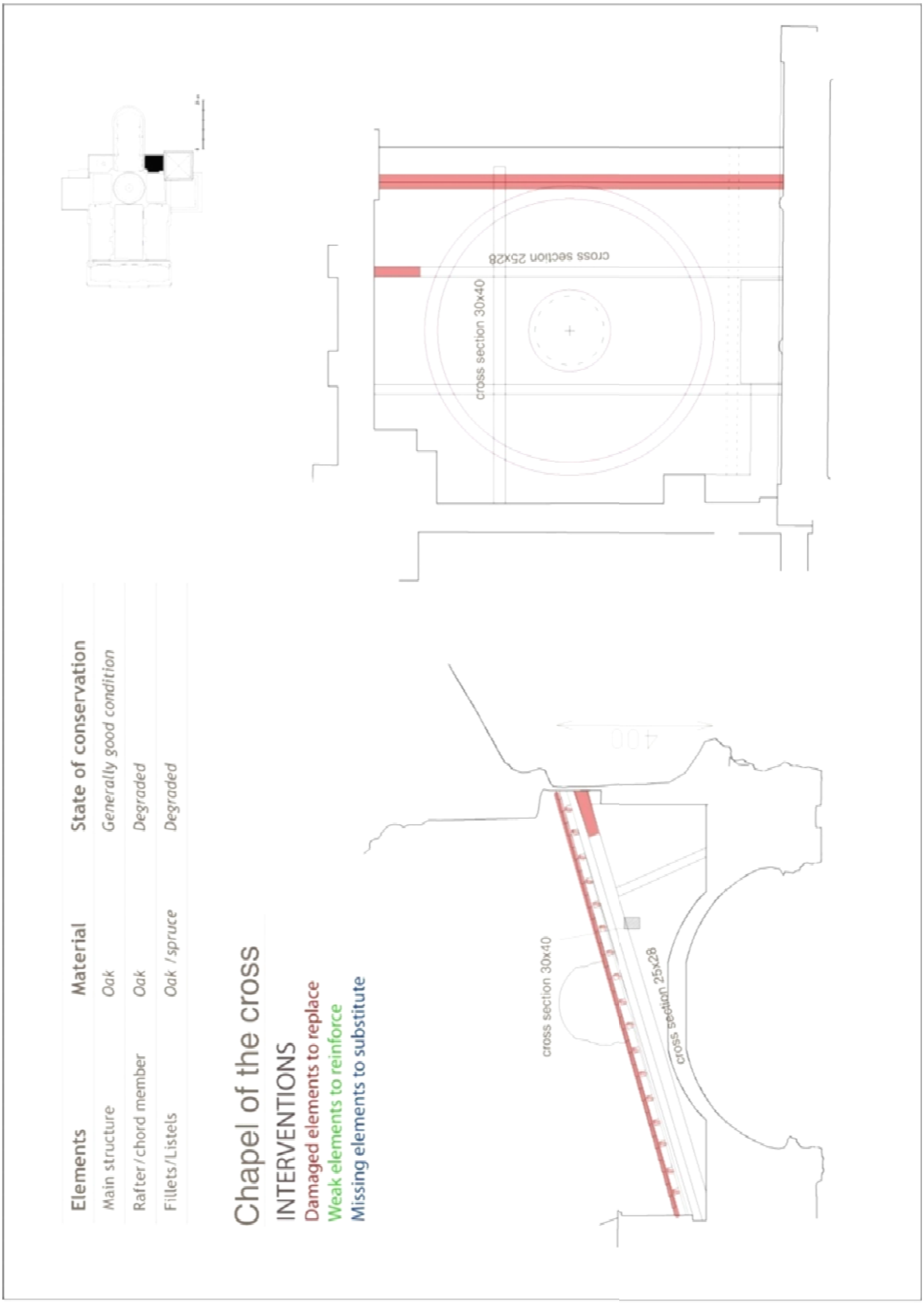
Plan 13


Transept right side
INTERVENTIONS
Damaged elements to replace
Weak elements to reinforce
Missing elements to substitute
Elements
Frame
Rafter/chord member
Fillets/Listels
Supporting elements
Material
Oak
Oak
Oak /spruce
Oak//iron
State of conservation
Generally good condition
Degraded
Degraded
Degraded
cross section 30x30
cross section 17x17
cross section 27x27
cross section 20x20
cross section 33x33
cross section 30x30
948
1449
450

Plan 14


Attic
INTERVENTIONS
Damaged elements to replace
Weak elements to reinforce
Missing elements to substitute
Elements
Material
State of conservation
Main structural element
Oak
Generally/moderate condition
Rafter / chord member
Oak
Moderate
Fillets/Listels
Oak / spruce
Degraded
Supporting elements
Oak / Iron
Degraded
Sagrato (Piazza sant'Eusebio)
cross section 29x29
Attic
+23 m
doormer window
aisle left
Main aisle
aisle right

Plan 15


Elements
Material
State of conservation
Main structure
Oak
Generally good condition
Rafter/chord member
Oak
Degraded
Fillets/Listels
Oak / spruce
Degraded
Chapel of the cross
INTERVENTIONS
Damaged elements to replace
Weak elements to reinforce
Missing elements to substitute
cross section 30x40
cross section 25x28
cross section 30x40
cross section 25x28

Plan 16

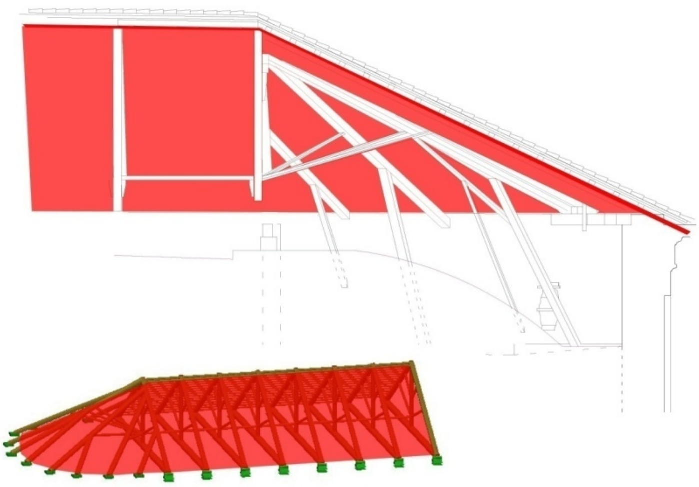
6.4.3.2. General Interventions (interventi complessi)

The aim of these interventions is to increase the strength of the entire structural unit.

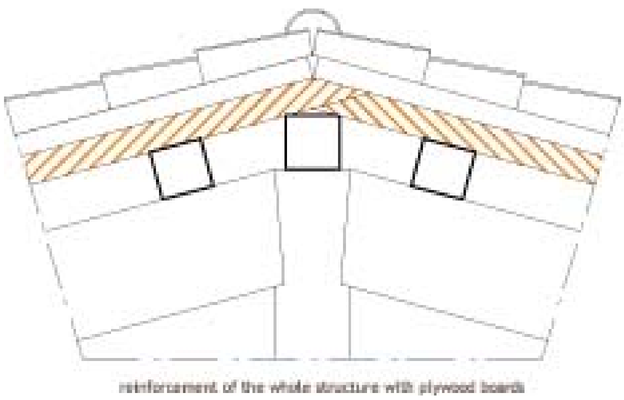
6.4.3.1. Timber panels

The intervention planed by Daniele De Luca doesn’t foresee any panels. He wants to maintain the original structure and the original bearing system. It was planned to cover the roof with new tiles and reuse the original tiles above. This has been impossible, because of cost reasons. Now two new rows of tiles one above the other are foreseen.
The advantage using timber panels:
It would be a good idea to cover the whole roof under the tiles with timber plates (plywood or LVL boards) to achieve a higher over all stiffness of the structure. In general changing the rigidity of a structure is risky it can lead to overloads in points which haven’t been designed to take forces as high as they may occur after the intervention, but in this case the load is distributed over the whole structure and shouldn’t lead to any further damage. Furthermore the plates are not as heavy as the foreseen tiles.
In every case (Version De Luca or timber panels) load will be added to the structure and the structure will have to be calculated again.

Red: added timber panels nailed on the beams



Plan 17



Plan 18

6.4.3.3. Punctual Interventions

The difference to the previous interventions, which have the goal to increase the strength of the entire structural unit, is that these are interventions in specific sections aimed at restoring or at increasing the resistance of the single element. The idea is to plan the single repairs meanwhile the intervention takes place. This is a very good, but stressing way to work. The real condition of the element (even if a very careful and detailed analyse has been done) can be only seen when it is dismantled and this is the case directly before the intervention has to take place. Therefore the planning has to go very quickly. I would recommend a further exploratory drilling on the critical points (joints) after the elements have been freed, to get even more reliable information of the structural resistance of the timber elements.
To intervene the trusses will have to be shored up.

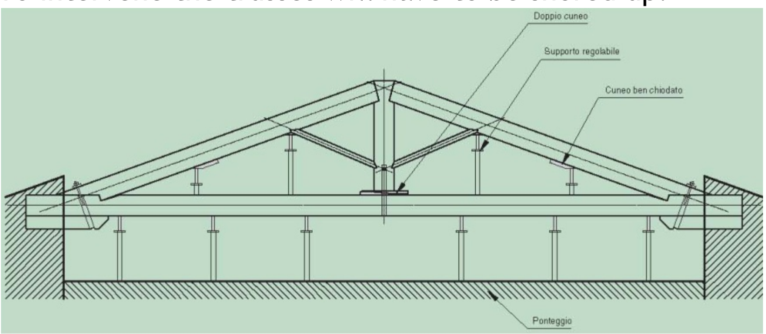


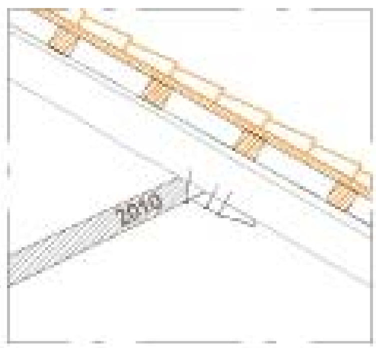
Figura 9 *Schema di puntellazione per interventi sulle testate.*

Illustration 64 underpining a truss manuale legno strutturale

Possibilities to underpin (manuale del legno strutturale, interventi sulle strutture, interventi sulle capriate lignee-consolidamento, Figura9)

Wood on wood, or wood – different material (steel, concrete…)
Generally is to say that wood on wood connections are preferable, because a new and the old timber pieces (if same species and humidity content) have the same properties, there are no points, where water can be collected and cause damage, no thermal bridge, the same deformation…

6.4.3.3.1. Substitution of missing elements



Plan 19

The trusses in the main aisle and the choir, but also the timber frames in the left and right aisle have been designed symmetrically. Now some elements are missing. They should be substitute. Oak wood should be used and the joints should be the same once like the once of the original structure. It is important to mark these elements to make it clear for later restorations that they have been added later. To avoid problems of shrinkage and deformations, the new timber element should have the same moisture content as the rest of the original structure (Timber roof Vercelli about 16%). The element should be connected in the same way as the original one has been (In the case of the detail above nailed).

6.4.3.3.2. **Replacing damaged timber elements**

The following solutions are for the bearing of the beams on the masonry:

- The elements can get connected to the masonry by means of *cramps, copper clasps or iron cramps and metal fibulae*. (Alberti (1485) and Milizia (1785).

-The timber elements can bear on timber stringers fixed on the masonry, or are rested on brackets on consoles; the joint between beam and timber element is a mortise and tenon joint; (Emy and later also by Breymann (1880))

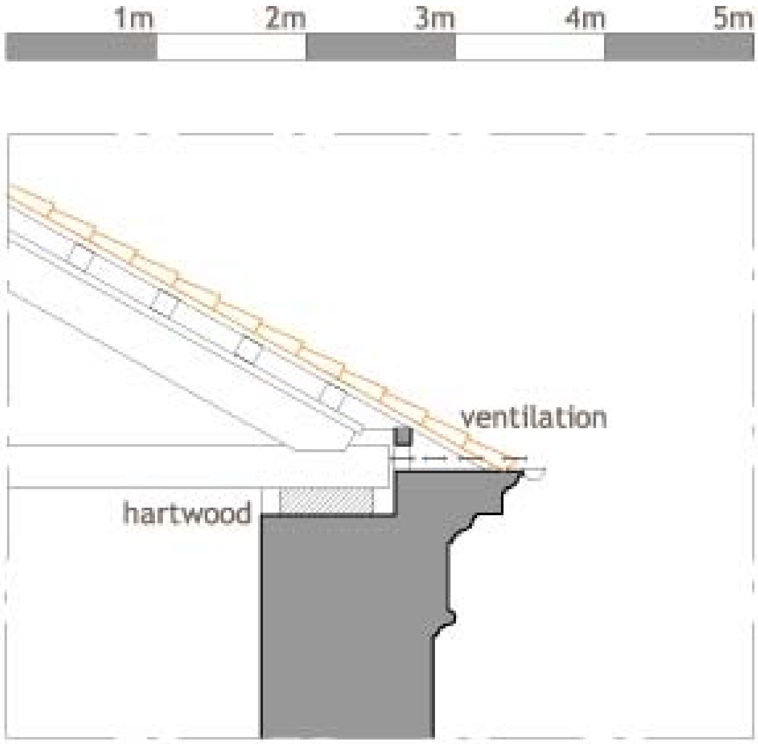
To avoid the decay of the headpieces of the timber beams infixed in the masonry, the following steps can be taken:

- Prepare an air space around the headpiece! (Alberti, Emy)
- A hole on the outer wall allowing the airing of the headpiece would be favourable! It should be covered with a grid. (Pareto and Sacheri)
- Insert hardwood or stone brackets under the headpieces of the tie-beams! (Emy);
- Set dry or air bricks around the headpiece! (Formenti, Donghi and Chevalley)
- In case of masonry with a moderate thickness and a roof which protects the outstanding elements (they are not allowed to be exposed to the rain) lengthen the beams headpieces up to the outer surface! (Emy, Pareto, Sacheri)

Proposals:

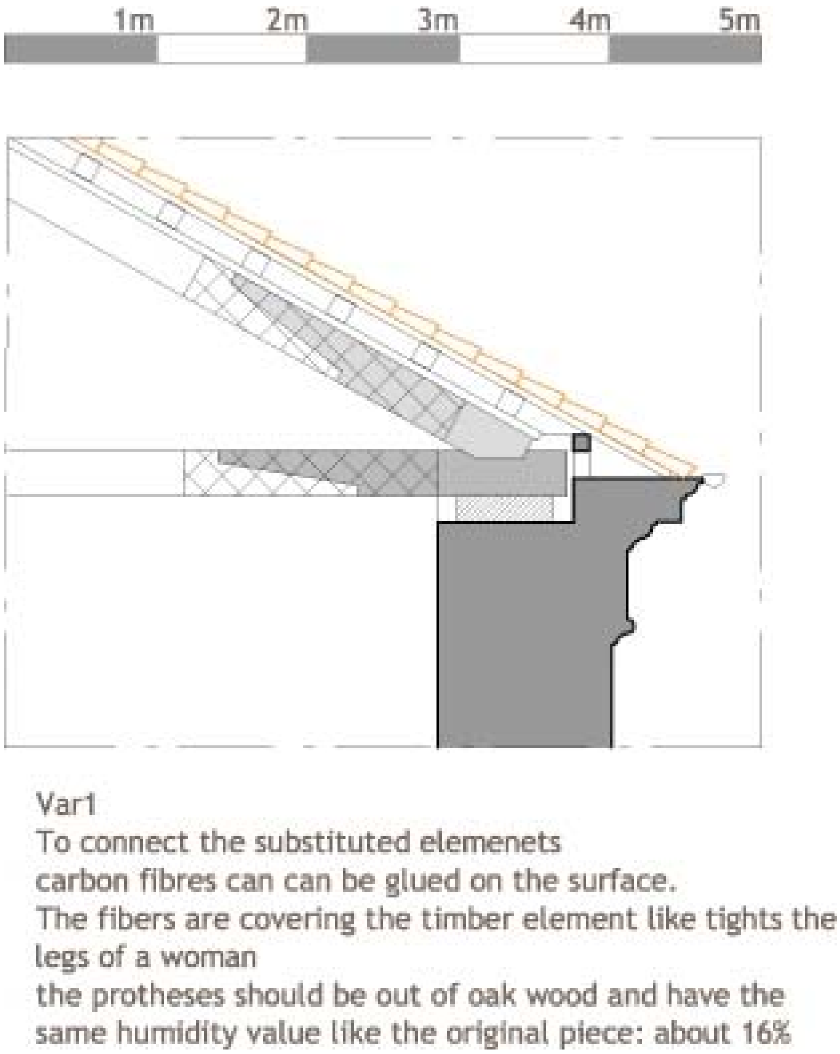
The first detail shows how the bearings should be prepared. In the timber element there should not remain any firm water. Therefore it is important that water cannot penetrate the timber element. In case this should happen anyway the element must have the possibility to dry out.

The further 4 Details are 4 different proposals how an intervention could look like. These interventions are not only for the heads of the trusses but can be used for all kind of prosthesis which have to be performed in the cathedral.



The tie beam bears on a hartwood timber element
the wall has a hole
like this the beam is better ventilated
(all bearings which have to be redone (not only in the choir
and the main aisle) should be redone like this)

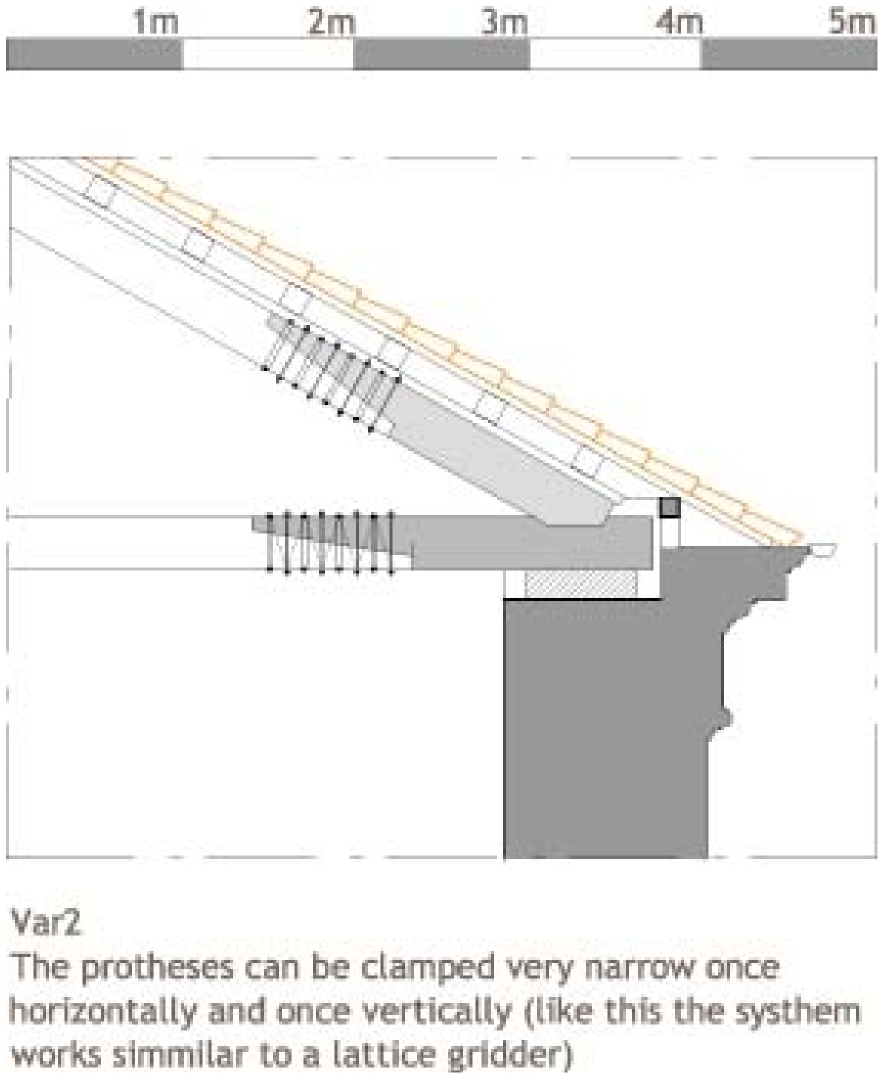
Plan 20



Plan 21

Illustration 65 intervention

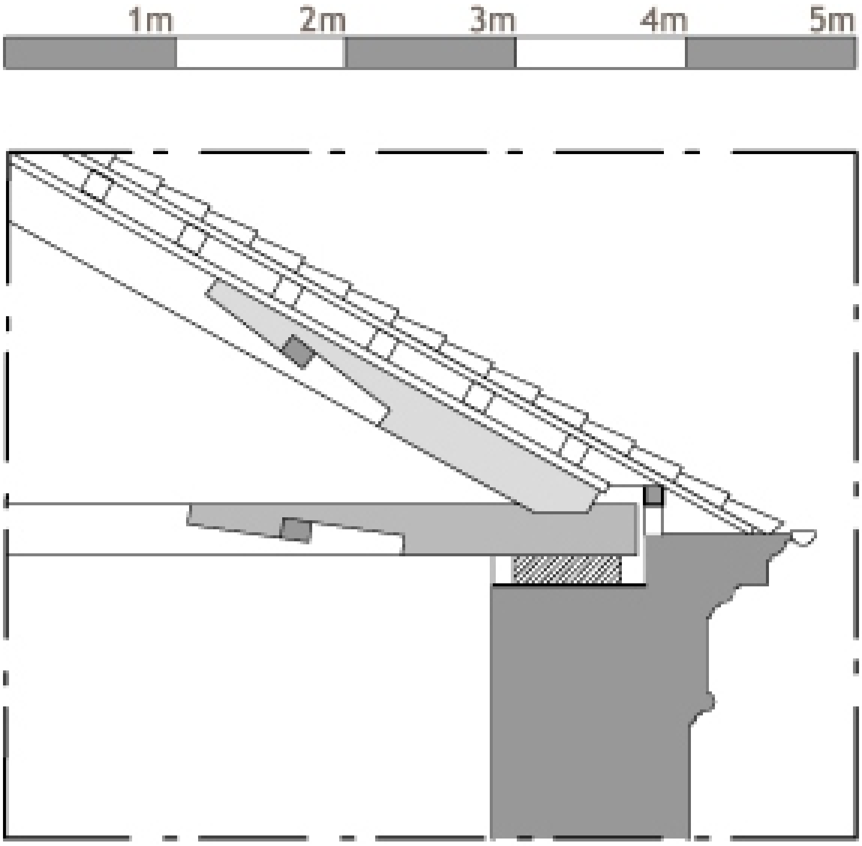
To intervene with carbon fibre is a quite young restoration technology. Normally the fibres get cut into the wood parallel to the fibre direction. In this case the carbon fibre is covering the timber element like a net. The advantage of having the fibres outside is that the intervention is reversible. If the element is exposed an invisible reinforcement inside the element may be preferable. This method could be eventually used as well for beams with ring shakes, fissures and so on.



Plan 22

Illustration 66 intervention

The advantage of this method is that it is quite common and can be done by an ordinary carpenter.

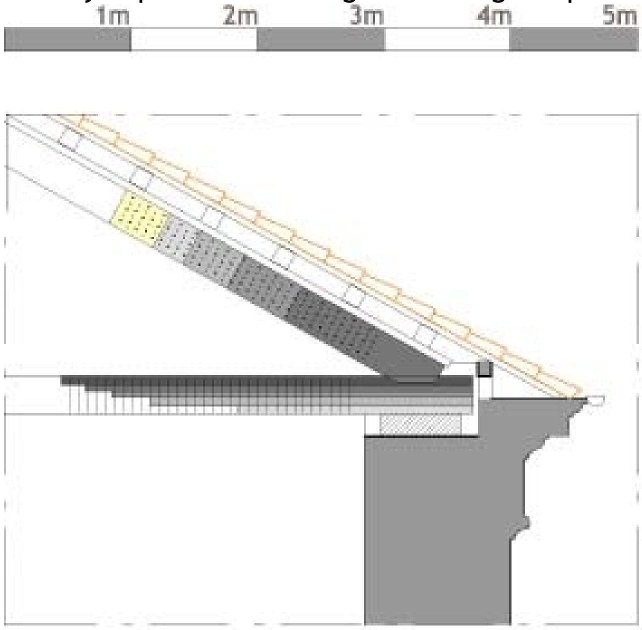


var3
Arrow of Jove
it can get screwed or glued together the inner part can be out of hardwood or new materials like carbonfiber...

Plan 23

Illustration 67 intervention

This proposal is the ancient, but very efficient way to connect prosthesis. This method is the historic maybe most elegant solution. The carpenter has to have already experience and high knowledge to produce such a joint.



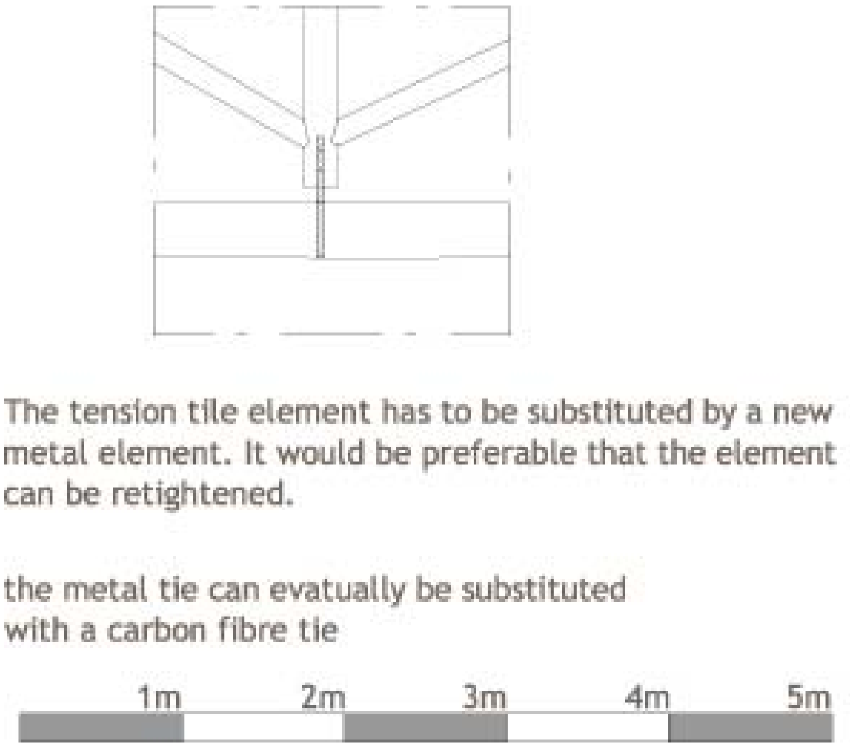
Var4
The protesis works like a glulam beam out of new and old timber. It gets glued and screwed with timber screws, from both sides. The srews are verry narrow and they are missplaced, so that the screw form the bottom cannot meet the one coming from abouve. The systhem works in bouth directions (in this case the rafter prothesis works vertically and the tie beam horizontally)

Plan 24

Illustration 68 intervention

The last proposal is the most efficient one. After the resistance drilling the weakened points can be cut out. Nearly no healthy timber gets “wasted”.

6.4.3.3.3. **Replacing damaged metal elements**



Plan 25

Illustration 69 metal connection

Many of the metal elements do not work anymore, mainly because of the elastic characteristics of metal. The elements got bigger and cannot overtake loads anymore. These elements have to be substituted. It would be preferable to choose a system which can be readjusted, to avoid such problems in future.

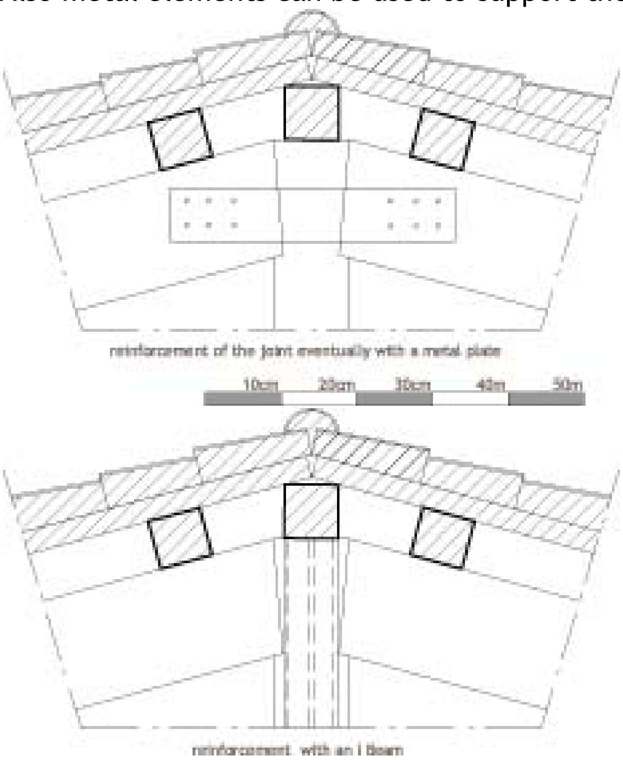
6.4.3.3.4. **Reinforcing elements with an un-sufficient load capacity**

The problem of the elements which are unable to carry the loads can be resolved in various ways.

The simplest way is often the best one. Therefore, in the case where the elements have above themselves already different little timber elements to change the inclination, I would recommend adding a timber piece on top and connecting the two elements (double the beam).

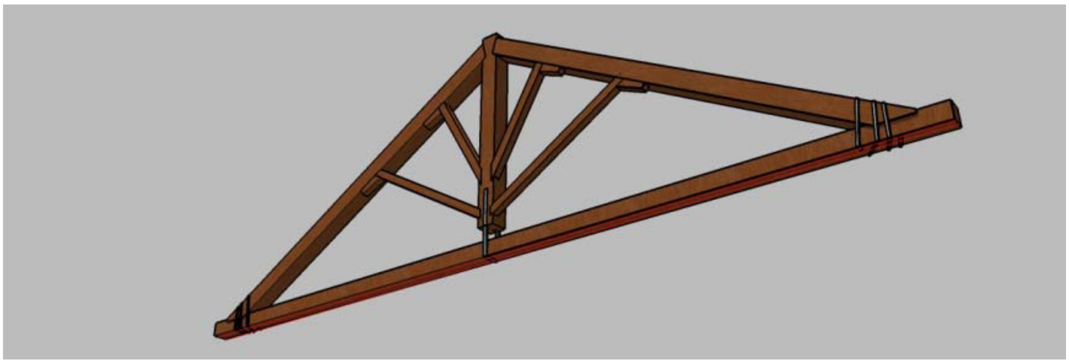
Illustration 70 doubled beam

Also metal elements can be used to support the existing structure.



Plan 26

In situations where this is not possible because of lack of space I would suggest a modern technology like the reinforcement with carbon fibre inside the beam.

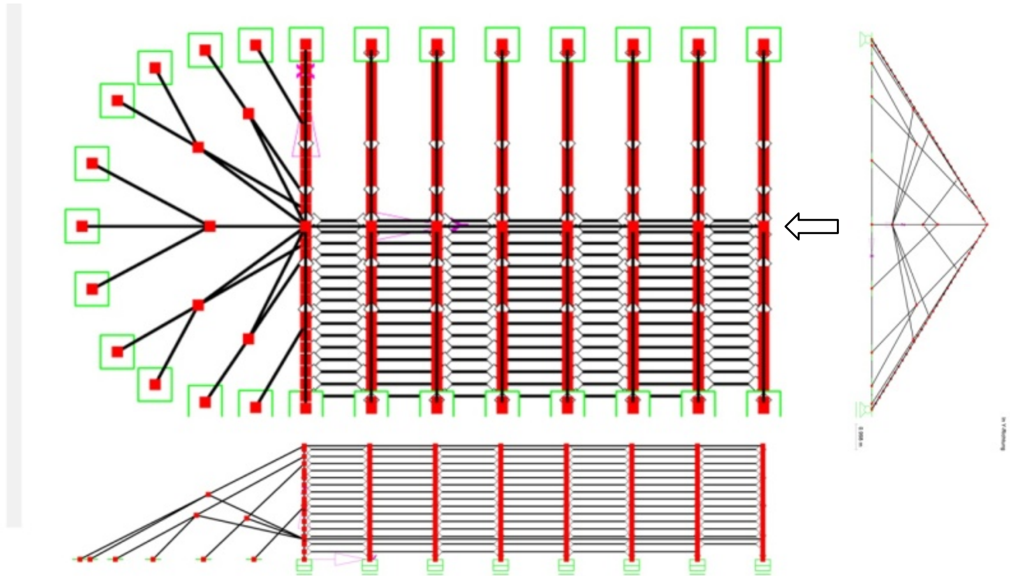


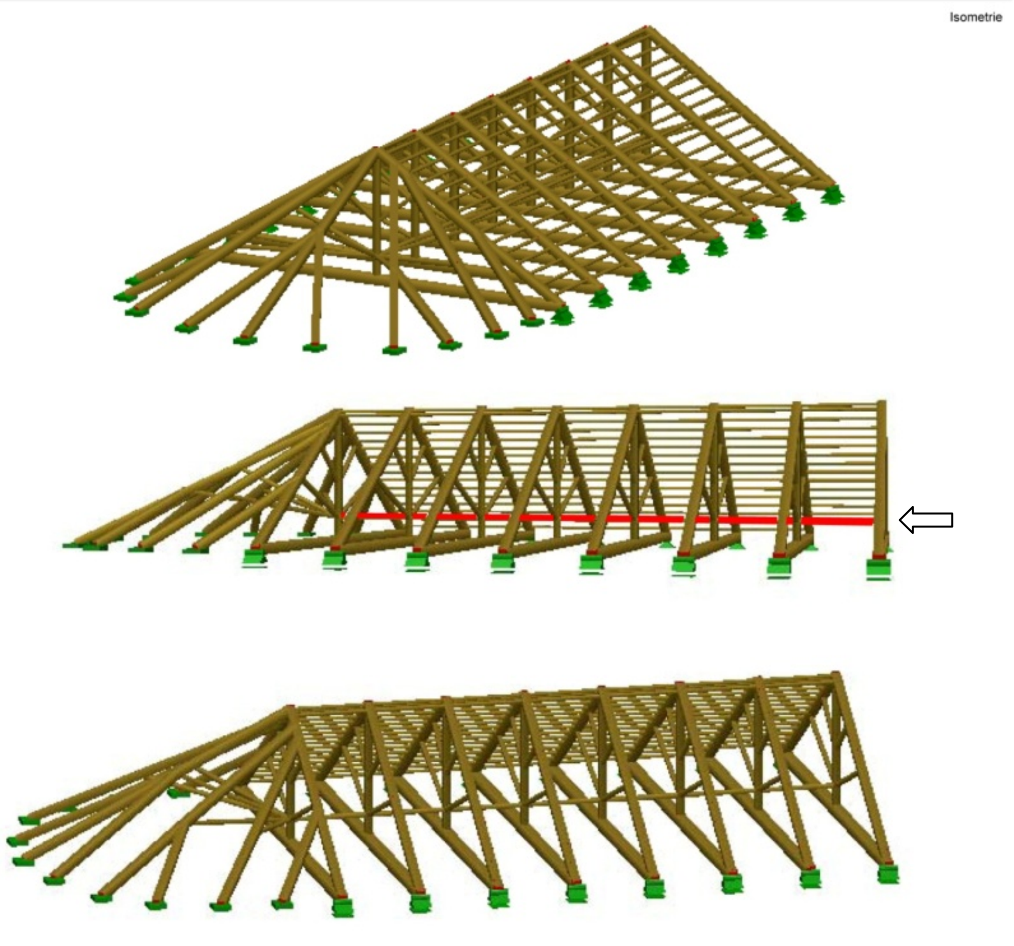
sketch 17reinforcement

The most difficult point to resolve is the situation in the choir and the main aisle, where the umbrella construction intersects with the king post. Either the original situation could be reconstructed (The beam connecting the trusses proceeds up to the inner wall), or a metal element can be added to the truss to overtake the too high forces.

Illustration 71 umbrella structure

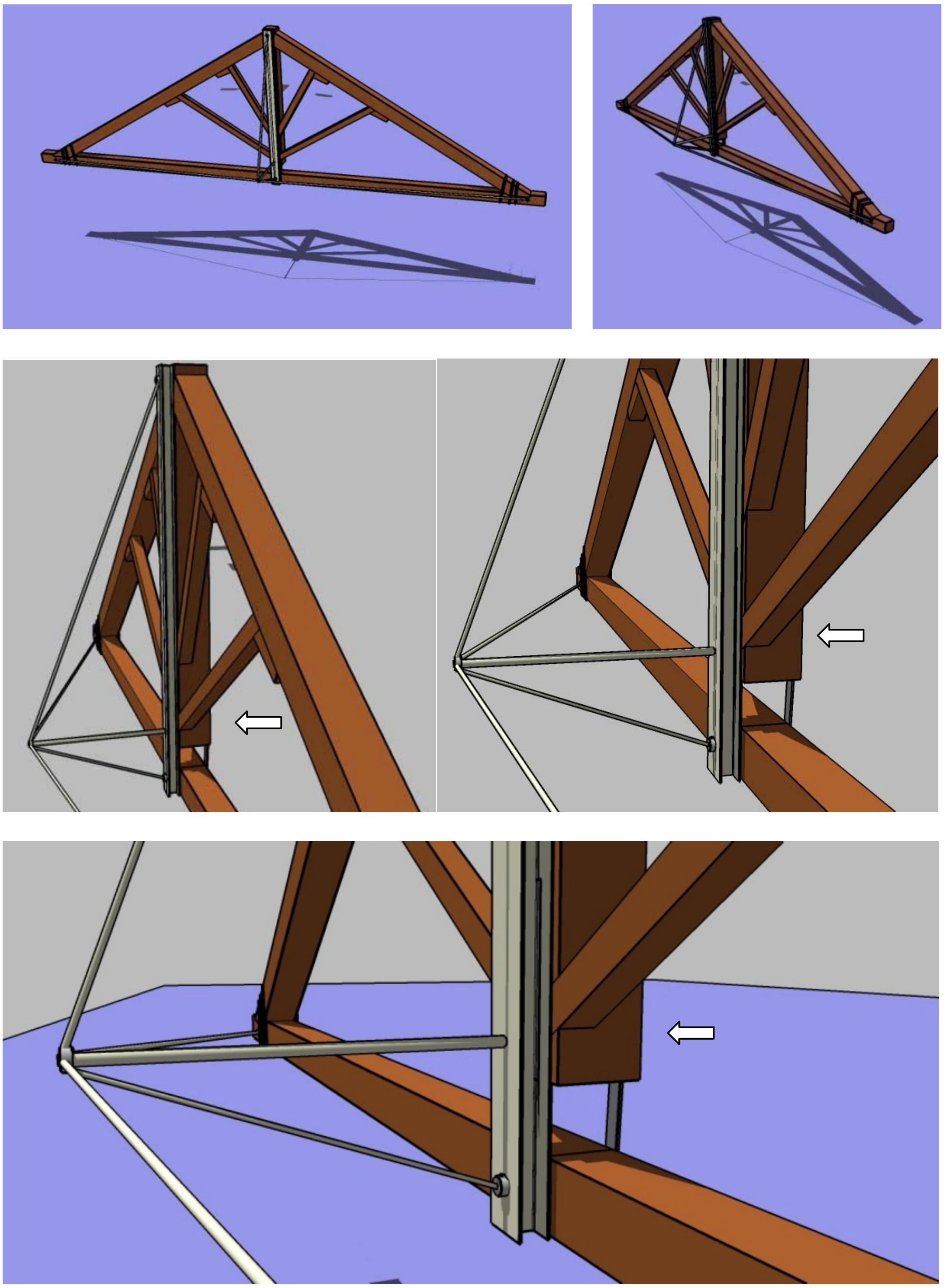
Pic: Original version (inserting the missing horizontal elements connecting the trusses)





sketch 18

Vers2: Adding metal elements



sketch 19

The problem with the first method (original structure) is that it is not perfectly clear, that the structure once really looked like this and that it will work without problems.
The second possibility is not a calculated proposal which has to look exactly like this. It is just an idea how such a metal structure may look like.
Of course both possibilities have to be checked and optimised by an engineer before executing them. Otherwise the intervention may not be sufficient and therefore useless!

6.4.3.4. Preservative choices

To give the timber a longer life preservative formulations, which are all based on fungicides (but a good fungicide does not necessarily make a good preservative), can help.
But there are many factors to be considered:
Some fungicides are effective against a broad spectrum of fungi, others are more specific.
There are formulations to slow down the entry of water into wood, while allowing free exit of water vapour.
Some can control rot having the ability to lodge in or on the wood in sufficient amount; others penetrate the timber as far as is needs to control rot.
It has to be considered that preservative formulations will never be permanent. They may resist or leach out by water, ultraviolet radiation, or by micro-organisms etc.
Most of the preservative formulations change the colour of the Historical timber members, therefore also aesthetic issues have to be considered.
In case the formulation should be removed later it is necessary to know how or if it is possible to erase the application.

At last the cost point has to be thought about.

But these are not the only problems also the environmental impact (both during application and afterwards), the workers safety, during application and the visitor safety, subsequent to application have to be considered.

As chemicals can cause many problems in the case of the dome of Vercelli I would recommend using no preservative formulations (at least for the moment) as the roof will be sufficiently ventilated and maintained after the conservation.

6.4.3.5. Maintenance

Regular inspections of the timber structure are highly recommended. Treated structures have to be inspected, because preservative chemicals eventually leach out of wood, and regular re-treatment will be necessary. But also untreated wood structures should be visited frequently (once or twice a year) to initiate the eventually necessary maintenance measures in a good time. If these inspections do not take place it is likely that major and more expensive repairs will be needed.

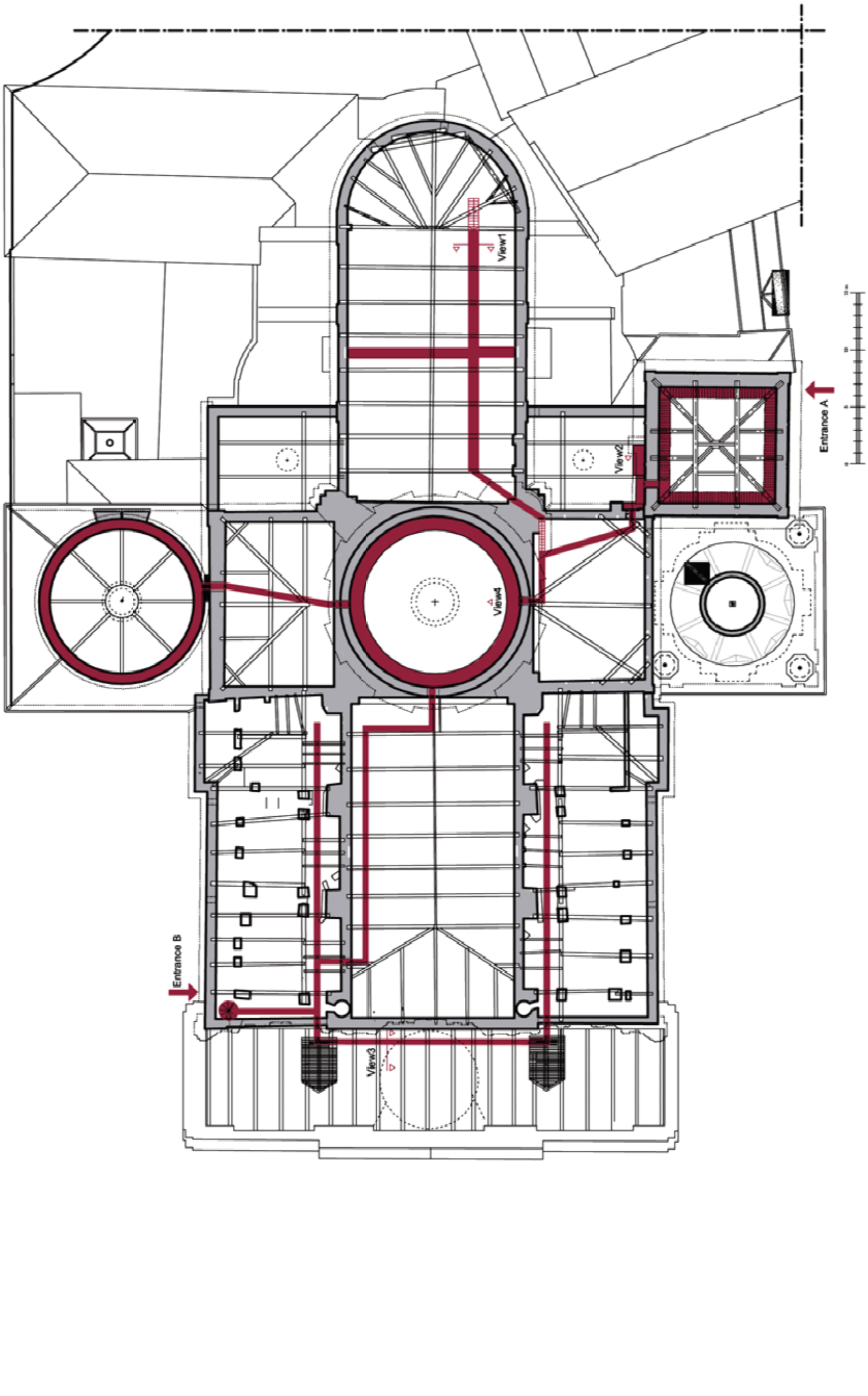
After the interventions took place a maintenance plan has to be made. It has to contain how often, what, who and which points of the structure have to be inspected.
Not only the structure itself, but also the surrounding ambience has to be checked frequently. It also has to be considered that the use can change over the years and this can lead to different loads.

maintenance manual			
address	Dome of Vercelli Piazza Sant' Eusebio,13100 Vercelli	Person in charge	Arch. Daniele De Luca
maintenance tile covering			
instruction manual			
Particular care should be taken at fragile tiles and displacements of the elements			
maintenance manual			
Examination of the condition of the whole covering. Especially after bad weather conditions the roof has to be checked. Leafage, accumulations, bird's nests, Have to be removed. Not dense roof tiles have to be substituted. Tiles which got out of place Have to be brought into place. Doing these interventions special care has to be taken, not to cause further displacements or damage.			
maintenance code	**Description**	**frequency**	**qualified person**
Int.1	The roof has to be cleaned.	6 month	specialized enterprise
Int.2	Disconnected elements have to be replaced.	1 year	specialized enterprise
Int.3	Partial substitution of the tile covering.	whenever necessary	specialized enterprise
maintenance gutter			
instruction manual			
Particular care should be taken that no heavy elements are lying on top of them or are blocking or closing the elements. Gutters are not walk able.			
maintenance manual			
Examination of the condition and functionality (no loss, rust or oxidation). Especially after bad weather conditions the roof has to be Checked. Leafage, accumulations, bird's nests, Have to be removed. The connection points have to be checked. Damaged elements have to be substituted.			
maintenance code	**Description**	**frequency**	**qualified person**
Int.1	The roof gutter has to be cleaned.	6 month	plumber
Int.2	Substitution or repair of damaged elements.	5years	plumber
maintenance battens			
instruction manual			
maintenance manual			
Examination of the condition of the whole structure. Special attention should be taken, that no water infiltrations occur. Leafage, accumulations, bird's nests, have to be removed. It should be checked, that the ventilation works and the battens are not out of place. Damaged elements have to be substituted. Doing these interventions special care regarding the security has to be taken.			
maintenance code	**Description**	**frequency**	**qualified person**
Int.1	Control of the roof covering	6 month	specialized enterprise
Int.2	Partial substitution of the battens.	whenever necessary	specialized enterprise
maintenance carrying timber structure			
instruction manual			
Rafters, tie beam, king post and struts have to be cleaned and eventually treated with anti fungi /anti insect product. The moisture content of the elements has to be measured and shouldn't be over 18-20%. The climatic conditions of the surrounding Ambience has to be controlled as well (ventilation/humidity of the air...). No heat producing elements (like lights) should be added Directly on the timber structure. The connectors (screws, nails..) and further metal elements have to be controlled (corrosion/ deformation).It should be controlled if the elements are still in their original position (displacement).			
maintenance manual			
Examination of the condition of the whole structure. It has to be checked if new fissures, insect attacks, fungi, have damaged the Structure. It has to be controlled that the moisture content is not too high and that there are no points, where condensation can take place. In case of problems an intervention has to take place immediately.			
maintenance code	**Description**	**frequency**	**qualified person**
Int.1	Verification of the climatic conditions of the surrounding.	4 month	user
Int.2	Treatment with protective products.	5 year	specialized enterprise
Int.3	Control of the condition of the trusses. (fissures, insects, fungi moisture content, disconnections, displacements and joints)	1 year	specialized enterprise /user
Int.4	Substitution of decayed elements.	whenever necessary	specialized enterprise

Table 7

7. Open the roof to the public

The main question is: Why make all of this research and effort to save the structure if no one can see it?
Meanwhile the workshop is open and the whole structure is secure (security plan) and relatively easy to access. This means that the construction site can be visited by professionals and also private people. For Example the Chapel Palatina in Palermo was open to the public while the refurbishment of the roof was done. Sometimes the restoration phases are exhibited on posters in churches after the conservation has been finished.
As the structure of the dome of Vercelli is considered as culturally valuable it would make sense to open the roof to the public. This would create a kind of “historic building technique museum” apart from the “beauty” of the hidden architecture of the roof, the visitor could learn about ancient structure systems. Guided tours once a month (if requested even more often) with groups of about 5 people would give an additional value to the cathedral.
Some small adjustments would be sufficient to realize such a project.
It is important to create a secure path through the cathedral and to lighten the structure to ensure the visibility.
To maintain the general impression of the structure as few interventions as possible are recommended. The use of “light” materials (small cross sections reduced visibility) is preferable and to give a contrast to the existing structure (that it won’t be mistaken as original, easy to distinguish) a different material than the original one should be used.
The lightening system has to be chosen carefully. It is important that eventual heat created by lamps cannot harm the timber structure.
There are two possibilities to enter the roof of the Dome of Vercelli. One is over the stairs of the tower and the other one over the left aisle. The different zones are all connected sometimes also on the outside over the roof (for example the access to the attic). The corridor in the main cupola of the cathedral works like a hub which connects all areas of the roof. To enter the choir a height difference has to be considered this is why a part of the virtual path may be, like a bridge. The following plan shows a possible path through the cathedral.



Plan 27

render 1

View :1 Bridge over the trusses of the choir

render 1

View2: The connection to the right transept (a handrail would make the path secure)

render 3

View 3: Path over the attic (a handrail and a little bridge out of glass)

View4: The main cupola working like a hub

render 4

8 Conclusions

No inappropriate radical interventions

The master thesis about the Dome of Vercelli is a documentation of the interventions which have or will be done on the timber structure of the cathedral. In addition to the steps planed by Arch. Daniele De Luca, who is responsible for the restoration site, I give an overview about preliminary diagnostic methods and different types of interventions. As a result the different methods are evaluated; I give a personal evaluation and a proposal how to intervene in such cases.
Of course refurbishment is quite sustainable. You avoid the demolishment of a structure and therefore you have less building site rubble. If you plan it properly you may even save money. But this is not the main point of the thesis.

The outcome:

With the help of a case study, the thesis should show that it is inadequate to demolish a timber structure simply because it is old and has some decayed elements. The weak points of the structure can been identified and punctual interventions will be sufficient to maintain the timber structure, as in the case of the roof of Vercelli.

Enhancement the roof structure

It would make sense to exhibit the roof structure. Often this is done by posters pined on the wall of the cathedrals or churches, but it would make much more sense to open the roof to the public. There are two main reasons for doing this. One is that the structures which get refurbished are normally considered as culturally valuable and people should have the possibility to visit such sites. The second reason is that students as well as experts in various fields (architects, engineers, wood technologists, craftsman, historians and many more) can learn from such exhibitions.
Being often on site and following the different phases of the workshop I learned much more than I could out of books. It is absolutely necessary to visit workshops either while they proceed or afterwards at an exhibition space. After the experience I had with the Dome of Vercelli, I tried to gain access to various other roofs, unfortunately without success. The major problem was not only to find the responsible person, but also that they were afraid, that the structure is unsafe to enter! Small adjustments would make the structures secure and therefore also easier to maintain. The access to the roof structure, even after restoration works, allows also the maintenance of the structure through planned inspections.

The outcome:

Roofs are often the forgotten part of a building, though they are as important as all the other elements. The timber roof structure of the Dome of Vercelli is also cultural heritage, not just the inner parts of the cathedral. Nobody would propose to demolish the wall with a fresco, or some columns and replace them with a concrete wall, because it is not in a perfect condition and you do not need so many experts to realize it. Roofs are often hidden and therefore not considered as important. So: MAKE THE ROOFS OPEN TO PUBLIC.
Some small interventions regarding the security and lightning system would be sufficient to make the roofs accessible.

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Archive of the Dome of Vercelli

Lectures urban wood 2009/2010

10 List of Illustrations / PLANS/ Tables

ILLUSTRATIONS 8-25 Archive of the Dome of Vercelli

ILLUSTRATIONS 32 Hoadley (2002) “understanding the wood” The Tauton press

ILLUSTRATION 26 Cremona diagram for a plane truss

http://en.wikipedia.org/wiki/File:Cremonadiagram.jpg (10.11.2009)

ILLUSTRATIONS 44-46, page 64 manuale legno strutturale (Vol IV)

ILLUSTRATIONS 35/36 Lectures Urban Wood 2009

All further ILLUSTRATIONS (including attachment) Pia Panosch

PLANS 1-16 Arch. D. De Luca refined and or changed by P. Panosch

All further PLANS by P. Panosch

PLANS Attachment: Arch. D. De Luca refined and or changed by P. Panosch

TABLE 1:Page 3.7 (tab 3.4) file: www.fpl.fd.fed.us/documnts/fplgtr/fplgtr/ch03.pdf

TABLE 2/3: UNI 11119:2004

TABLE 6: Time -plan by Arch. Daniele De Luca and Arch. Riccardo Pasquino

All further TABLES P. Panosch

TABLE attachment: Table Appendix 1: UNI 11119:2004

All further TABLES in attachment P. Panosch

RENDER 1-4 P. Panosch

11 Appendix

Inhalt

11.1. Loads

Permanent load

Dead load

Tile roof covering $G_{k,tile} = 0.45\, kN/sqm$

Timber (Oak) $G_{k,timber} = 8.00\, kN/m^3$

Combination coefficient for dead loads (EURO CODE 5)
This value is for ultimate limit state:
Disadvantageous $\gamma_G = 1.35$

Variable Loads (DM 14.01.2008: 3.1.4)

Snow load (DM 14.01.2008: 3.4)

Snow load roof covering $G_{k,snow} = \mu_i \cdot q_{sk} \cdot c_E \cdot c_t$

μ_i Form coefficient:
Double pitch roof
Only snow => CASE 1 $\mu_1 = 0.8$ **(DM 14.1.2008: tab. 3.4.II)**

q_{sk} Ground characteristics of the snow load
ITALY: Zone 1 – Alpine

$$G_{k,snow} = 1.39 \cdot \left[1 + \left(\frac{250}{728} \right)^2 \right] = 1.55\, kN/sqm$$

Exposition coefficient: $c_E = 1$
Thermal coefficient: $c_t = 1$

$$G_{k,snow} = 0.8 \cdot 1.55 \cdot 1 \cdot 1 = 1.24\, N/sqm$$
$$G_{k,snow} = 1.24\, N/sqm$$

Combination coefficient for highest variable load (snow) (EURO CODE 5)
This value is for ultimate limit state:
Partial factor (stress analysis) $\gamma_{Q,snow} = 1.5$
To control the serviceability *limit state, we must apply another coefficient:*
Partial factor (deformation) $\psi_{Q,snow} = 0.2$

Wind load (DM 14.01.2008: 3.3)

Wind velocity profile $v_b = v_{b,0} = 25\, m/s$
Zone 1 Sea level = 250 mslm $< a_0 = 1000m$

Wind pressure $p = q_b \cdot c_e \cdot c_p \cdot c_d$

q_b Consideration of the kinetic pressure

$$q_b = \frac{1}{2} \cdot 1.25 \cdot 25^2 = 391 N/m^2 = 0.391 kN/m^2$$

c_e Exposition coefficient

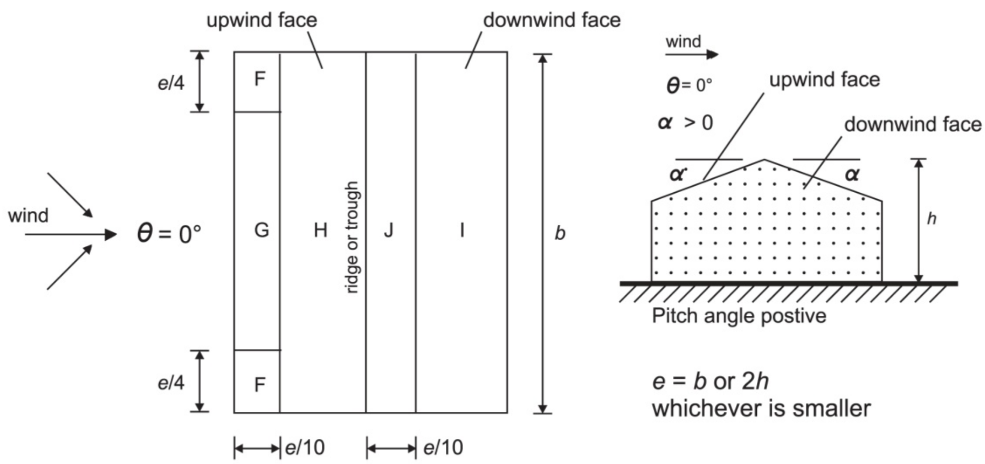
Classification of the surface finish of the ground
Zone 1
Distance to the coast > 30 km
Sea level < 500 mslm
⇨ Exposition class IV (DM 14.1.2008: Fig. 3.3.2)

$c_e = 1{,}8$ (DM 14.1.2008: Fig. 3.3.3)

c_p Design coefficient (Eurocode 5)
This value is combined out of two coefficients the internal and the external one.

External pressure

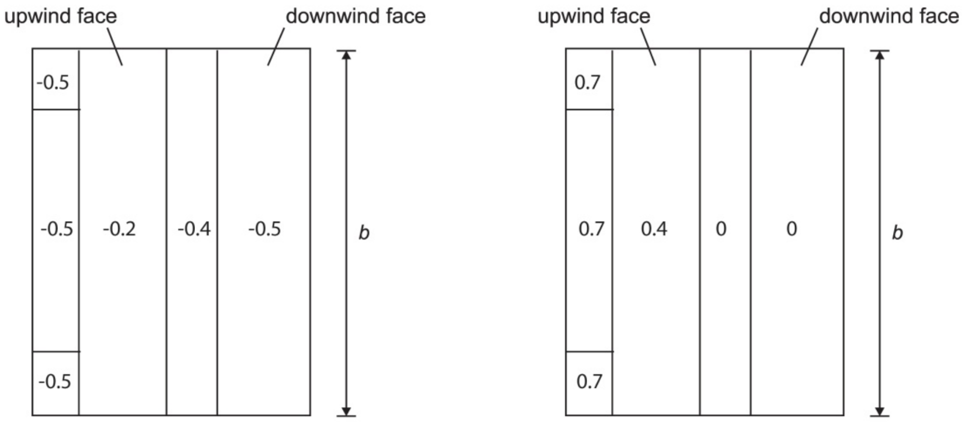
Inclination of the roof area ca. 30°
Zone for wind direction Θ = 0° (Θ = 90° is not taken into consideration, because the major wind load is given by Θ = 0°)
(Table 7.4a – External pressure coefficients for duopitch roofs p. 45)



(pic. – prEN 1991-1-4:2004, p. 44)

$b \approx 32m \quad 2h \approx 46m \quad \rightarrow e = 32m$

$\rightarrow e/10 = 3.20m \quad \rightarrow e/4 = 8m$



Internal pressure

To get a significant result the external pressure in not sufficient. The internal pressure has to be considered as well and the two pressures shall be considered to act at the same time.

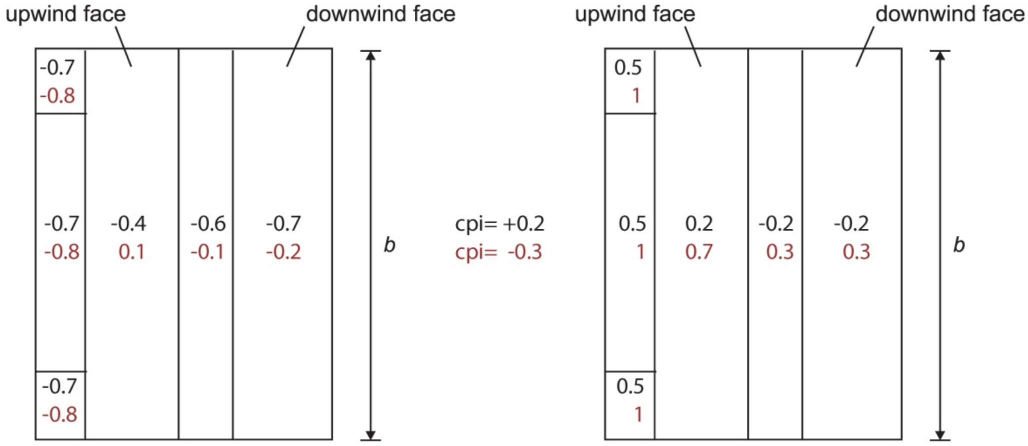
Normally the internal pressure coefficients for uniformly distributed openings are gained with the formula:

$$\mu = \frac{\sum \text{area of openings where } c_{pe} \text{ is negative or - 0,0}}{\sum \text{area of all openings}}$$

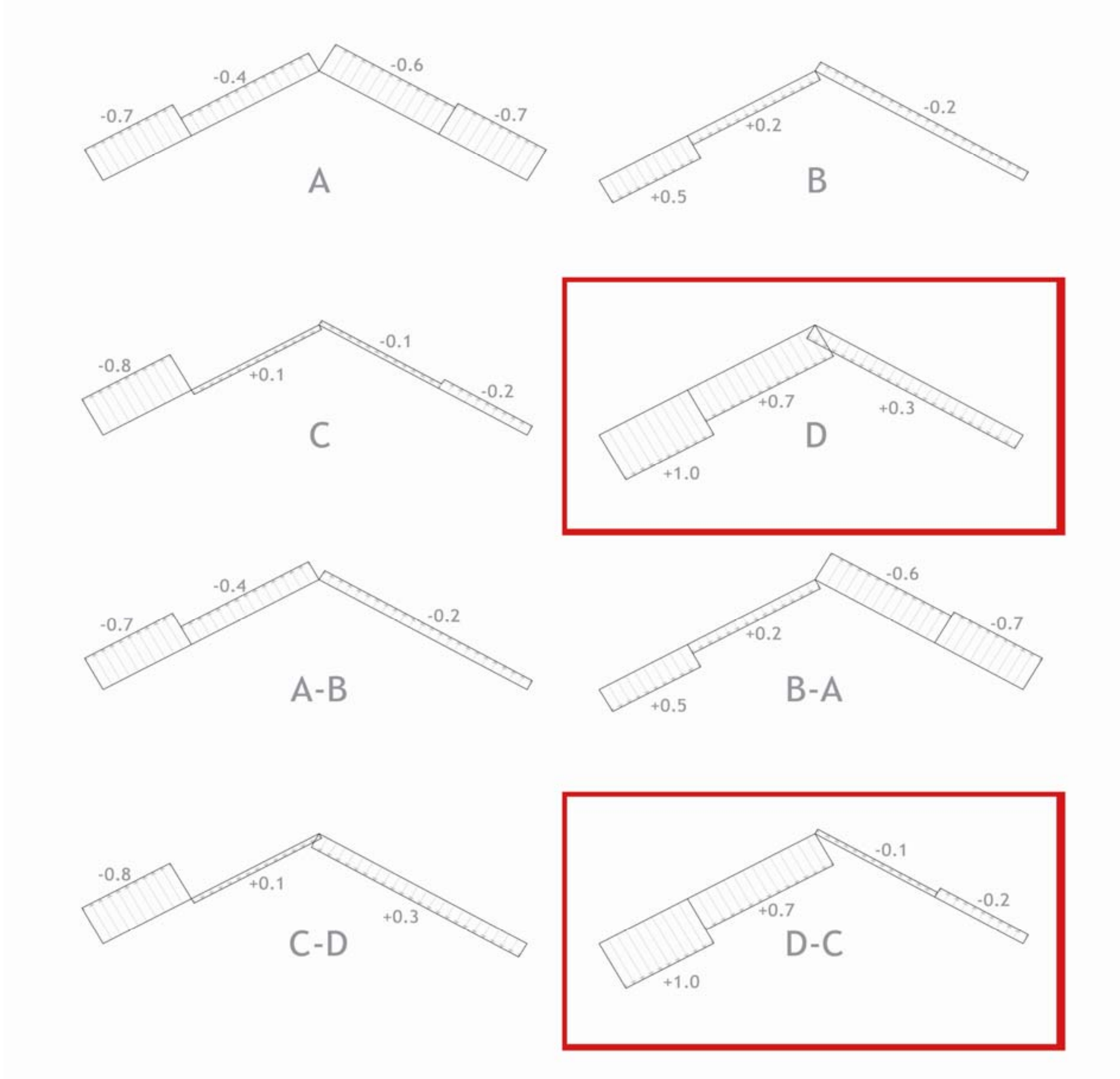
In our case we have very few openings, which are difficult to calculate and it is not considered justified, to estimate μ for this particular case. The cpi should be taken (as suggested by the Eurocode 5: prEN 1991-1-4:2004, p.53) as the more onerous of +0,2 and -0,3.

The code gives us these two values, because the internal load on the windward roof surface can be both pressure and suction. So both cases have to be calculated:

$$c_{pe} - c_{pi} \qquad c_{pe} - (0.2)\ for\text{Pressure} \qquad c_{pe} - (-0.3)\ for\text{Suction}$$



Possible load cases:



c_d dynamic coefficient $\qquad c_d = 1$

For the calculations only the values in the red squares have been considered, because they are the determining factors (highest pressure (D) and highest eccentricity (D-C)):

D: dynamic pressure (luv) $\qquad Q_{k,above} = 0.391 \cdot 1.8 \cdot 1 \cdot 1 = 0.704 kN/sqm$

dynamic pressure (luv)

$Q_{k,above} = 0.391 \cdot 1.8 \cdot 0.7 \cdot 1 = 0.493 kN/sqm$

dynamic pressure (lee)

$Q_{k,above} = 0.391 \cdot 1.8 \cdot 0.3 \cdot 1 = 0.211 kN/sqm$

D-C: dynamic pressure (luv) $\qquad Q_{k,above} = 0.391 \cdot 1.8 \cdot 1 \cdot 1 = 0.704 kN/sqm$

dynamic pressure (luv)

$Q_{k,above} = 0.391 \cdot 1.8 \cdot 0.7 \cdot 1 = 0.493 kN/sqm$

dynamic pressure (lee)

$Q_{k,below} = 0.391 \cdot 1.8 \cdot -0.1 \cdot 1 = -0.070\, kN/sqm$

dynamic pressure (lee)

$Q_{k,below} = 0.391 \cdot 1.8 \cdot -0.2 \cdot 1 = -0.141 kN/sqm$

Combination coefficient for further variable loads (wind) (EURO CODE 5)

Partial factor (stress analysis) $\gamma_{Q,wind} = 1.5$

2nd load:
Factor for combination value
of a variable action $\psi_{O,wind} = 0.6$

$\gamma \cdot \psi = 0.6 \cdot 1.5 = 0.9$

Partial factor (deformation) $\psi_{Q,wind} = 0.5$

Live load (DM 14.01.2008: 3.3)

Service load CAT H1 Only accessible for maintenance

$Q_k = 0.5 kN/sqm$ *(tab 3.1.II)*

Combination coefficient for further variable loads (service) (EURO CODE 5)

Partial factor (stress analysis) $\gamma_{Q,service} = 1.5$

3rd load:
Factor for combination value
of a variable action $\psi_{O,service} = 0.6$

$\gamma \cdot \psi = 0.6 \cdot 1.5 = 0.9$

Partial factor (deformation) $\psi_{Q,service} = 0.5$

<u>Load combinations</u>

The loads have to be combined as follows (**Euro code 5**):

Stress analysis:

$$\sum \gamma_{G,j} \cdot G_{k,j} + \gamma_{Q1} \cdot G_{k,1} + \sum_{i \geq 1} \gamma_{Q,i} \cdot \psi_{O,i} \cdot Q_{ki}$$

Maximum stresses of on site timber of the load bearing system

The supporting beams are oak timber.
The table 1 shows the maximum stresses allowed in application of admissible stresses methods and the average bending modules of elasticity of oak wood, with a moister content of about 12%, according to the **UNI 11119:2004.**

		Maximum Stresses (N/mm^2)

Species	On site grade	Compression		Static bending	Tension parallel to the grain[1)]	Shear parallel to the grain	Bending MOE
		Parallel to the grain	Perpendicular to the grain				
Oak	I	12	3,0	13	12	1,2	13500
	II	10	2,5	11	10	1,0	12500
	III	7,5	2,2	8,5	7	0,9	11500

Table Appendix 2

1) Maximum stresses with tension perpendicular to the grain is conventionally equal to zero

Deformation:

$$\sum 1 \cdot G_{k,j} + 1 \cdot G_{k,1} + \sum_{i \geq 1} \gamma_{Q,i} \cdot \psi_{O,i}$$

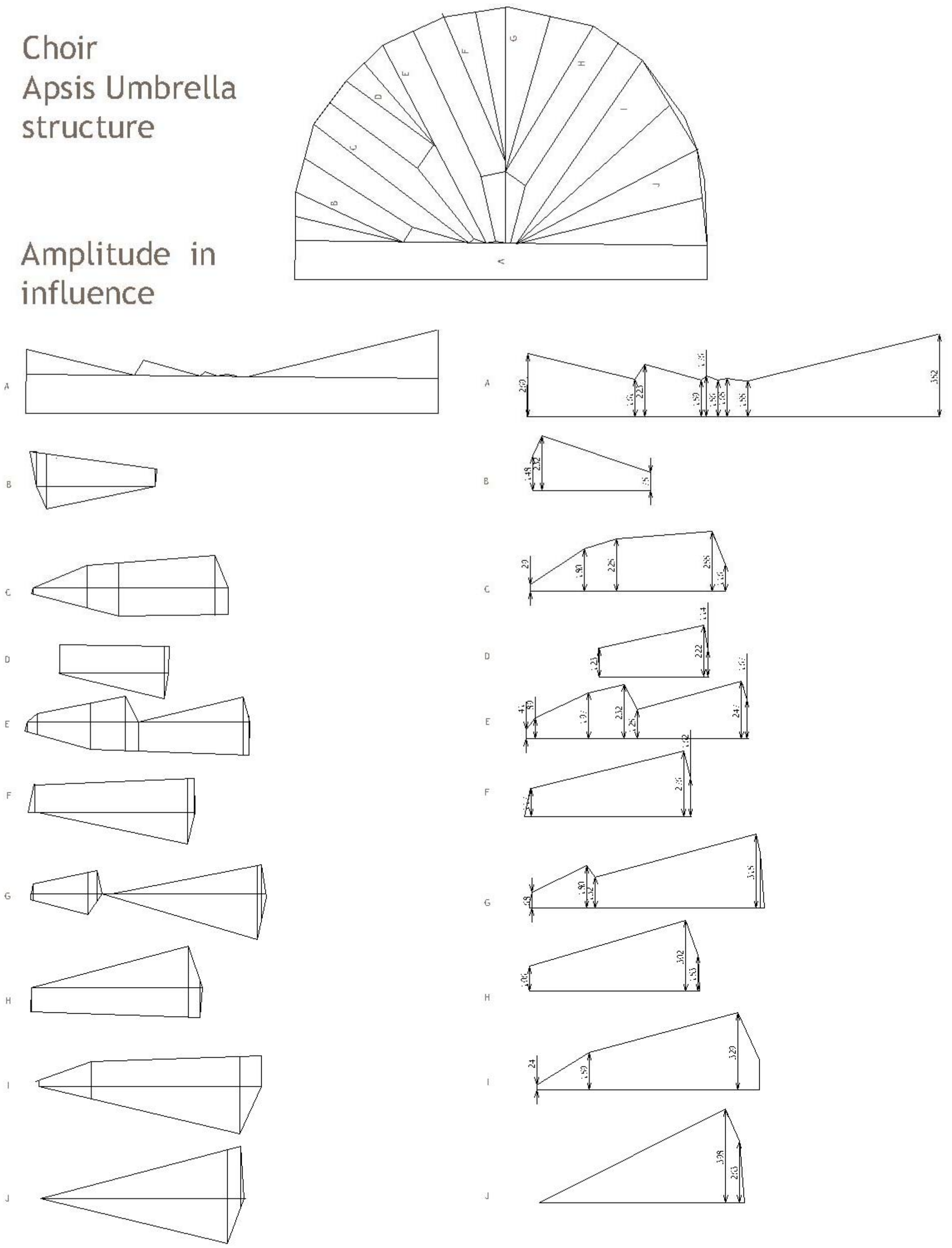
$$\delta \leq 300$$

11.2. Ad Characteristics of the timber structure

Choir

Further calculations which have been executed:

Loads of the timberelements on the absis:



Model abside choir:

Loads:
The loading conditions wind- and live load haven`t been taken into consideration, because the highest load and therefore the determining factor is the snow load.

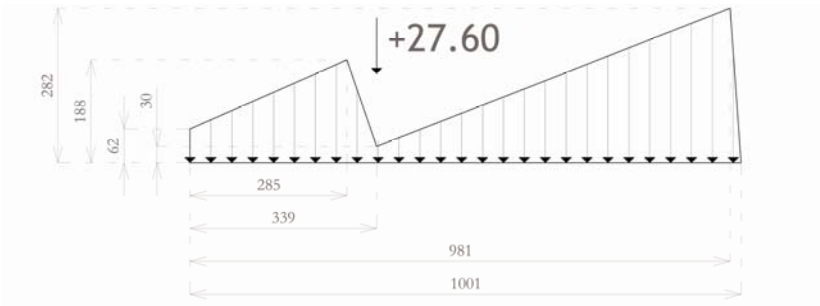
128.80 sqm

$$G_{k,tile} = 0.45\,kN/sqm \cdot 128.8sqm = 57.96kN$$

$$G_{k,batt} = 0.04 \cdot 0.04 \cdot 14 \cdot 10 \cdot 128.8 = 28.85kN$$

$$G_{k,snow} = 1.24\,kN/sqm \cdot 128.8sqm = 159.71kN$$

$$\sum G_k = 246.52kN$$



Tile roof covering

$$G_{k,tile} = 0.45\,kN/sqm \cdot 27.6sqm = 12.42kN$$

$$G_{k,tile} = 0.45\,kN/sqm \cdot 2.87m = 1.29kN/m$$

$$G_{k,tile} = 0.45\,kN/sqm \cdot 1.88m = 0.85kN/m$$

$$G_{k,tile} = 0.45\,kN/sqm \cdot 0.62m = 0.28kN/m$$

$$G_{k,tile} = 0.45\,kN/sqm \cdot 0.30m = 0.14kN/m$$

$$\gamma_G = 1.35$$

Timber (Oak)

$$G_{k,timber} = 8.00\,kN/m^3$$

The weight of the structural parts is considered in the model

Battens 4x4cm

$0.04 \cdot 0.04 \cdot 14 \cdot 10 \cdot 27.6 = 6.18kN$ $\gamma_G = 1.35$

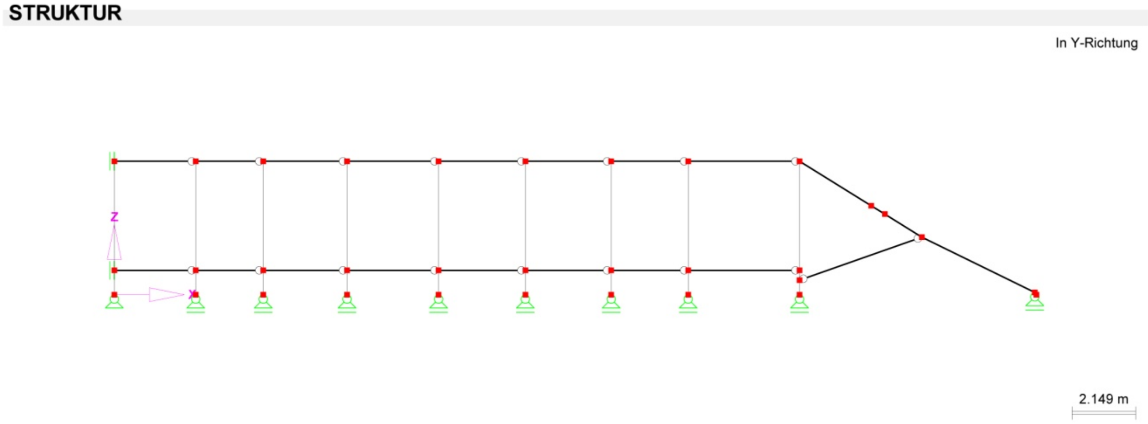
$$0.04 \cdot 0.04 \cdot 14 \cdot 10 \cdot 2.87m = 0.64kN/m$$

$$0.04 \cdot 0.04 \cdot 14 \cdot 10 \cdot 1.88m = 0.42kN/m$$

$$0.04 \cdot 0.04 \cdot 14 \cdot 10 \cdot 0.62m = 0.14kN/m$$
$$0.04 \cdot 0.04 \cdot 14 \cdot 10 \cdot 0.30m = 0.07kN/m$$

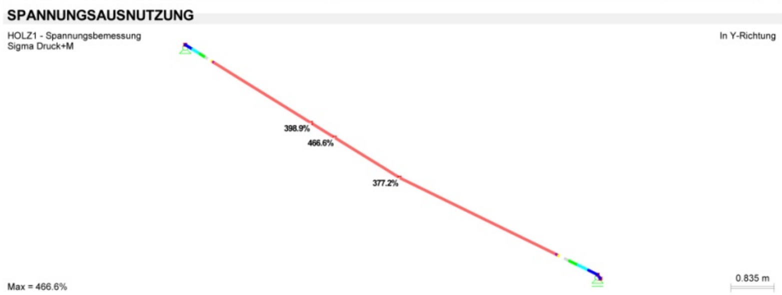
Snow load (DM 14.01.2008: 3.4)

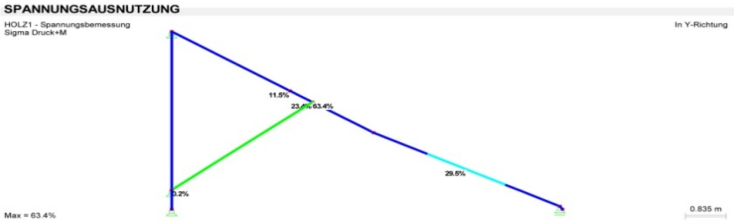
$$G_{k,snow} = 1.24\,kN/sqm \cdot 27.6sqm = 34.22kN \quad \gamma_G = 1.5$$
$$G_{k,snow} = 1.24\,kN/sqm \cdot 2.87m = 2.56kN/m$$
$$G_{k,snow} = 1.24\,kN/sqm \cdot 1.88m = 2.33kN/m$$
$$G_{k,snow} = 1.24\,kN/sqm \cdot 0.62m = 0.77kN/m$$
$$G_{k,snow} = 1.24\,kN/sqm \cdot 0.30m = 0.37kN/m$$

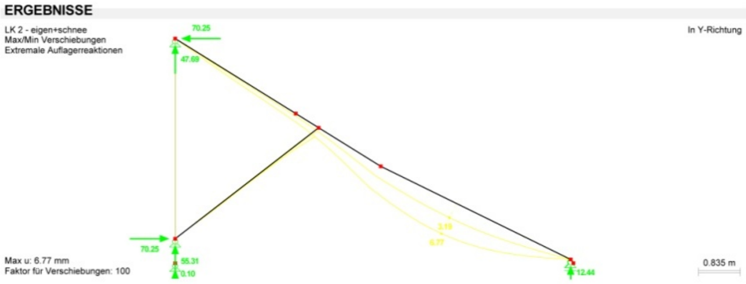


According to the program the structure is labile in this direction.

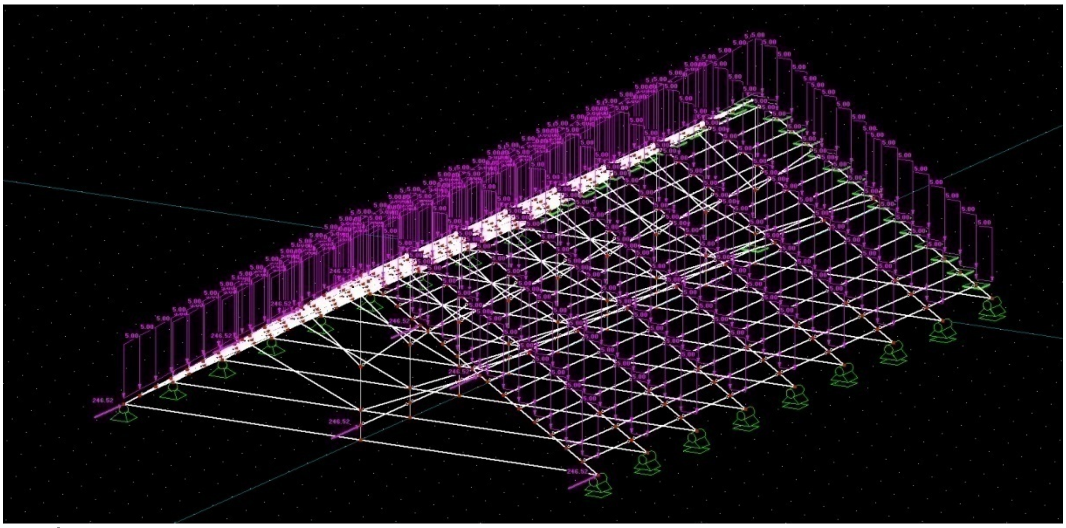
try: beam allone is sufficient? NO



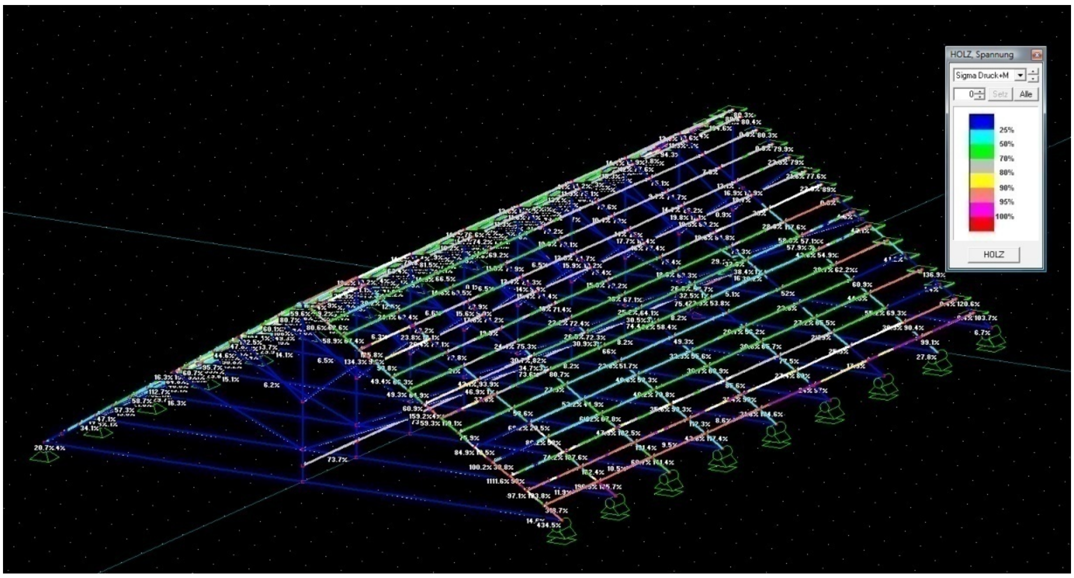




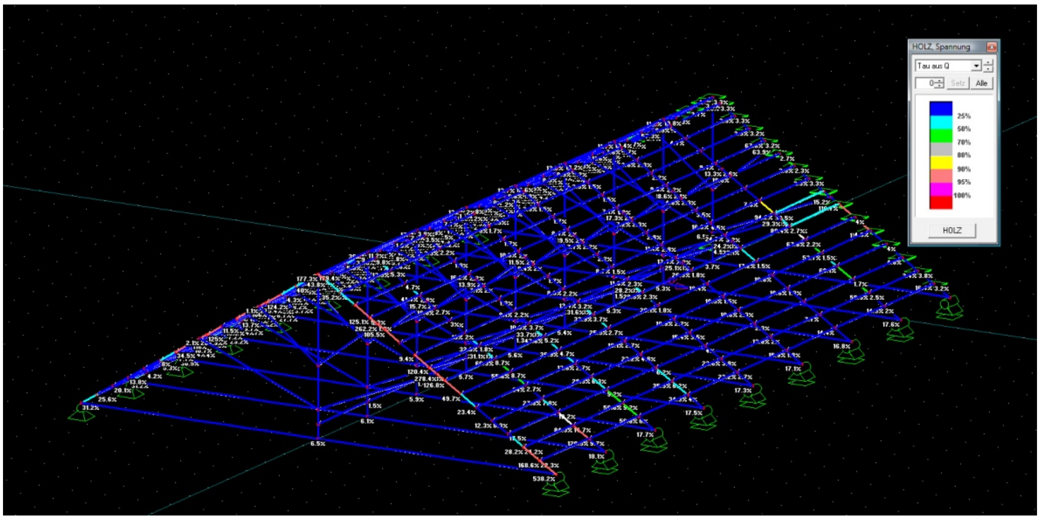
3D:

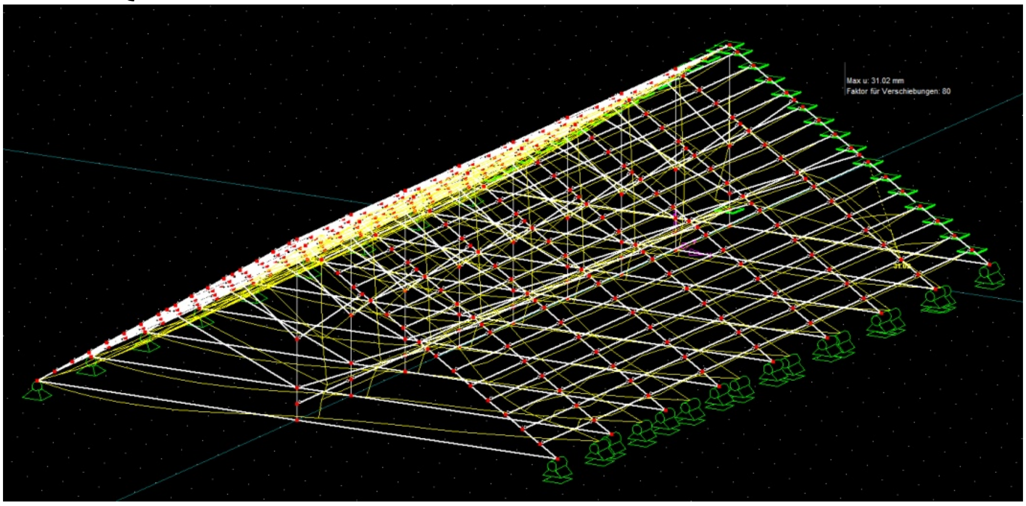


Loads

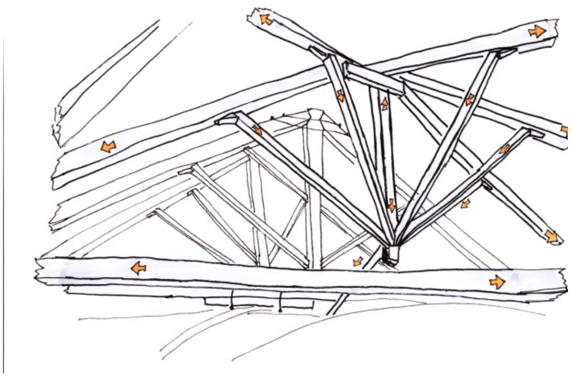


Stresses M/pressure


Stresses Q


Deformation

Main Aisle



sketch 20

Static characteristics

The Choir consists of 7 Trusses (every 3 meters), with a span of about 15 meters. The structure of the trusses is the same as in the choir. As it was built later it is generally in better condition, but it is interesting that some of the trusses have only 2 angled struts instead of 4, though it is very unlikely that the structure was

designed like this. The elements may have been simply removed because of their weak condition.
As in the choir, the ridge beam of the structure is missing. This means that all the little beams (third order) on top of the rafters have to transmit the loads in the longitudinal direction of the main aisle. An "umbrella construction" on the west end of the structure also helps to distribute the forces. The loads which are taken by this structure are transmitted over a beam bearing on the vault. It is likely that the loads like in the choir originally have been contributed over all 7 trusses. The deformations at the main aisle are smaller than in the choir.

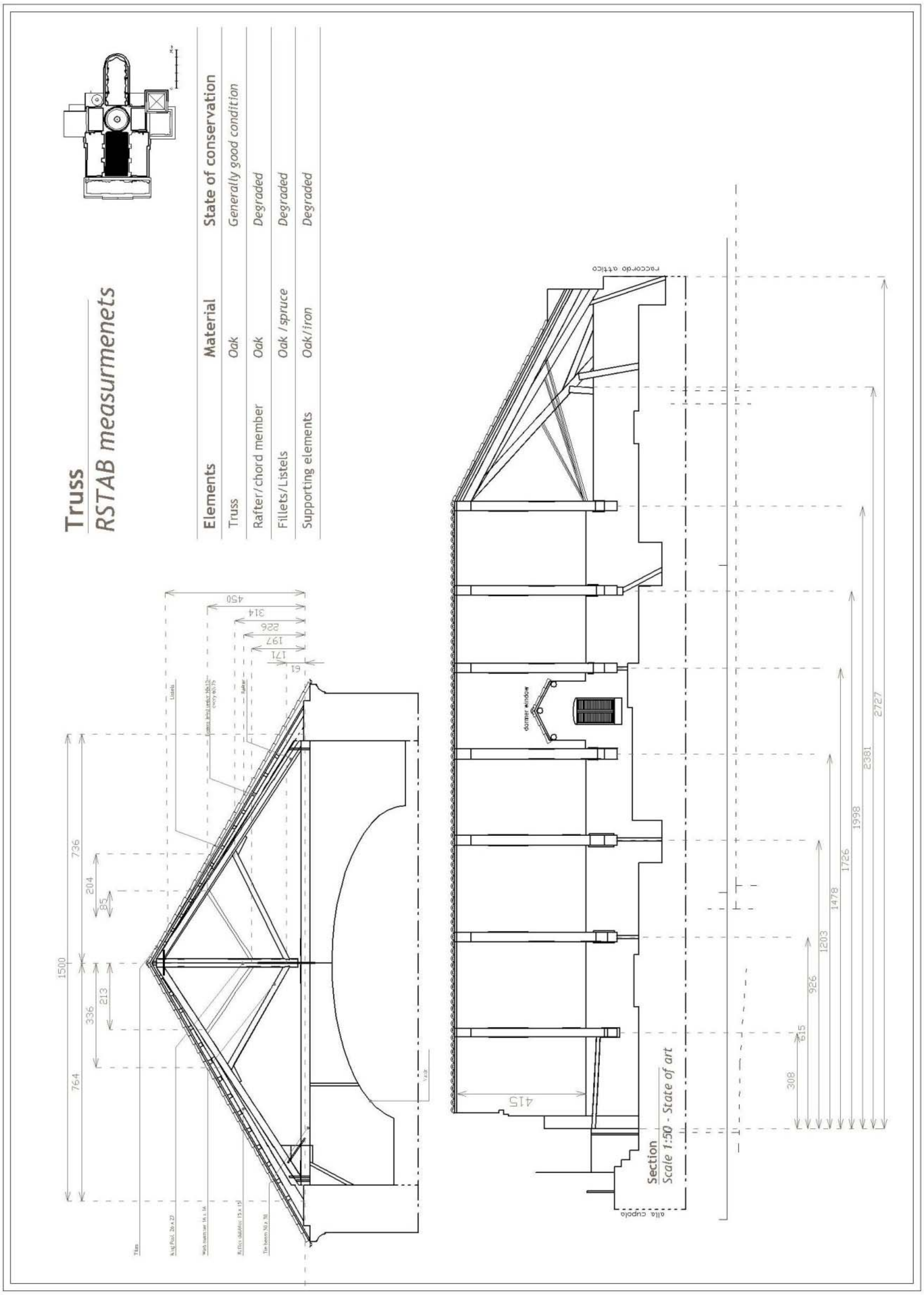
The intermediate cross sections of the elements of the trusses are:

Truss 1	
Rafter (N)	35x35cm
Rafter (S)	35x35cm
Tie- beam	30x30cm
Kingpost	35x25cm
Web member a (N)	15x15cm
Web member a (S)	15x15cm
Web member b (N)	12x12cm
Web member b (S)	12x12cm

The intermediate cross sections of the false rafters in the apses are:

False rafter 1-7	21x21cm

Isometric drawing



Plan_Appendix 1

Optimised static model RPLAN

As for the choir the load bearing capacity of the truss has been modelled assuming an optimal condition of every single timber element.
Forces, reactions and rigidity of the joints see point 3.3.3 optimised static model RPLAN Choir
The load cases which have been calculated are: the one for the permanent death load, a combination of death and snow load, death and wind load and for a combination of death, wind, snow and living load.
To get detailed information about the assumed loads used for the model have a look at point Loads.
The values (max. stress, modulo of Elasticity…) for oak timber have been taken out of table 1 Appendix **UNI 11119:2004**.
If your table does not show the maximum stresses allowed in application of admissible stresses, the values can be adapted as follows:

$$X_d = \frac{K_{\text{mod}} \cdot X_k}{\gamma_m}$$

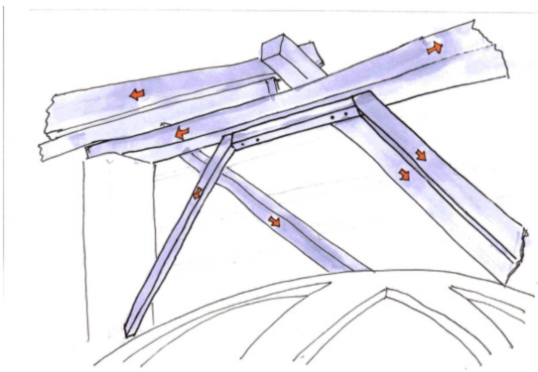
X_k the characteristic value of a strength property

$K_{\text{mod}} = 0.9$ the modification factor taking into account the effect of the duration of load and moisture content(EN14081;EN 14080)

$\gamma_m = 1.3$ partial factor for a material property

Loads:
L= 19,98m (7 compartments)
Influence length 19.98/7 = 2.85 ~2.90m
2.90m = influence length choir therefore further load assumptions see choir

Aisles left



sketch 21

Static characteristics

The left aisle is divided into three parts. Each sector has a main beam (girder) which is bearing from a wall or a brick column to another brick pillow. Some of the elements are supported by struts (web members). These beams are carrying the three or four big rafters (longer span) which are bearing on the exterior walls of the cathedral and the smaller beams bearing from the main rafter to the interior walls of the dome. On these chords timber battens are positioned to carry the roof tiles.
The intermediate cross sections of the elements of the timber structures 1-3 are:

Timber structure	1-3
Girder	30x33cm

Web member a (E)	17x15cm	
Web member a (W)	10x13cm	

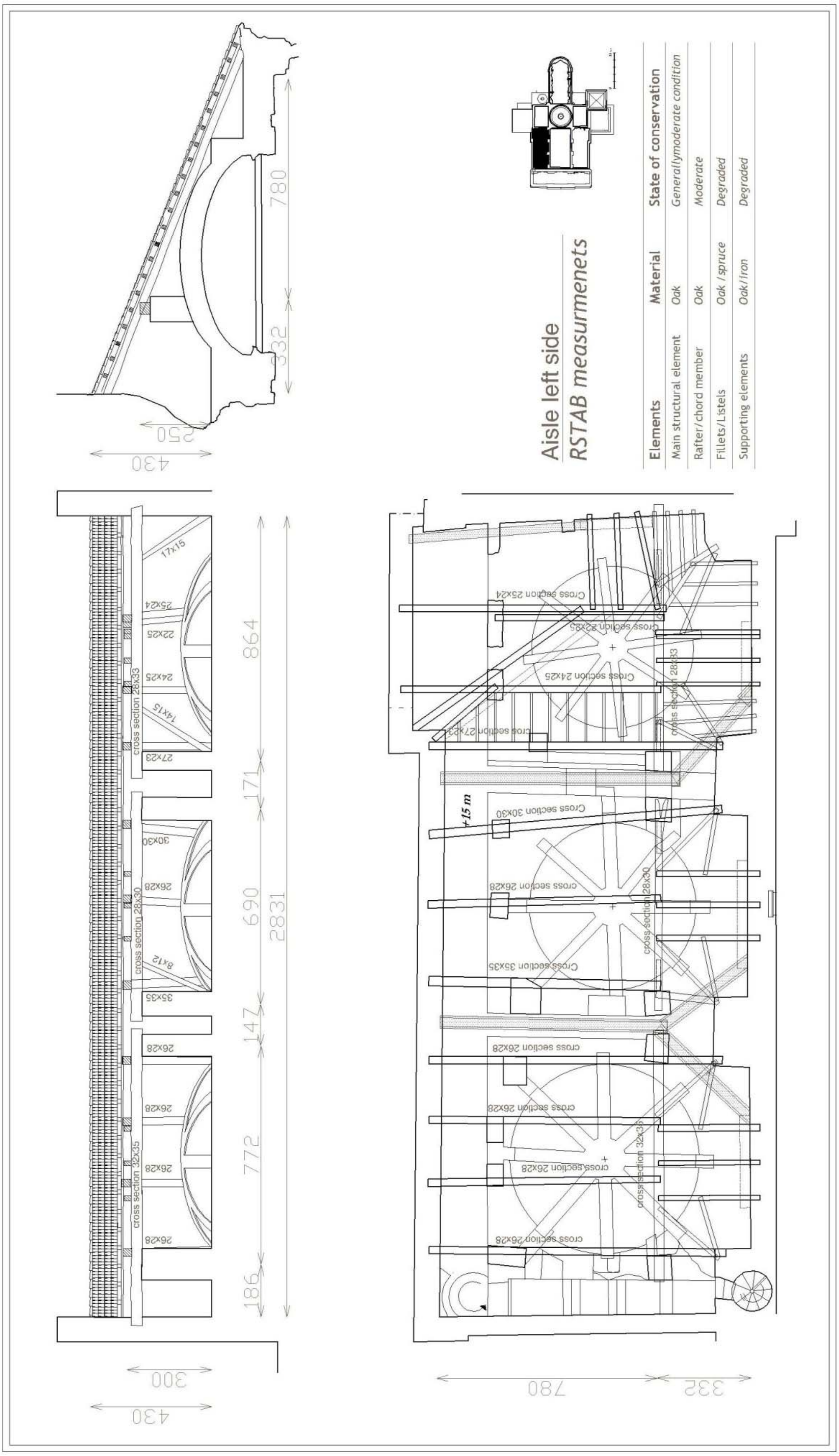
The intermediate cross sections of the false rafters in the apses are:

False rafter 1-11	26x28cm	or bigger
False rafter 12	09x09cm	

The intermediate cross sections of most of the side beams are:

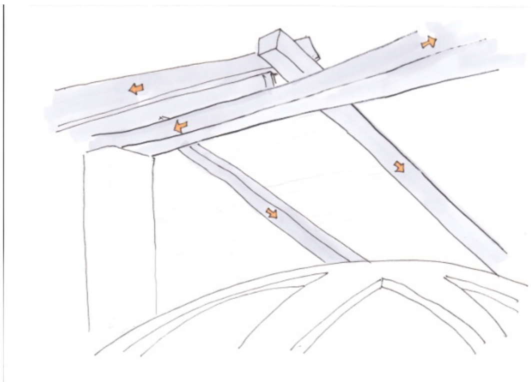
Side beams	15x15cm

Isometric drawing



Plan_Appendix 2

Aisles right



sketch 22

Static characteristics

The right aisle is, like the left aisle, divided into three parts. Each sector has a main beam (primary structure) which is bearing from a wall or a brick column to another brick pillow. The difference to the left aisle is that all of the main chords are supported by two struts and most of them have additionally a false edge to fix them. The main beams are carrying (like in the left aisle) the three or four longer rafters (secondary system) and the smaller beams bearing from the main rafter to the interior walls of the dome. The roof tiles carry on timber battens, which are positioned above the chords of secondary order.

The intermediate cross sections of the elements of the timber structures 1-3 are:

Timber structure	1-3
Girder	28x29cm
False edge	10x12cm
Web member a (E)	13x13cm
Web member a (W)	13x13cm

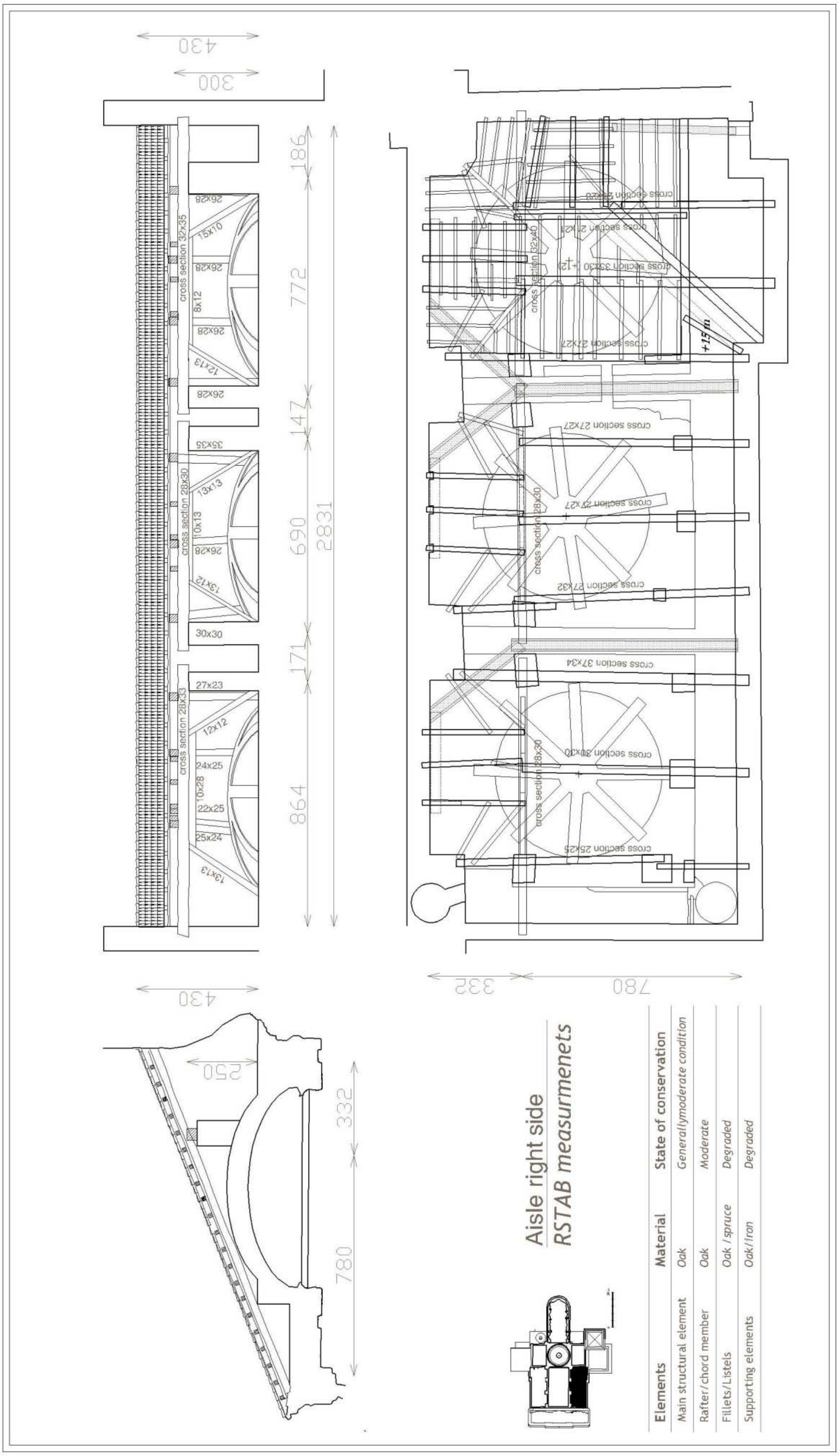
The intermediate cross sections of the false rafters in the apses are:

False rafter 1-10	23x20cm

The intermediate cross sections of most of the side beams are:

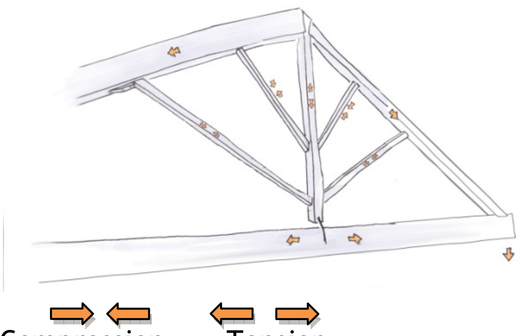
Side beams	15x15cm

Isometric drawing



Plan_Appendix 3

Transept left



Compression Tension

sketch 23

Static characteristics

The transept has two main load bearing structures. The first one is a truss, which has the same characteristics like the trusses in the choir and the main aisle. Additionally to the basic triangle it consists out of a king post and 4 web members. The second main structure is a timber frame which is working similar to an arch. It has a timber girder on top and two false rafters connected at the ends. To join the elements on each connection point two timber bars have been added. They fix the rafters and the main beam from both sides. Additionally a strut, bearing on the external wall, on each side of the frame is supporting the false rafters.
From the top of the truss over the frame into the angles (north side) two false rafters are positioned to create the cubage of the roof. To get a stiffer structure and to position the timber battens for the roof tiles, three further false rafters have been installed; one from the middle of the truss over the frame into the middle of the brick wall on the north side, and the other two from the joints of the frame (rafters - main beam) to the northern wall. Simplified: the truss and the arch structure work like portals, which carry the 3 long rafters and maintain the free span.

The intermediate cross sections of the elements of the truss are:

Truss 1	
Rafter (N)	30x30cm
Rafter (S)	30x30cm
Tie- beam	25x26cm
Kingpost	27x27cm
Web member a (W)	14x08cm
Web member a (E)	14x08cm
Web member b (W)	12x08cm
Web member b (E)	12x08cm

The intermediate cross sections of the elements of the false truss are:

False Rafter (W)	30x30cm
False Rafter (E)	30x30cm
Web member (W)	14x12cm
Web member (E)	17x14cm

The intermediate cross sections of the elements of the arch timber structure are:
Arch timber structure

Rafter (W)	15x20cm
Top chord (middle)	33x33cm
Rafter (E)	21x18cm
Web member 1, 2(W)	10x20cm
Web member 1, 2(E)	10x20cm

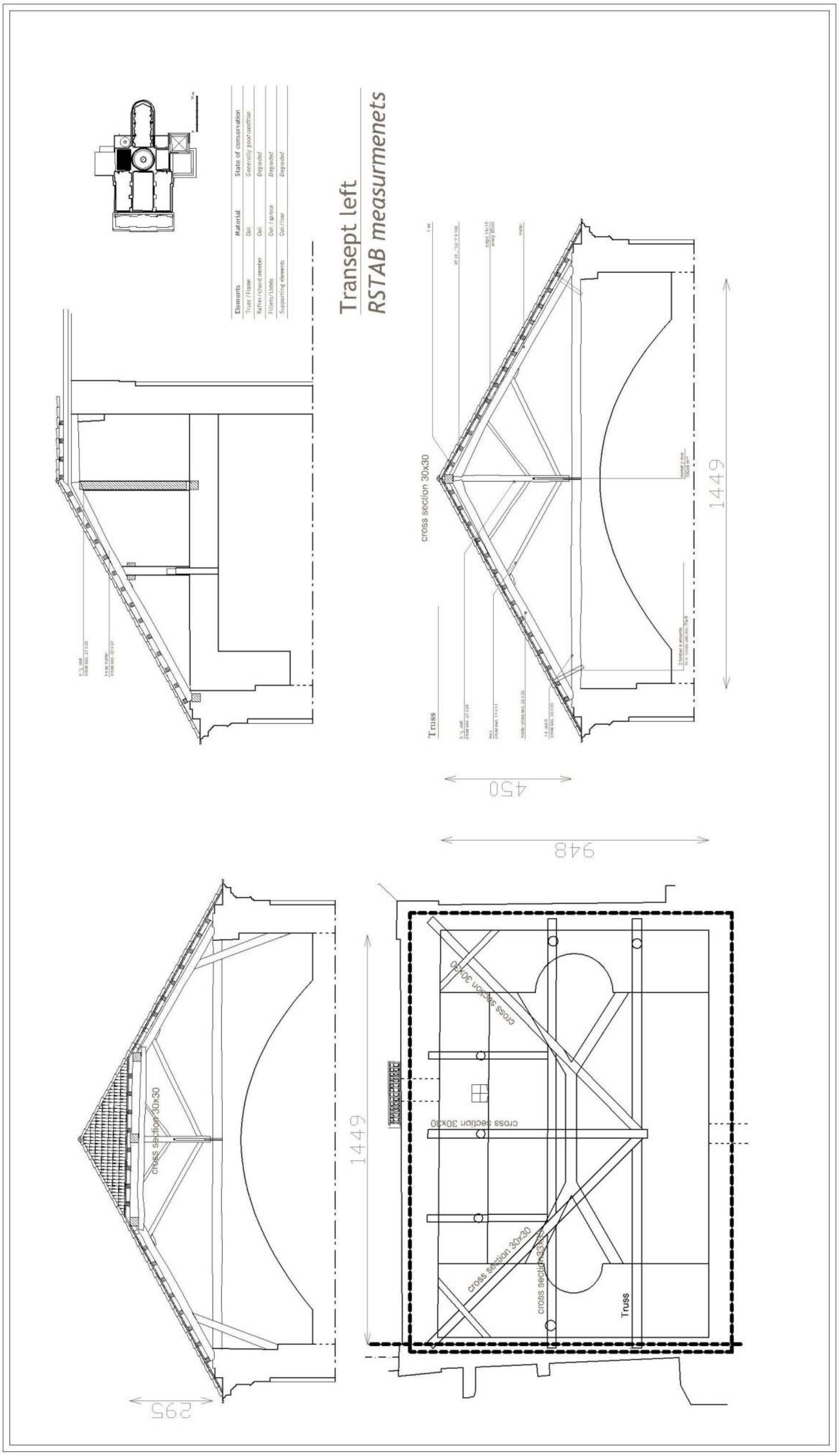
The intermediate cross sections of the main false rafters in the apses are:

False rafter 1-2	30x30cm

The intermediate cross sections of the elements of the secondary timber structures are:

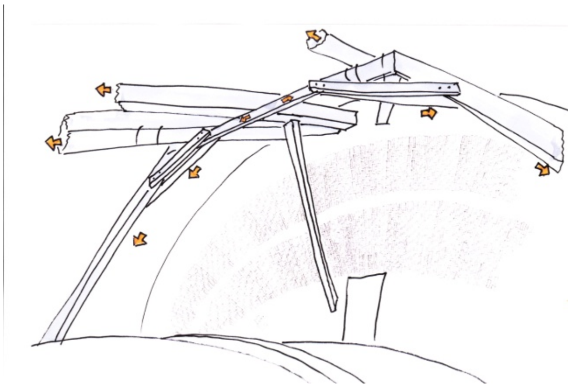
False rafter	25x25cm
Web member	15x15cm

Isometric drawing



Plan_Appendix 4

Transept right



sketch 24

Static characteristics

The structure of the transept on the right side is older and differs a bit from the one on the left side. It has only one main load bearing structure, the timber frame which is working similar to an arch. It has the same elements like the one in the left aisle. Instead of the truss it the structure is using the existing brick wall which is separating the transept from the main cupola.

From the midpoint of the wall on the north side over the frame to the midpoint of the wall on the south side a huge false rafter (A) is positioned to create the cubage of the roof. To get a stiffer structure and to position the timber battens for the roof tiles two further false rafters (B/C) have been placed, parallel to the false rafter (A), from the joints of the frame (rafter - main beam) to the northern wall. To get the direction west - east a bit stiffer (as the truss is missing) two structural timber elements have been positioned on each side connecting the false rafters (B/C) with the wall on the eastern and western side.

The intermediate cross sections of the elements of the false trusses are:

False Truss	
False Rafter (W)	30x30cm
False Rafter (E)	25x30cm
Web member (W)	16x14cm
Web member (E)	19x16cm

The intermediate cross sections of the elements of the arch timber structure are:

Arch timber structure	
Rafter (W)	30x25cm
Top chord (middle)	30x25cm
Rafter (E)	25x30cm
Web member 1, 2(W)	10x20cm
Web member 1, 2(E)	10x20cm

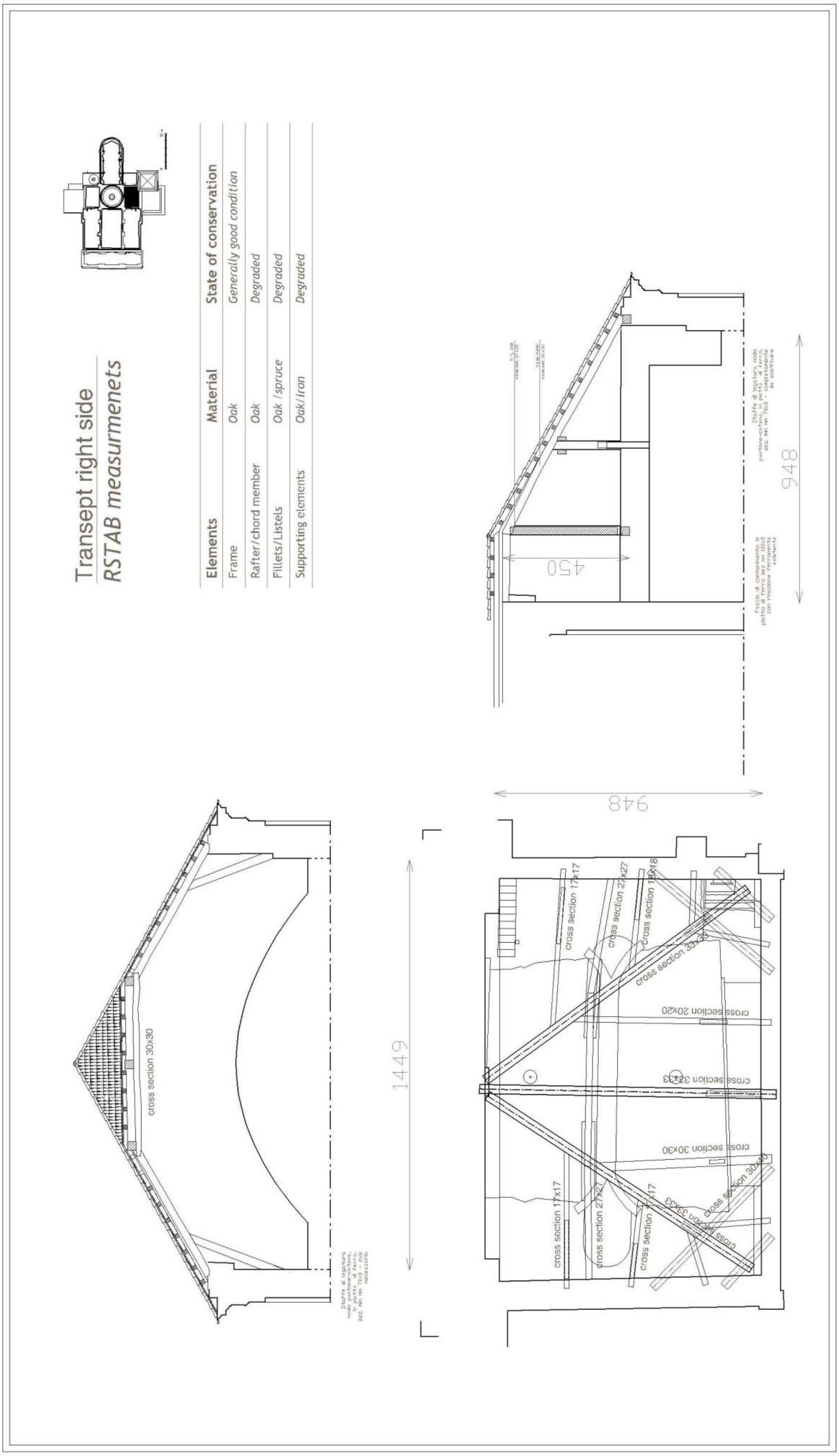
The intermediate cross sections of the main false rafters in the apses are:

False rafter 1-3	33x33cm

The intermediate cross sections of the elements of the secondary timber structures are:

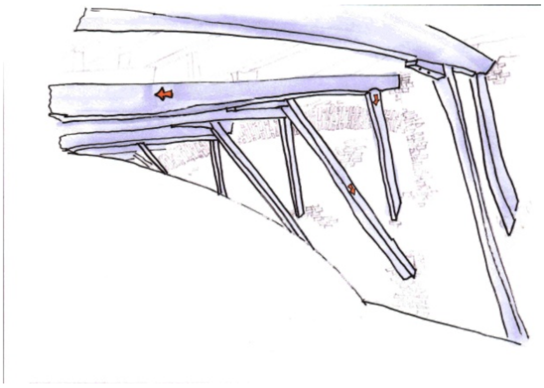
False rafter	20x20cm
Web member	12x12cm

Isometric drawing



Plan_Appendix 5

Attic



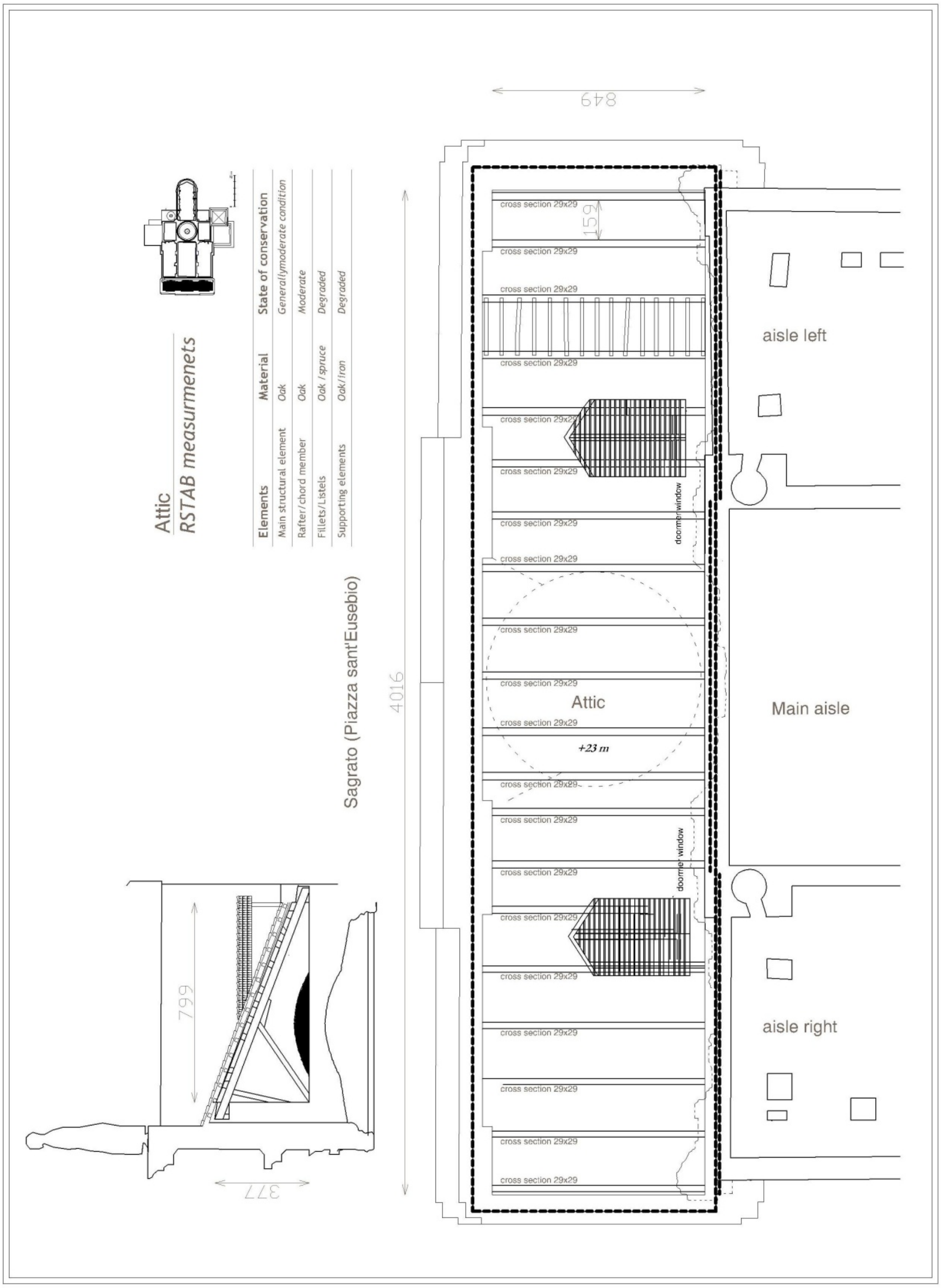
Static characteristics

The structure of the attic is very simple. It consists of twenty big joists (west east). Each of them is supported by two brackets (struts). To balance eventual deformations or differences in the cross sections some little timber elements are positioned above the joists.

The intermediate cross sections of the elements of the timber structure are:

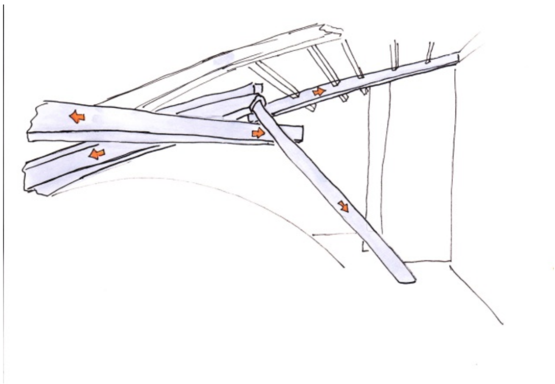
Timber structure	
Joists	29x29cm
Web member	20x20cm
Web member (a)	15x15cm

Isometric drawing



Plan_Appendix 6

Chapel right "Capella del Crocifisso"



sketch 25

Static characteristics

The structure of the chapel is very simple. It consists of a big joist (west - east). On the structural element two false rafters are bearing (north - south). Each of them is supported by a strut. To balance eventual deformations or two differences in the cross sections of the rafters some little timber elements are positioned above the joists.

The intermediate cross sections of the elements of the timber structure are:

Timber structures 1-2

Joist (long)	25x22cm
Joist (short)	18x22cm
Web member	18x21cm
Web member (a)	19x10cm

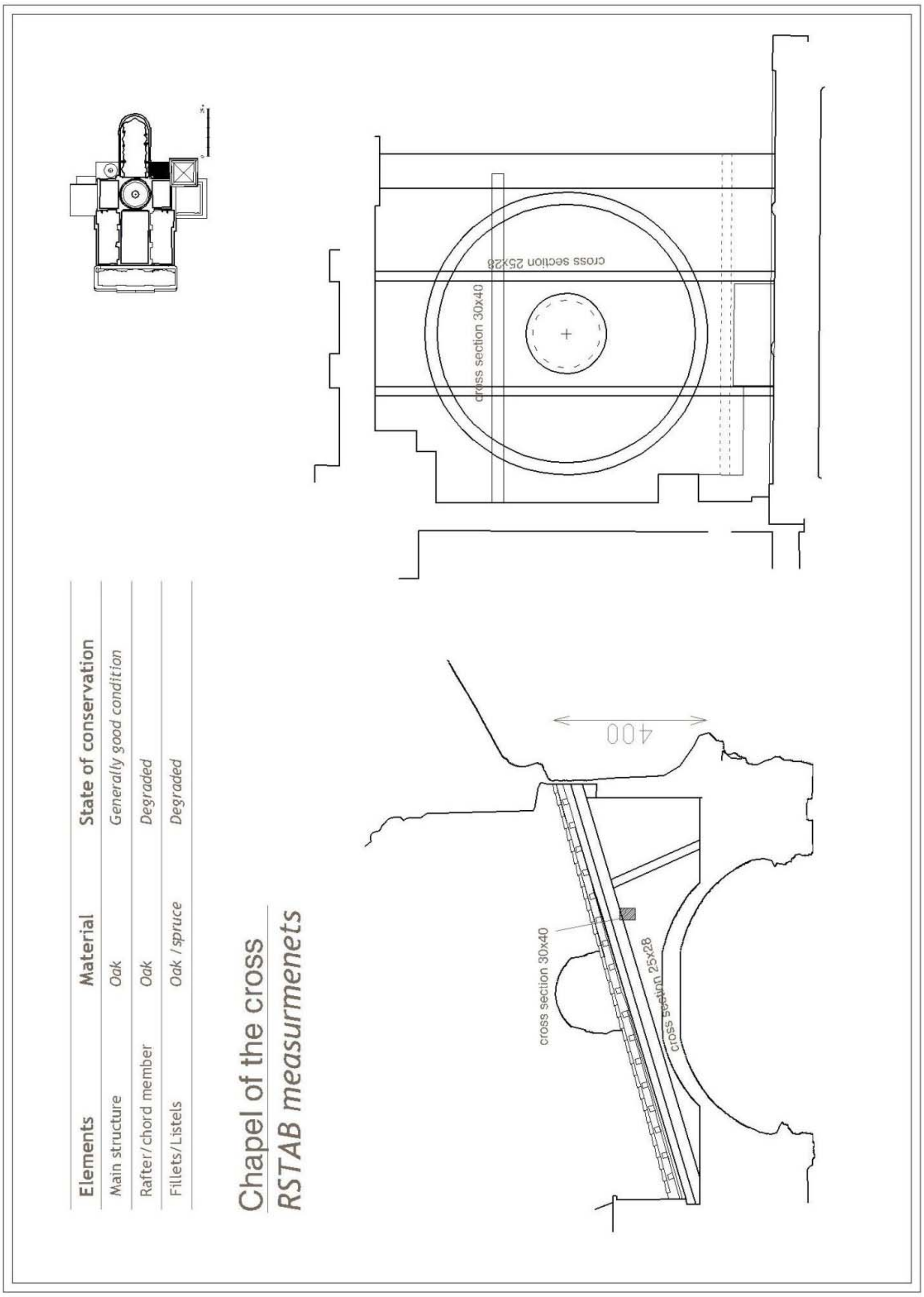
The intermediate cross sections of further joists are:

Top chord (long)	30x30cm
Top chord (long)	15x15cm

The intermediate cross sections of timber elements 3rd/4th order are:

Battens	8x8cm
Contra-battens	4x4cm

Isometric drawing

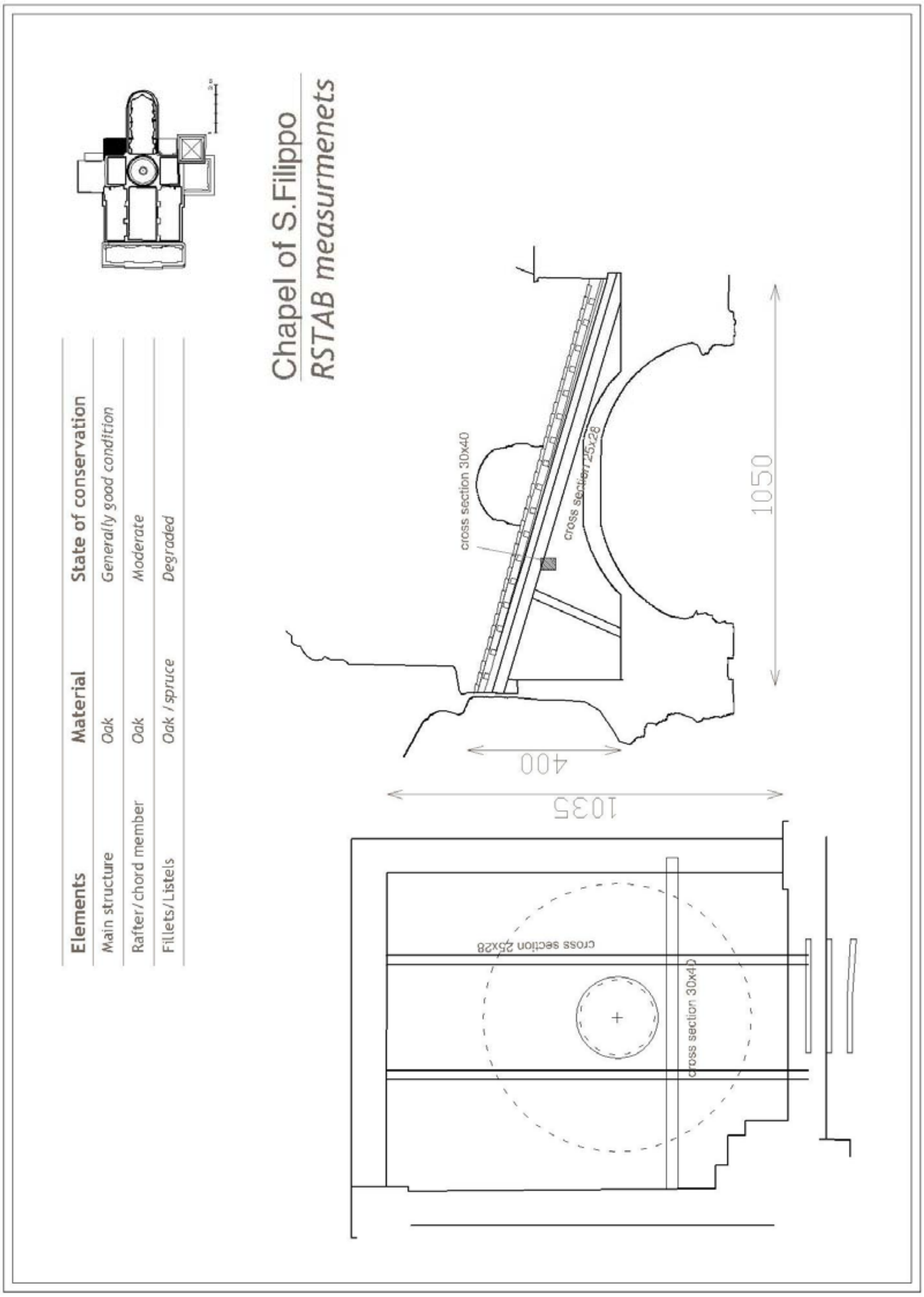


Plan_Appendix 7

Chapel left "Capella di S. Filippo"

It was impossible to enter the roof structure of the chapel! Therefore is no information of the condition of the roof structure available.

Isometric drawing



Plan_Appendix 8

Cupola Chapel of S. Eusebio

Static characteristics

To protect the cupola from outer influences sixteen rafters, always maintaining the same distance, are positioned in a circle bearing from the top (centre) of the dome to the exterior wall. The chords are connected with little beam on which the timber battens are positioned to carry the roof tiles.
The intermediate cross sections of timber elements are:

Rafter 1-16 21x21cm

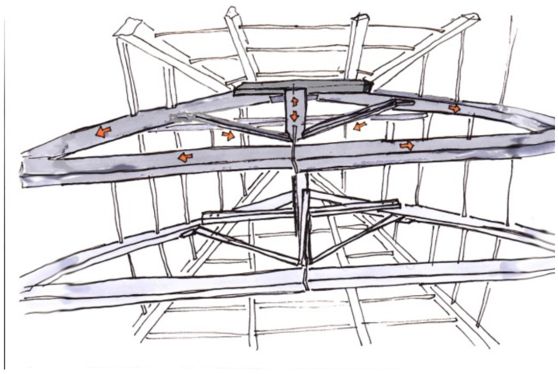
Cupola Chapel of S. Beato Amedeo

It was impossible to enter the roof structure of the chapel! Therefore is no information of the condition of the roof structure available.

Main Cupola

The cupola is made out of stone and has a metal covering. As there are no timber elements the state of the cupola wasn't analysed.

Tower



sketch 26

Static characteristics

Two trusses carrying from the west to the east brick wall of the tower built the main structure. The elements are classical Italian trusses with an interrupted king post and a strut on each side connecting the post with the rafters.
On these two rafters many false rafters (beams) are bearing. On these chords timber battens are positioned to carry the roof tiles, which protect the structure from outer influences.

11.3. Ad Diagnostics of the actual state

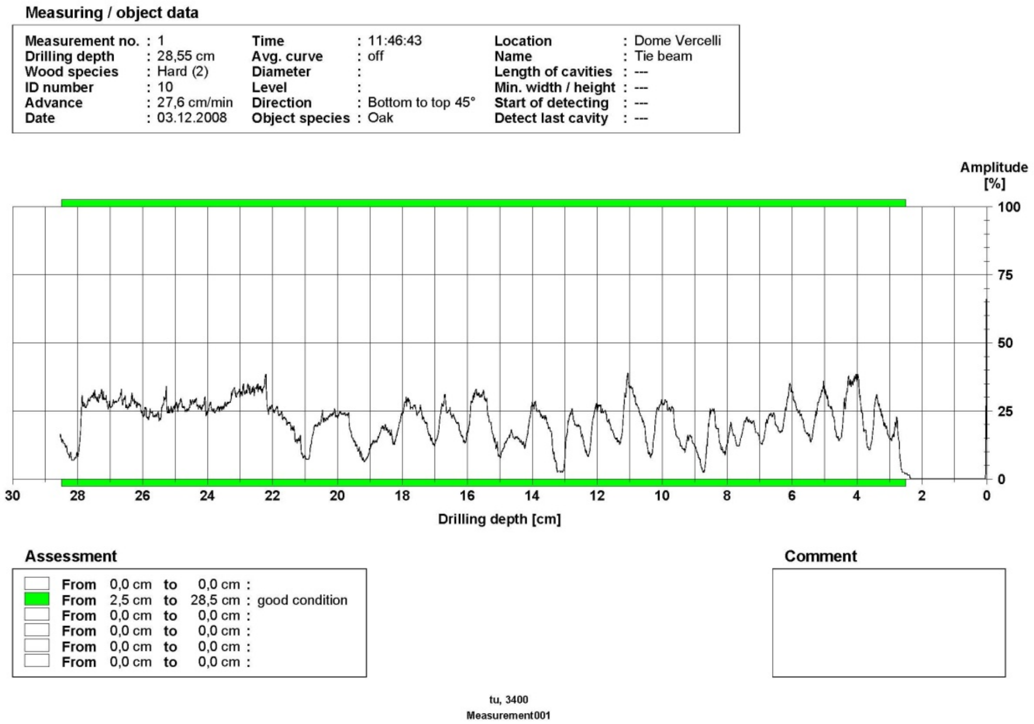
Choir

Description of every single element

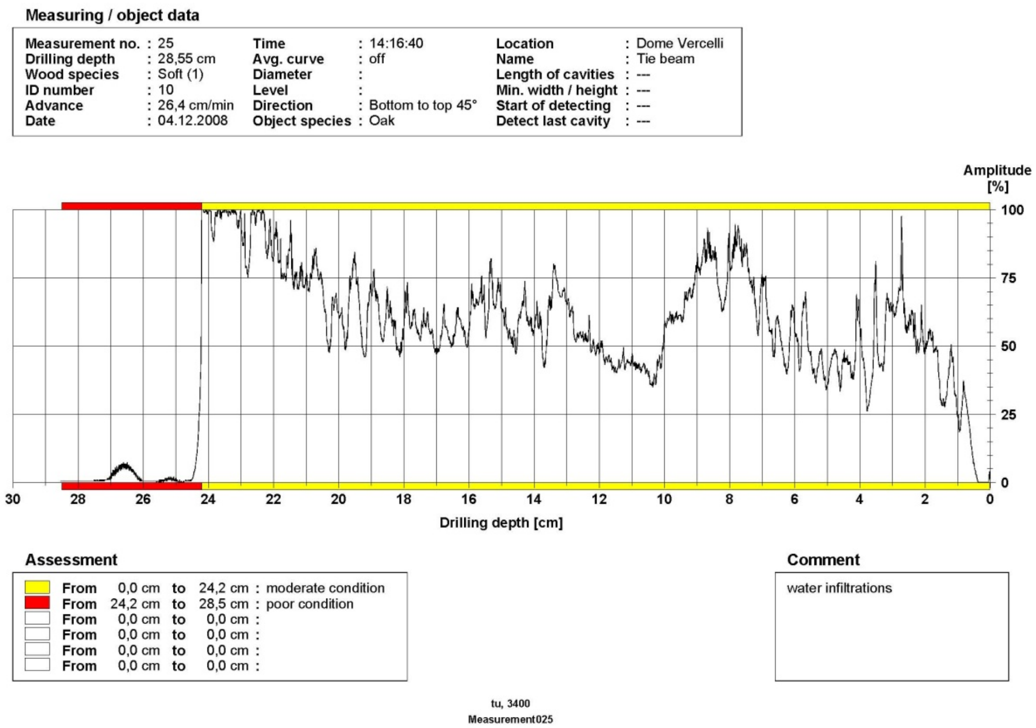
Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 1**		**Choir**	
Tie-beam				
Biological decay	From fungi		Fungi is present. It interests the superficial part of the element for about 1cm depth on each side.	
	From insects		Absent	
Defects	Joints		Weak (intervention necessary)	
	Ring-shakes		No signs (absent)	
	Twist		deviation of the fibre direction	
Wooden species	Oak			
Moisture content	18 % Water infiltration visible N and S side			
Average dimensions of the element	30 x 30 cm			
	Section		Rectangular	
	Geometric peculiarity		Wane	Wane and deviation of the fibre direction
			Deformations	Slightly deformed
Other characteristics	The state of the truss is critical, because the joint (bottom chord - top chord) doesn't work anymore. Water infiltrations provoked grow of fungi (Xilofagi), which caused a heavy degrade at the final part of the bottom chord (point of support on the wall). The bottom chord (tie beam) enters on both sides (N and S) 75cm into the wall.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
3.12.08	R 1	front end north side	underside to top side inclination 45° (ref. exterior wall)	The test was executed on firm timber. The first 3 cm are zero because measuring in inclination, the drill head doesn't enter into the timber immediately.



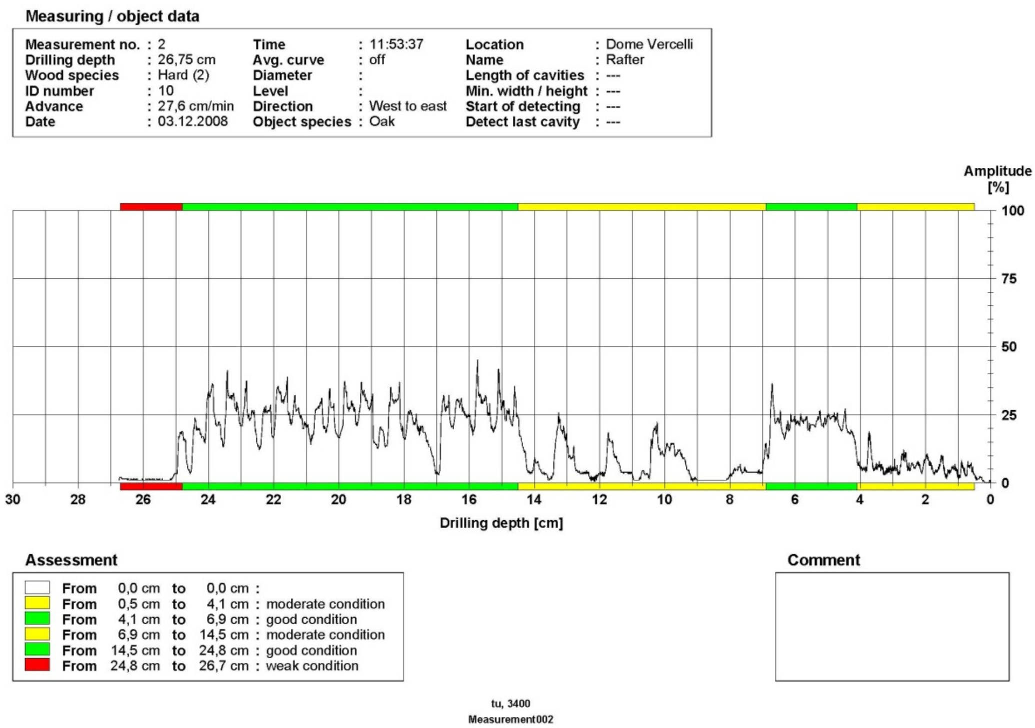
3.12.08	R 25	front end south side	underside to top side Inclination 45° (ref. exterior wall)	The test was executed on soft timber on the truss 1. The drill shows the moderate condition of the structural element in the first phase and the low load bearing capacity of the structural element in the second phase. It has to be considered that the structural element is drenched with water.



Rafter	**North Side**	
Biological decay	From fungi	Fungi is present in the superficial part of the element.
	From insects	Absent
Defects	Joints	Moderate (connection tie beam) Better (connection king beam)
	Ring-shakes	No signs (absent)

	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	27 x 21 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing found
		Deformations	
Other characteristics	Knots, but generally in a good condition		

Data	**Profile N°**	**from**	**Direction**	**Observations**
3.12.08	R 2	front end north side	orthogonal	The test was executed on firm timber on the rafter on the north side. It was tested orthogonal to the member from the west side to the east side, which means into the direction of the apses.



Rafter	**South Side**		
Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints	Weak (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	16 % Water infiltration visible		
Average dimensions of the element	27 x 27 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	Wane, generally in a moderate condition		
King Post			
Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a moderate condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted).	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	

Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	22 x 25 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	The post is not lined up with the tie beam. The horizontal connections joining the king posts with each other caused a displacement of the timber element. Knots and wane, but generally in a moderate condition		

PHOTO

IMG_0686
Truss 1

IMG_0735
Knot (king post – rafter)

IMG_0737
Knot (king post – chord member)

IMG_0739 / IMG_0736
Knot (rafter – chord member)

IMG_0652 / IMG_0651
Knot (rafter – tie beam) South side

IMG_0681/ IMG_0682
Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

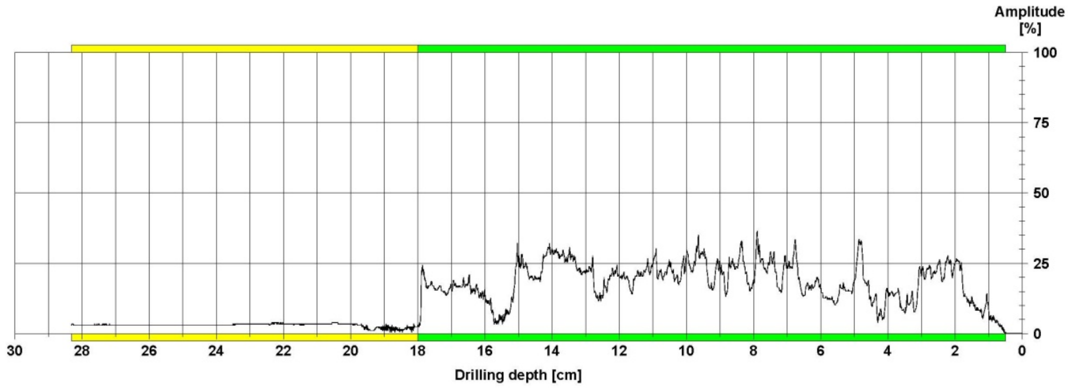
IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 2**		**Choir**	
Tie-beam				
Biological decay	From fungi		Sapwood: fungi attack	
	From insects		Absent	
Defects	Joints		See rafter	
	Ring-shakes		Single deviation of the fibre direction	
	Twist			
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	30 x 30 cm			
	Section		Rectangular	
	Geometric peculiarity		Wane	Absent
			Deformations	Absent
Other characteristics	The head (south side) of the element is twisted and shows a fracture which starts at the other end of the tie beam. The timber in this area is weakened and the sap wood is missing. A protection cover has been introduced at the end of the beam. On the topside of the bottom chord is an interior void which is covered by a timber cap. The bottom chord has shrinking fractures with an obligatory inclination. The timber of the chord can be classified in the 3rd category.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**

3.12.08	R 3	front end north side	underside to top side inclination 45° (ref. exterior wall)	- Drill 3 (executed on firm timber): the test was taken on the truss 2.

Measuring / object data

Measurement no. : 3		**Time**	: 12:08:32	**Location**	: Dome Vercelli
Drilling depth	: 28,32 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Hard (2)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---
Date	: 03.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	**to**	0,0 cm :	
From	0,5 cm	**to**	18,0 cm :	good condition
From	18,0 cm	**to**	28,3 cm :	moderate condition
From	0,0 cm	**to**	0,0 cm :	
From	0,0 cm	**to**	0,0 cm :	
From	0,0 cm	**to**	0,0 cm :	

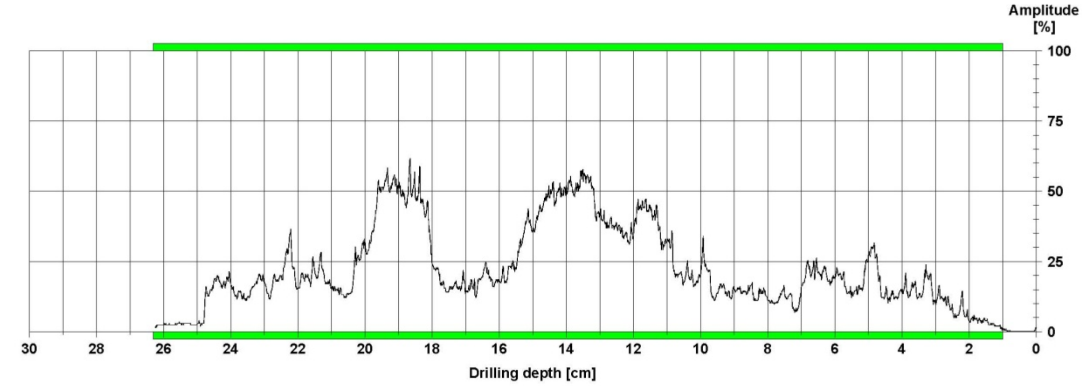
Comment

tu, 3400
Measurement003

3.12.08	R 4	front end north side	underside to top side Inclination 45° (ref. exterior wall)	- Drill 4 (executed on firm timber): the test was taken on the truss 2.

Measuring / object data

Measurement no.	: 4	**Time**	: 12:22:18	**Location**	: Dome Vercelli
Drilling depth	: 26,25 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Hard (2)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---
Date	: 03.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	to	0,0 cm	:	
From	1,0 cm	to	26,3 cm	:	good condition
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	

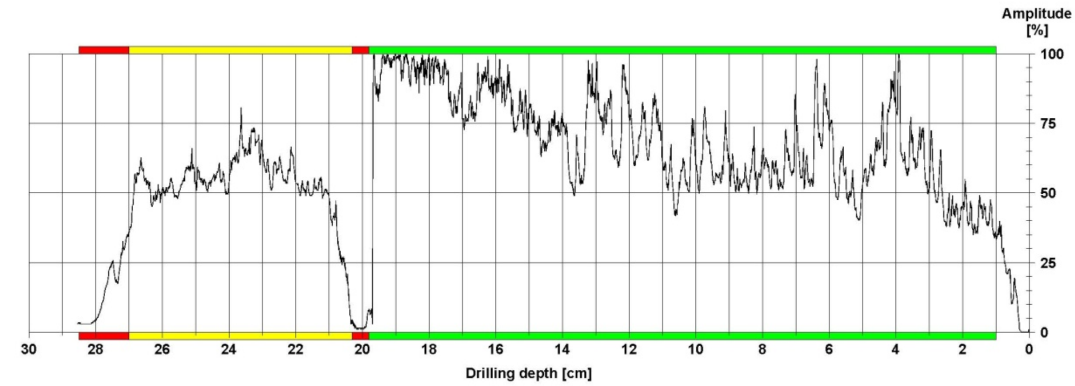
Comment

tu, 3400
Measurement004

3.12.08	R 5	front end north side	underside to top side Inclination 45° (ref. exterior wall)	- Drill 5 (executed on soft timber): the test was taken on the bottom chord in distance of about 2 meters from the front end, after the timber joint (bottom chord - top chord). A fracture about the twentieth centimetre was registered.

Measuring / object data

Measurement no.	: 5	**Time**	: 12:32:49	**Location**	: Dome Vercelli
Drilling depth	: 28,55 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	:	**Start of detecting**	: ---
Date	: 03.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



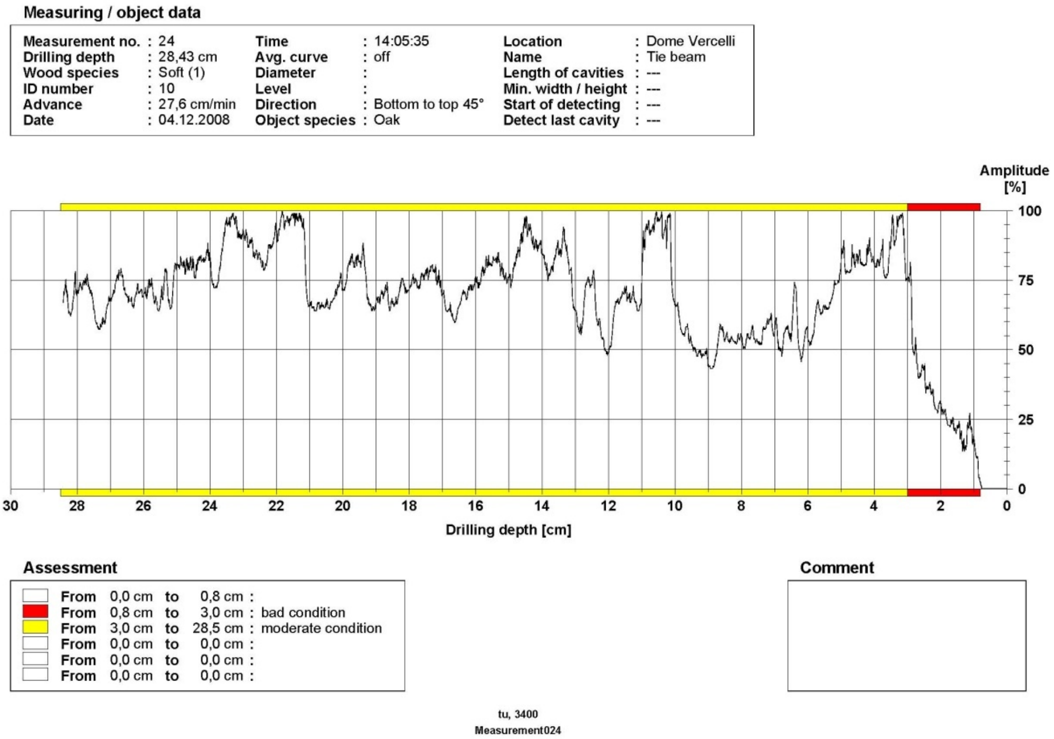
Assessment

From	0,0 cm	to	0,0 cm	:	
From	1,0 cm	to	19,8 cm	:	good condition
From	19,8 cm	to	20,3 cm	:	crack
From	20,3 cm	to	27,0 cm	:	moderate condition
From	27,0 cm	to	28,5 cm	:	weak
From	0,0 cm	to	0,0 cm	:	

Comment

tu, 3400
Measurement005

3.12.08	R 24	front end south side	underside to top side Inclination 45° (ref. exterior wall)	- Drill 24 (executed on soft timber): the test was taken on the truss 2. The drill shows the extremely bad condition of the structural element in the first part and that the condition of the beam improves in the second part.

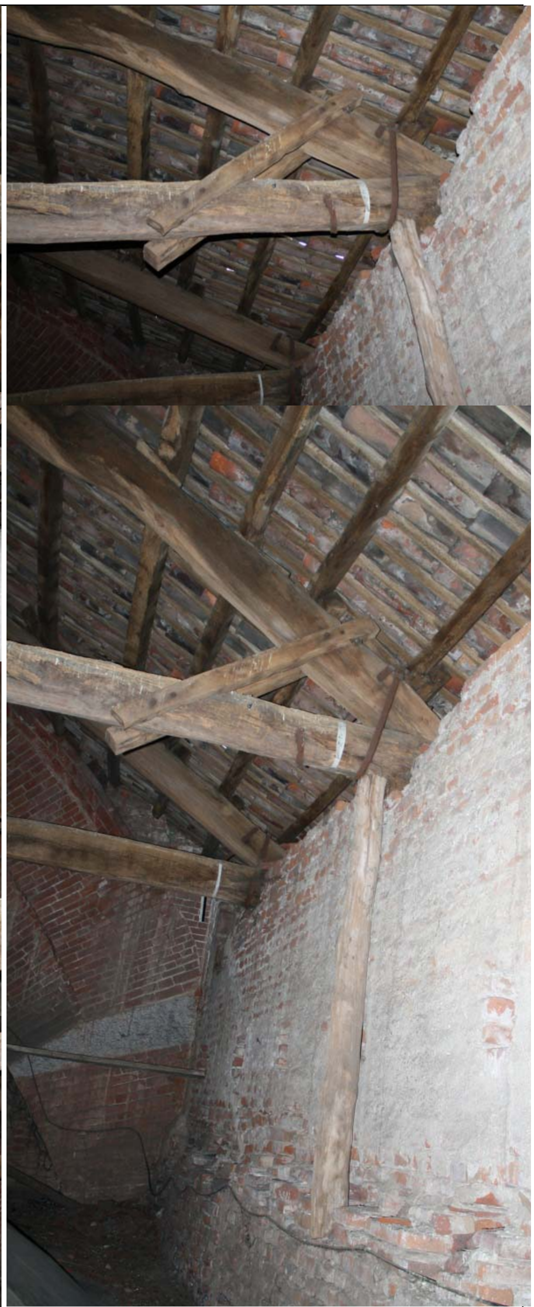


Rafter	North Side		
Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints Ring-shakes Twist	The joint of the truss on the north side (bottom cord - top chord) has a double connection with nailed timber elements in an angle of circa 25-28 ° compared to the horizontal direction of the bottom truss. The joint (bottom cord - top chord) on north side is supported by a wooden “barotto” placed vertically and next to the external wall.	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	28 x 28 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane Deformations	Nothing to observe.
Other characteristics	Single deviation of the fibre direction		

Rafter	South Side		
Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints Ring-shakes Twist	The whole sapwood on the joint (bottom cord - top chord) is degraded by fungi. The joint of the south side (bottom cord - top chord) shows a transversal fracture provoked by a load cutting parallel to the fibre of the bottom chord.	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	25 x 23 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane Deformations	Nothing to observe.
Other characteristics	Single deviation of the fibre direction		

King Post

Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a good condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted).	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	22 x 23 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Knot and wane
		Deformations	
Other characteristics	The post is not lined up with the tie beam. The horizontal connections joining the king posts with each other caused a displacement of the timber element. The presence of the tenon in the connection with the tie-beam is evident in profiles 36a and 38a. From the profiles are not visible particular decay signs.		
PHOTO			
n. Photo	IMG_0687 Truss 2	IMG_0730 Knot (king post – rafter)	
PHOTO			
n. Photo	IMG_0729 Knot (king post - chord member)	IMG_0731 / IMG_0732 Knot (rafter - chord member)	

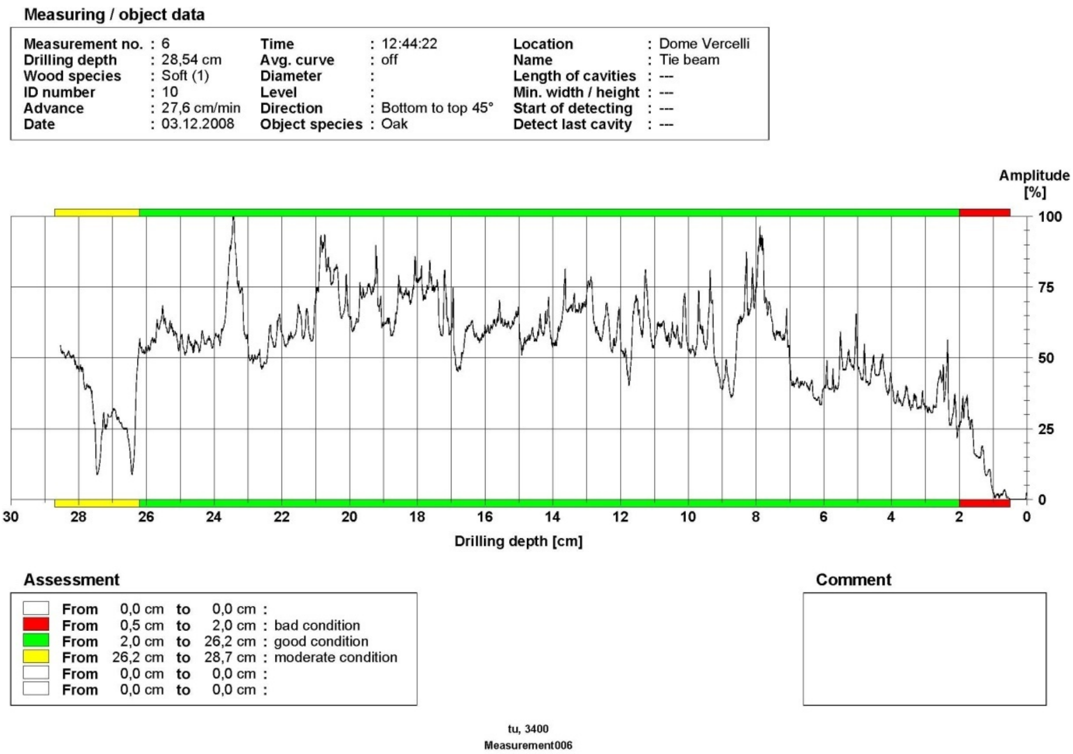
PHOTO		
n. Photo	IMG_0649 / IMG_0650/ IMG_0728/ IMG_0679 Knot (rafter – tie beam) South side	IMG_0678/ IMG_0677 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

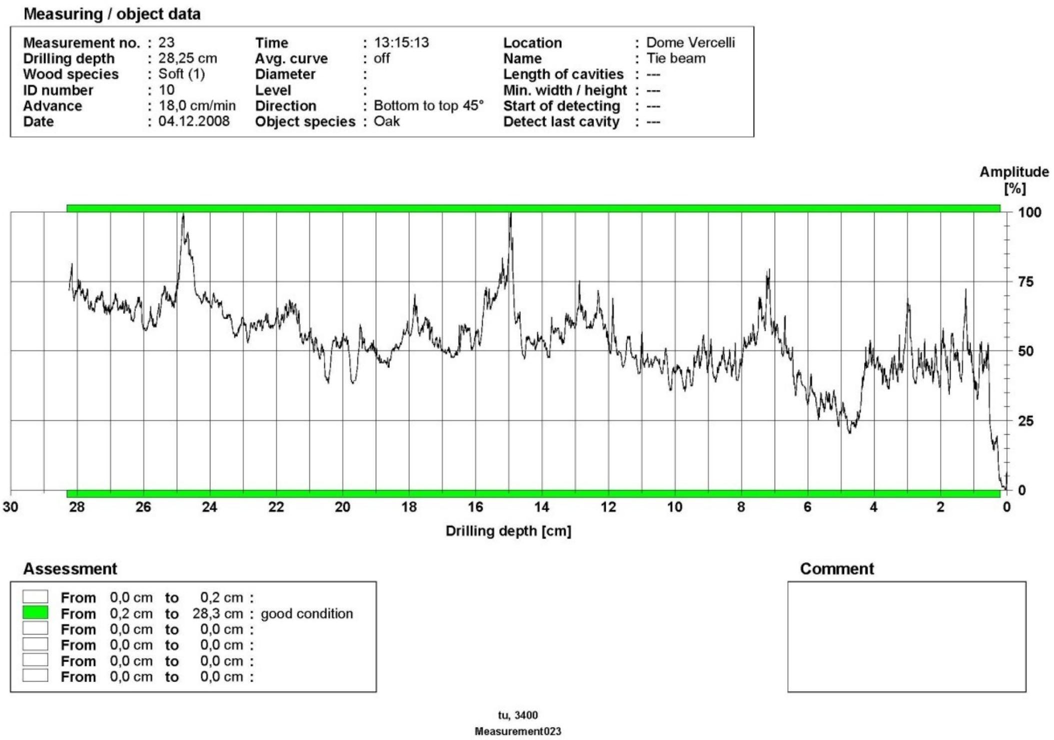
IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3^{rd}/4^{th} /12^{th} Dec. 08, 6^{th}/9^{th} Mar. 09, 6^{th}/12^{th} May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 3**	**Choir**
Tie-beam		
Biological decay	From fungi	Sapwood: fungi attack
	From insects	Absent

Defects	Joints	See rafter		
	Ring-shakes	Nothing observed		
	Twist			
Wooden species	Oak			
Moisture content	15% N side			
Average dimensions of the element	30 x 30 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Absent	
		Deformations	Absent	
Other characteristics	The state of the beam is moderate. A single knot is visible.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
3.12.08	R 6	front end north side	underside to top side inclination 45° (ref. exterior wall)	Drill 6 (executed on soft timber): the test was taken on the truss 3.



3.12.08	R 23	front end south side	underside to top side Inclination 45° (ref. exterior wall)	- Drill 23 (executed on soft timber): the test was taken on the truss 3. The drill shows the good condition of the structural element.



Rafter	**North Side**		
Biological decay	From fungi	Nothing observed	
	From insects	Absent	
Defects	Joints	The joint of the truss on the north side (rafter tie beam) is realised in a zone of sapwood. This is a big problem considering that in this area the sapwood is degraded and the joint cannot work probably.	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Moisture content	21%		
Average dimensions of the element	28 x 28 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing observed
		Deformations	
Other characteristics	The rafter is in a good condition. Some knots are visible.		
Rafter	**South Side**		
Biological decay	From fungi	Nothing observed	
	From insects	Absent	
Defects	Joints	Nothing observed	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	24 x 29 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing observed
		Deformations	
Other characteristics	Injuries on the living tree are visible. The rafter is in a moderate condition.		
King Post			
Biological decay	From fungi	Nothing observed	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a good condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted).	
	Ring-shakes	Nothing observed	

	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	26 x 20 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Knot and wane
		Deformations	
Other characteristics	The post is not lined up with the tie beam. The horizontal connections joining the king posts with each other caused a displacement of the timber element. The king post is in a moderate condition.		
PHOTO			
n. Photo	IMG_0688 Truss 3	IMG_7058 Knot (king post – rafter)	
PHOTO			
n. Photo	IMG_0725 Knot (king post – chord member)	IMG_0726 / IMG_0727 Knot (rafter – chord member)	

PHOTO		
n. Photo	IMG_0646 /IMG_0647 Knot (rafter – tie beam) South side	IMG_0674 IMG_0723 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

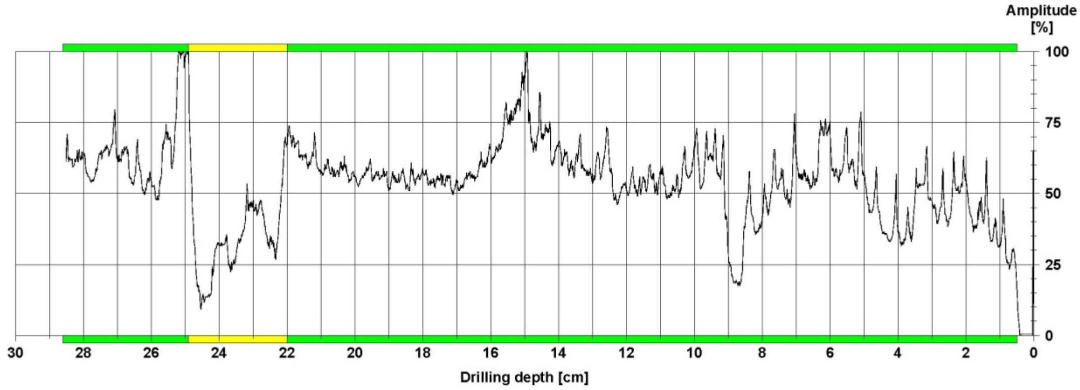
IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 4**	**Choir**		
Tie-beam				
Biological decay	From fungi	Sapwood: fungi attack		
	From insects	Injuries caused by insects		
Defects	Joints	See rafter		
	Ring-shakes	Nothing visible		
	Twist			
Wooden species	Oak			
Moisture content	> 30% N			
Average dimensions of the element	30 x 30 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Absent	
		Deformations	Single knot	
Other characteristics	On the south side the tie beam, where the beam gets in contact with the wall, is completely degraded. On a length of about ¾ of the tie beam on the south side tunnels, created by insects when the tree was still living, are visible. The tunnels have an oval form and the size of about 3 x 1 cm: they enter into the wood up to 10 cm's (including sapwood and heartwood).			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**

3.12.08	R 7	front end north side	underside to top side inclination 45° (ref. exterior wall)	- Drill 7 (executed on soft timber): the test was taken on the truss 4. It has to be taken into account that the zone where the borehole was drilled has been drenched with rain.

Measuring / object data

Measurement no.	: 7	**Time**	: 12:56:11	**Location**	: Dome Vercelli
Drilling depth	: 28,52 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 26,4 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---
Date	: 03.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	to	0,0 cm	:	
From	0,5 cm	to	22,0 cm	:	good condition
From	22,0 cm	to	24,9 cm	:	moderate condition
From	24,9 cm	to	28,6 cm	:	good condition
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	

Comment

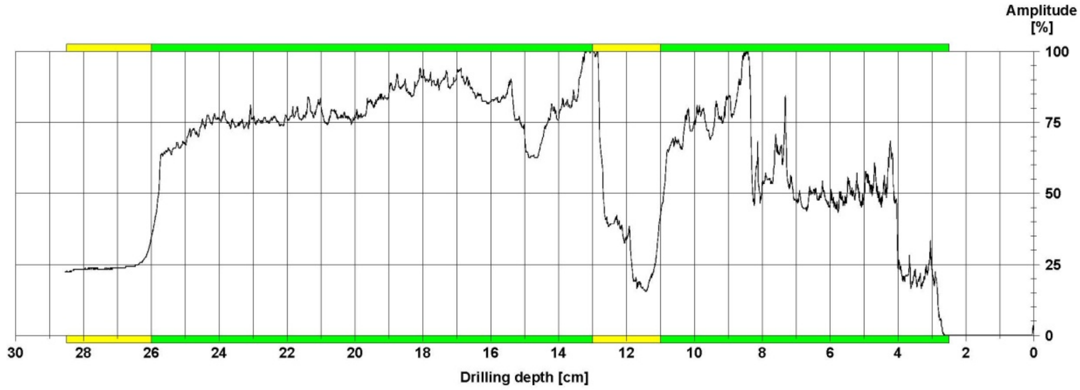
It has to be taken into account that the zone where the borehole was drilled has been drenched with rain.

tu, 3400
Measurement007

3.12.08	R 21/22	front end south side	underside to top side Inclination 45° (ref. exterior wall)	- Drill 21 and 22 (executed on soft timber): The test was taken on the tie beam, showing the good condition of the structural element.

Measuring / object data

Measurement no.	: 21	Time	: 12:58:00	Location	: Dome Vercelli
Drilling depth	: 28,55 cm	Avg. curve	: off	Name	: Tie beam
Wood species	: Soft (1)	Diameter	:	Length of cavities	: ---
ID number	: 10	Level	:	Min. width / height	: ---
Advance	: 30,0 cm/min	Direction	: Bottom to top 45°	Start of detecting	: ---
Date	: 04.12.2008	Object species	: Oak	Detect last cavity	: ---



Assessment

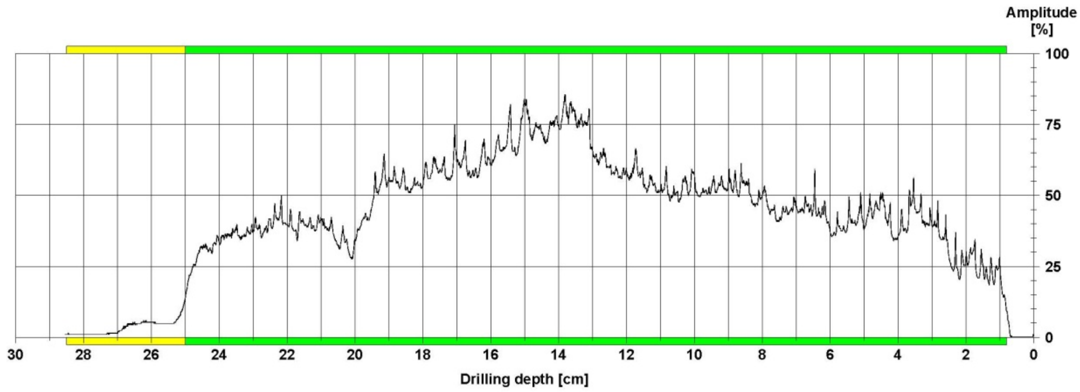
From 0,0 cm to 2,5 cm :
From 2,5 cm to 11,0 cm : good condition
From 11,0 cm to 13,0 cm : moderate condition
From 13,0 cm to 26,0 cm : good condition
From 26,0 cm to 28,5 cm : moderate condition
From 0,0 cm to 0,0 cm :

Comment

tu, 3400
Measurement021

Measuring / object data

Measurement no.	: 22	Time	: 13:00:36	Location	: Dome Vercelli
Drilling depth	: 28,55 cm	Avg. curve	: off	Name	: Tie beam
Wood species	: Soft (1)	Diameter	:	Length of cavities	: ---
ID number	: 10	Level	:	Min. width / height	: ---
Advance	: 28,8 cm/min	Direction	: Bottom to top 45°	Start of detecting	: ---
Date	: 04.12.2008	Object species	: Oak	Detect last cavity	: ---



Assessment

From 0,0 cm to 0,8 cm :
From 0,8 cm to 25,0 cm : good condition
From 25,0 cm to 28,5 cm : moderate condition
From 0,0 cm to 0,0 cm :
From 0,0 cm to 0,0 cm :
From 0,0 cm to 0,0 cm :

Comment

tu, 3400
Measurement022

Rafter	North Side	
Biological decay	From fungi	Nothing visible
	From insects	Absent
Defects	Joints	Moderate
	Ring-shakes	Nothing observed
	Twist	

Wooden species	Oak		
Moisture content	>30%		
Average dimensions of the element	27 x 27 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Knot and wane
		Deformations	
Other characteristics	On the rafter on the north side water infiltrations according to an un-tight roof are visible.		
Rafter	**South Side**		
Biological decay	From fungi	Nothing visible	
	From insects	Absent	
Defects	Joints	Moderate	
	Ring-shakes	Nothing observed	
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	28 x 28 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Knot and wane
		Deformations	
Other characteristics	The rafter is in a moderate condition.		
King Post			
Biological decay	From fungi	Absent	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a good condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted).	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	24 x 26 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	The post is not lined up with the tie beam. The horizontal connections joining the king posts with each other caused a displacement of the timber element. The post is in a moderate condition.		
PHOTO			
n. Photo	IMG_0689 Truss 4	IMG_7364 Knot (king post – rafter)	

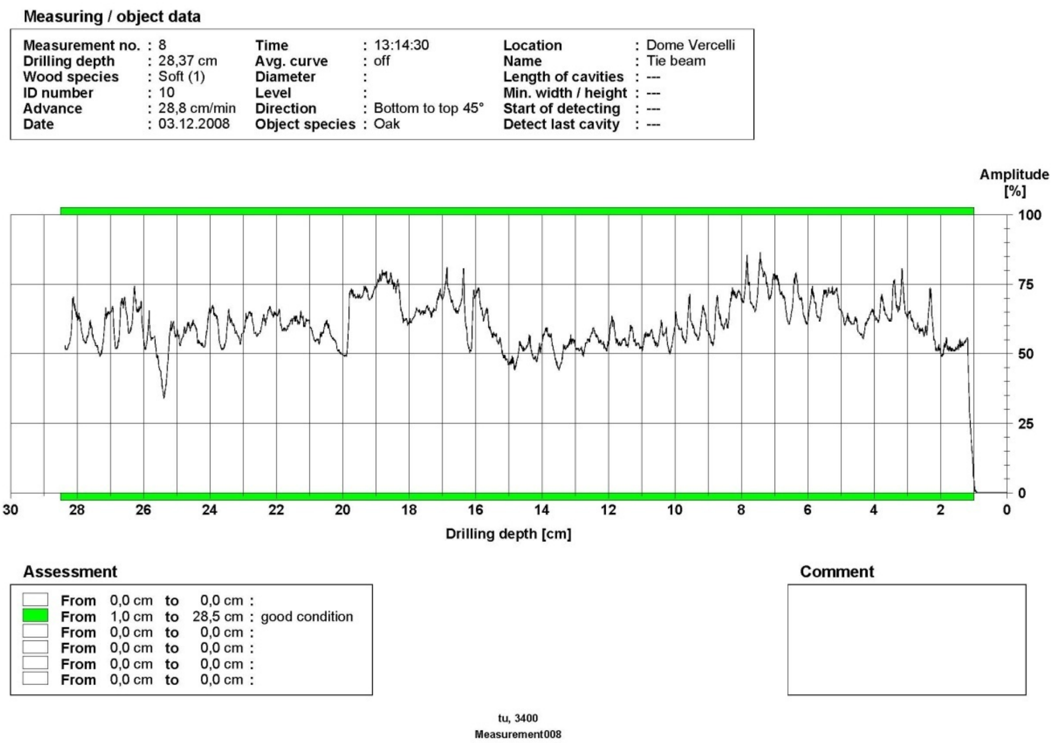
PHOTO		
n. Photo	IMG_0716 Knot (king post – chord member)	IMG_0618 / IMG_0719 Knot (rafter – chord member)
PHOTO		
n. Photo	IMG_0643 / IMG_0644 Knot (rafter – tie beam) South side	IMG_0671/ IMG_0672 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE

Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

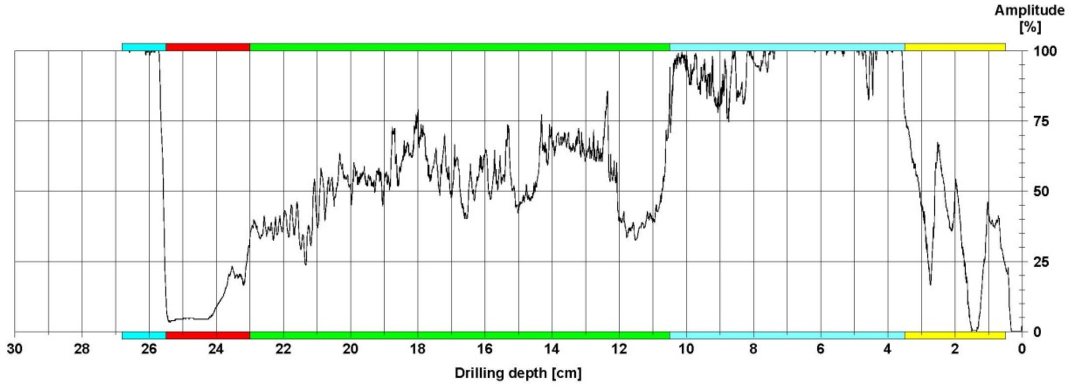
Truss	**N. 5**		**Choir**	
Tie-beam				
Biological decay	From fungi		Present (joints)	
	From insects		Absent	
Defects	Joints		See rafter	
	Ring-shakes		Nothing visible	
	Twist			
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	26 x 30 cm			
	Section		Rectangular	
	Geometric peculiarity		Wane	Absent
			Deformations	Absent
Other characteristics	Next to the joint with the rafter the tie beam has a big knot. This leads to a reduction of the effective cross-section. On the south side the tie beam is heavily degraded!			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
3.12.08	R 8	front end north side	underside to top side inclination 45° (ref. exterior wall)	Drill 8 (executed on soft timber): the test was taken on the truss 5.



3.12.08	R 19	front end south side	underside to top side Inclination 45° (ref. exterior wall)	**Drill 19 (had to be annulated because it had been taken next to a knot)**

Measuring / object data

Measurement no.	: 19	**Time**	: 12:37:40	**Location**	: Dome Vercelli
Drilling depth	: 26,65 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---
Date	: 04.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	to	0,0 cm	:	
From	0,5 cm	to	3,5 cm	:	moderate condition
From	3,5 cm	to	10,5 cm	:	extreamly high
From	10,5 cm	to	23,0 cm	:	good condition
From	23,0 cm	to	25,5 cm	:	weak
From	25,5 cm	to	26,8 cm	:	extreamly high

Comment

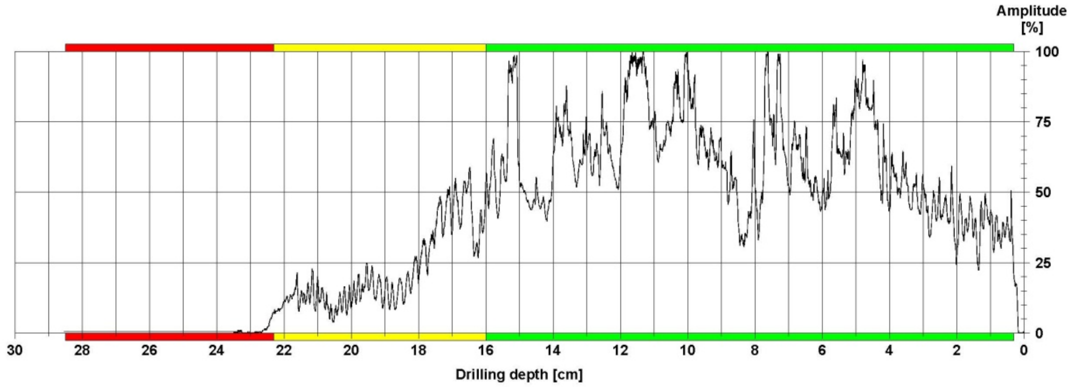
next to a knot
therefore not valid

tu, 3400
Measurement019

3.12.08	R 20	front end south side	underside to top side Inclination 45° (ref. exterior wall)	Drill 20 (executed on soft timber): The bore was taken on the tie beam. The first part shows a discreet result, while the second half of the beam has nearly no resistance.

Measuring / object data

Measurement no.	: 20	**Time**	: 12:40:05	**Location**	: Dome Vercelli
Drilling depth	: 28,55 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---
Date	: 04.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	to	0,0 cm	:	
From	0,3 cm	to	16,0 cm	:	good condition
From	16,0 cm	to	22,3 cm	:	moderate condition
From	22,3 cm	to	28,5 cm	:	weak
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	

Comment

tu, 3400
Measurement020

Rafter	**North Side**	
Biological decay	From fungi	Nothing visible
	From insects	Absent

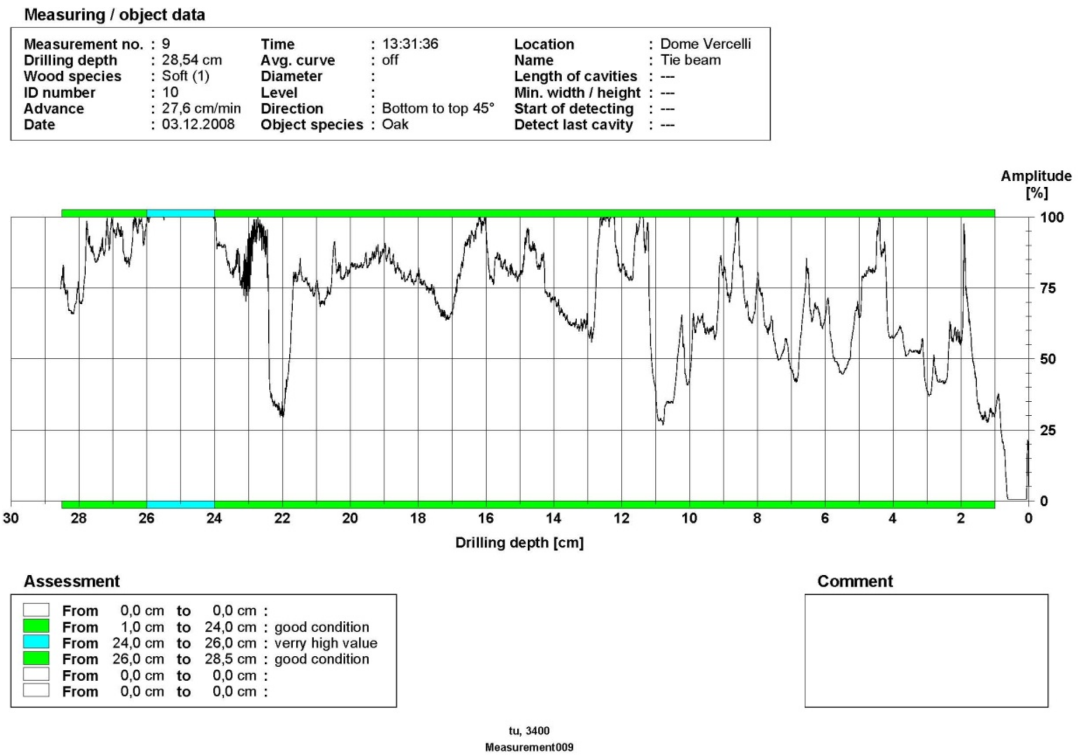
Defects	Joints	The load bearing capacity of the joint of the truss 5 on the north side (rafter tie beam) seems to be little efficient.	
	Ring-shakes	Nothing visible	
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	20 x 28 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane and knots
		Deformations	
Other characteristics	There is a superficial degradation on the rafter visible (south side towards the apses), which was caused by water infiltrations (rain).		
Rafter	**South Side**		
Biological decay	From fungi	Nothing visible	
	From insects	Absent	
Defects	Joints	Moderate	
	Ring-shakes	Nothing visible	
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	21 x 27 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing visible
		Deformations	
Other characteristics	The beam is in a moderate condition.		
King Post			
Biological decay	From fungi	Nothing visible	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a good condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted).	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	23 x 21 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing visible
		Deformations	
Other characteristics	The post is in a moderate condition. The post is not lined up with the tie beam. The horizontal connections joining the king posts with each other caused a displacement of the timber element.		
PHOTO			
n. Photo	IMG_0690 Truss 5	IMG_0710 Knot (king post – rafter)	

PHOTO		
n. Photo	IMG_0711 Knot (king post – chord member)	IMG_0712 / IMG_0713 Knot (rafter – chord member)
PHOTO		
n. Photo	IMG_0640 / IMG_0641 Knot (rafter – tie beam) South side	IMG_0668 / IMG_0669 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

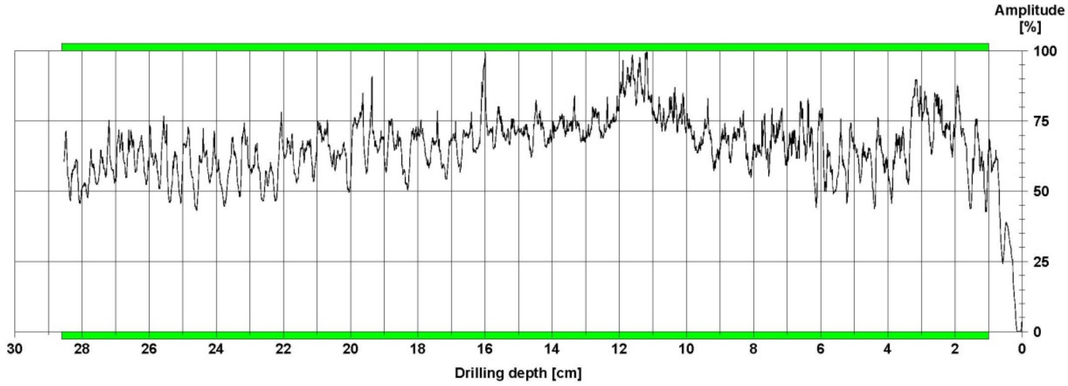
Truss	**N. 6**		**Choir**	
Tie-beam				
Biological decay	From fungi		Nothing visible	
	From insects		Absent	
Defects	Joints		See rafter	
	Ring-shakes		Nothing visible	
	Twist			
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	30 x 30 cm			
	Section		Rectangular	
	Geometric peculiarity		Wane	Absent
			Deformations	Absent
Other characteristics	Some knots are visible. The condition of the beam is moderate.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
3.12.08	R 9	front end north side	underside to top side inclination 45° (ref. exterior wall)	Drill 9 (executed on soft timber): the test was taken on the truss 6.



3.12.08	R 18	front end south side	underside to top side Inclination 45° (ref. exterior wall)	Drill 18 (executed on soft timber): the test was taken on the truss 6. The drill showed the good condition of the tie beam.

Measuring / object data

Measurement no.	: 18	**Time**	: 12:24:44	**Location**	: Dome Vercelli
Drilling depth	: 28,54 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---
Date	: 04.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	**to**	0,0 cm	:
From	1,0 cm	**to**	28,6 cm	: good conditions
From	0,0 cm	**to**	0,0 cm	:
From	0,0 cm	**to**	0,0 cm	:
From	0,0 cm	**to**	0,0 cm	:
From	0,0 cm	**to**	0,0 cm	:

Comment

tu, 3400
Measurement018

Rafter	**North Side**		
Biological decay	From fungi	Nothing visible	
	From insects	Absent	
Defects	Joints	The joint of the truss on the north side (rafter tie beam) is realised in a zone of sapwood. Considering that there is the joint (rafter tie beam) and that in this area the sapwood is degraded, the load bearing capacity of this connection is insufficient.	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	22 x 27 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane, knots
		Deformations	
Other characteristics	The rafter may have been substituted, because on one side the beam seems to be chopped, while on the other side the beam seems to be sawn.		

Rafter	**South Side**		
Biological decay	From fungi	Nothing visible	
	From insects	Absent	
Defects	Joints	Nothing to observe.	
	Ring-shakes		
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	23 x 27 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing visible
		Deformations	
Other characteristics	Some single knots are visible. The general condition of the rafter is quite good.		

King Post		
Biological decay	From fungi	Absent
	From insects	Absent

Defects	Joints	The connection with the rafters seems to be in a good condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted).	
	Ring-shakes	Nothing observed	
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	20 x 26 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	Some knots are visible. The king post is in a moderate condition. The post is not lined up with the tie beam. The horizontal connections joining the king posts with each other caused a displacement of the timber element.		
PHOTO			
n. Photo	IMG_0691 Truss 6	IMG_0704 Knot (king post – rafter)	
PHOTO			
n. Photo	IMG_0705 Knot (king post – chord member)	IMG_0706 / IMG_0707 Knot (rafter – chord member)	

PHOTO		
n. Photo	IMG_0637 / IMG_0638 Knot (rafter – tie beam) South side	IMG_0665 / IMG_0666 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

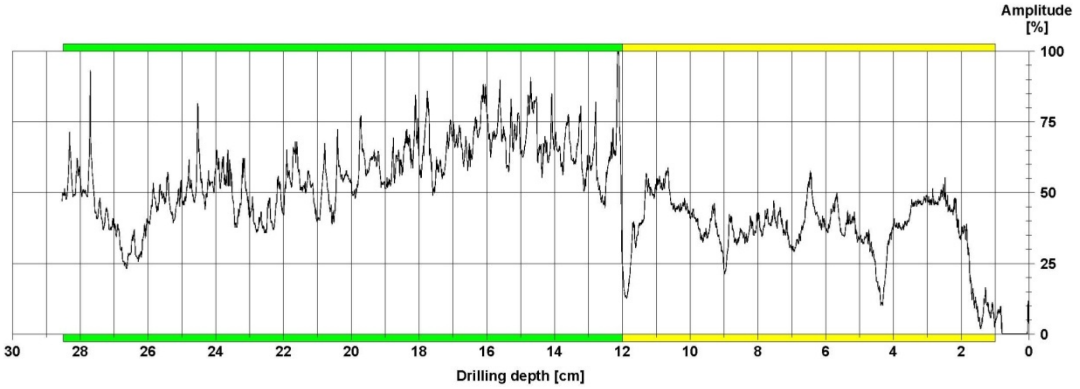
IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 7**	**Choir**		
Tie-beam				
Biological decay	From fungi	Fungi is present (sap wood).		
	From insects	Absent		
Defects	Joints	See Rafter.		
	Ring-shakes	Nothing observed.		
	Twist			
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	30 x 30 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Absent	
		Deformations	Absent	
Other characteristics	The efficient cross section is about 26 x 26 cm. A single group of small knots is visible. The beam is supported by wooden elements which are bearing on the stone vault of the choir (see photos: Knot (rafter – tie beam) South side). These elements should be eliminated, because instead of supporting the element, they may harm the structure.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**

3.12.08	R 10	front end north side	underside to top side inclination 45° (ref. exterior wall)	The test was executed on soft timber on the truss 7. .

Measuring / object data

Measurement no.	: 10	Time	: 13:41:19	Location	: Dome Vercelli
Drilling depth	: 28,54 cm	Avg. curve	: off	Name	: Tie beam
Wood species	: Soft (1)	Diameter	:	Length of cavities	: ---
ID number	: 10	Level	:	Min. width / height	: ---
Advance	: 12,0 cm/min	Direction	: Bottom to top 45°	Start of detecting	: ---
Date	: 03.12.2008	Object species	: Oak	Detect last cavity	: ---



Assessment

From	0,0 cm	to	0,0 cm	:
From	1,0 cm	to	12,0 cm	: moderate condition
From	12,0 cm	to	28,5 cm	: good condition
From	0,0 cm	to	0,0 cm	:
From	0,0 cm	to	0,0 cm	:
From	0,0 cm	to	0,0 cm	:

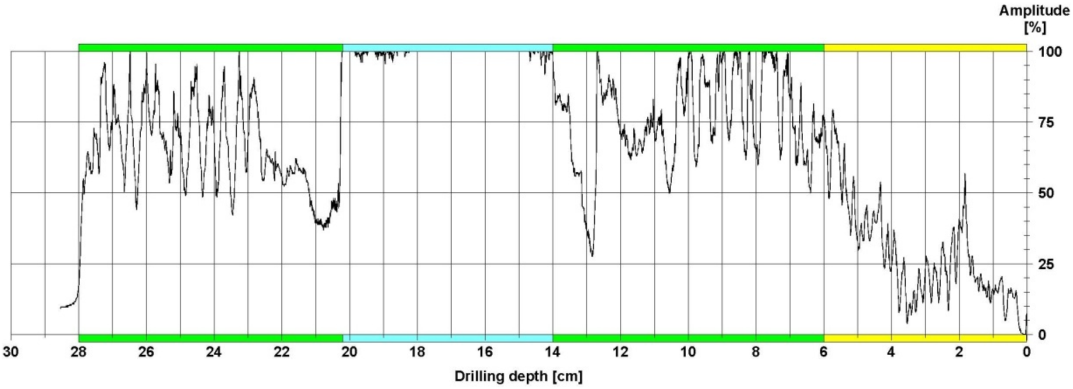
Comment

tu, 3400
Measurement010

3.12.08	R 17	front end south side	underside to top side Inclination 45° (ref. exterior wall)	The test was executed on soft timber on the truss 7. The drill shows the good condition of the tie beam.

Measuring / object data

Measurement no.	: 17	**Time**	: 12:09:05	**Location**	: Dome Vercelli
Drilling depth	: 28,54 cm	**Avg. curve**	: off	**Name**	: Tie beam
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---
Date	: 04.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	to	6,0 cm	:	moderate condition
From	6,0 cm	to	14,0 cm	:	good condition
From	14,0 cm	to	20,2 cm	:	high values
From	20,2 cm	to	28,0 cm	:	good condition
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	

Comment

tu, 3400
Measurement017

Rafter	**North Side**		
Biological decay	From fungi	Fungi is present (sap wood).	
	From insects	Absent	
Defects	Joints	The joint of the truss on the north side (rafter tie beam) is realised in a zone of sapwood. Considering that in this area the sapwood is degraded, the load bearing capacity of this connection is insufficient.	
	Ring-shakes	Nothing observed.	
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	28 x 26 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing observed.
		Deformations	
Other characteristics	The beam is in a moderate condition. Some knots are visible.		

Rafter	**South Side**		
Biological decay	From fungi	Fungi is present (sap wood).	
	From insects	Absent	
Defects	Joints	Looking at the connection (rafter tie beam) on the south side the matched joint doesn't fit: the tie beam bears only on the final end piece.	
	Ring-shakes	Nothing observed.	
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	26 x 26 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing observed.
		Deformations	
Other characteristics	The beam is in a moderate condition. A big single knot is visible.		

King Post		
Biological decay	From fungi	Fungi is present (sap wood).
	From insects	Absent

Defects	Joints	The joint connecting the rafters to the king beam seems to be in a good condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam (no tension forces can be transmitted).	
	Ring-shakes	Nothing observed.	
	Twist		
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	22 x 20 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing observed.
		Deformations	
Other characteristics	The post is not lined up with the tie beam. The horizontal connections joining the king posts with each other caused a displacement of the timber element. The post is in a moderate condition. Some knots are visible.		
PHOTO			
n. Photo	IMG_0692 Truss 7	IMG_0688 Knot (king post – rafter)	
PHOTO			
n. Photo	IMG_0699 Knot (king post – chord member)	IMG_0700 / IMG_0701 Knot (rafter – chord member)	

PHOTO	   	 
n. Photo	IMG_0633 / IMG_0635 / IMG_0697 / IMG_0663 Knot (rafter – tie beam) South side	IMG_0661 / IMG_0662 Knot (rafter – tie beam) Nord side

Main Aisle

1 main aisle trusses

2 main ailse umbrella structure

What was analysed?

The 7 trusses of the main aisle have been analyzed especially the tie beams, the king post and the rafters. The free span between the external walls is about 15,5m. Often the size of the cross section varies over the length of the structural elements. The cross section of the primary structural elements is mainly 30 x 30 cm or smaller

The chord members have not been classified, because some of them miss entirely, others have been substituted recently and a visual inspection seemed to be sufficient.

All of these elements are made of an entire tree trunk, which has been brought into their square form with an axe, some newer elements (mainly parts of secondary or third order) have already been sawn. As in the choir, the king post has been done with less attention than the other construction elements. Maybe because the element is over dimensioned and was therefore done by a student or with less attention.

Of course only the uncovered parts have been analysed. This means that none of the points of support have been analysed because they have not been visible during the inspection. The bottom chord has been examined on 4 sides. The top cords have been inspected on 3 sides. The upper part of the beam hasn't been taken into consideration, because it was not directly visible. The king post has been checked on 4 sides.

Used methods

The same standards as in the choir have been used to classify the timberstructure in the main aisle.

The standard: UNI 11119 (*Beni culturali – Manufatti lignei – Strutture portanti degli edifici – Ispezioni in situ per la valutazione dello stato di conservazione e la stima delle prestazioni degli elementi in opera*) includes the operative methods to classify a timber structure and was used to categorise the resistance of the roof structure of the Dome of Vercelli.

Additionally to a visual inspection on the 12th December 2008, special tools were used. The instrumental inspection to determinate the resistance of the beams was accomplished by a Resistograph and to measure the wood moisture content a Pin-type meter was used. The following inspections 2009 were only visual inspections often under bad lighting conditions. Regarding the results the view surveys have to be considered. To get detailed information about the conditions further expert's surveys are necessary.

General state of conservation

The heads of the beams on the south side are generally in a better condition, mainly because they are better ventilated in the external wall.

The king posts are better lined up with the tie beams than in the choir, mainly because they the forces aren't transmitted directly and the beams do not have to deal with big movements. The horizontal connections, which are present in the other aisle and which connect one king post with the next, are missing.

The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king post), are very interesting (unusual).

The doubled chord members (4 instead of the normal two for every truss) are connected with the king post with a face staggered joint system (tenon - mortise) and the joint with the rafter is done with the help with the con with an external screw and a supporting wooden element on which helps to maintain the chord member in the right angle (position).

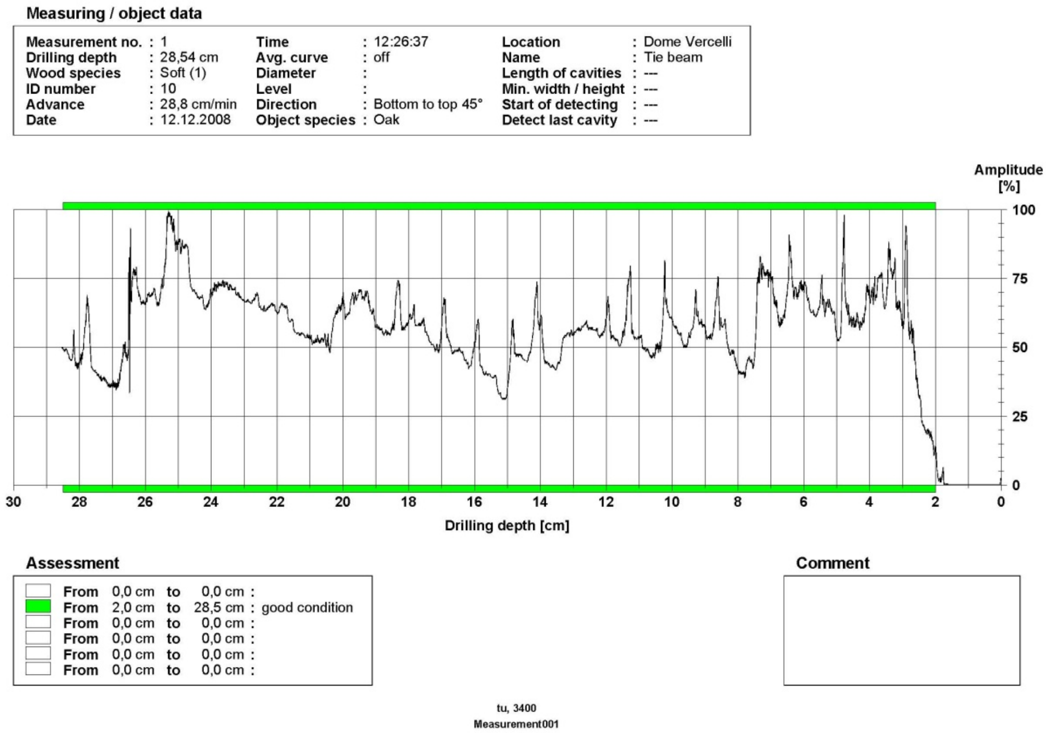
On the truss 6 a chord member is missing it would be useful to reconstruct it to ensure the symmetry of the structure.

Description of every single element

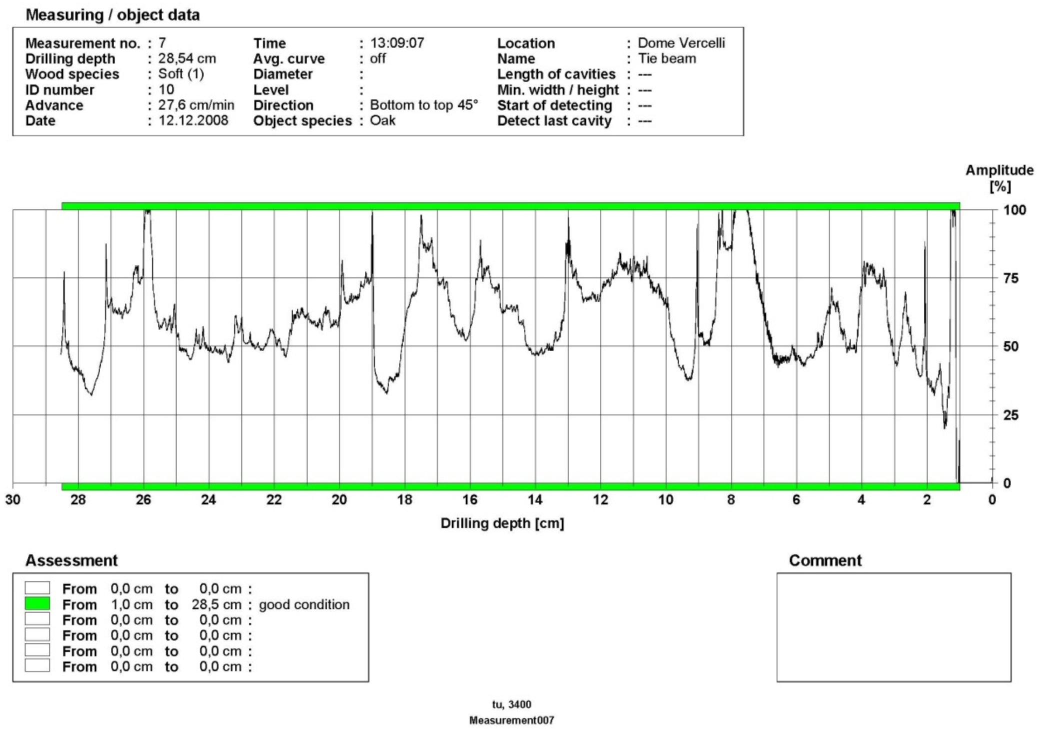
Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 1**	**Main aisle**		
Tie-beam				
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.		
	From insects	Absent		
Defects	Joints	**The joint on the south side is in a better condition, mainly because it is better ventilated in the external wall. On the lower part of the rafter next to the baring on the wall the element (south side) is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated.**		
	Ring-shakes	No signs (absent)		
	Twist	No signs (absent)		
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	30 x 30 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Slight wane and deviation of the fibre direction	
		Deformations	Slightly deformed (knots)	
Other characteristics	The tie beam seams slightly curved, has knots and shows deviation of the fibre. A former Intervention has been done to support the beam. (Small wood piece nailed on the tie beam) The final part of the beam seems to plunge and there is a fracture which does not continue up to the bearing of the wall. - Necessary intervention: next to the bearing on the wall the tie beam should be hardened.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
12.12.08	R 1	front end north side	-	The test was executed on soft timber on the truss 1. The drill shows the good condition of the structural element. - Necessary intervention: The bearing has to be freed from the material (stones), which have been added at a later moment, to ensure the ventilation.



12.12.08	R 7	front end south side	-	The test was executed on soft timber on the truss 1. The drill shows the good condition of the structural element.



Rafter	**North Side**	
Biological decay	From fungi	Fungi may has been present in the superficial part of the element.
	From insects	Absent
Defects	Joints	The bearing has to be freed from the material (stones), which have been added at a later moment, to ensure the ventilation.
	Ring-shakes	No signs (absent)

	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing found
		Deformations	
Other characteristics	Knots, but generally in a good condition		
Rafter	**South Side**		
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	**Good condition: The joint on the south side is in a better condition, mainly because it is better ventilated in the external wall.**	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Slight wane
		Deformations	
Other characteristics	**On the lower part of the rafter next to the baring on the wall the element is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated.**		
King Post			
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a moderate condition. The two fragile metal elements which are positioned on two sides to reinforce the connection are very interesting (unusual). The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted). The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king beam), are very interesting (unusual).	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	35 x 25 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	No signs (absent)
		Deformations	
Other characteristics	The upper part of the post may have suffered because of water infiltrations.		

PHOTO		 
n. Photo	IMG_0478 Truss 1	IMG_0482 / IMG_0486 Knot (king post – rafter)
PHOTO	 	 
n. Photo	IMG_0485 / IMG_ 0487 Knot (king post – chord member)	IMG_0490 / IMG_0491 Knot (rafter – chord member)

PHOTO	 	 
n. Photo	IMG_7397 / IMG_7398 Knot (rafter – tie beam) South side	IMG_7410/ IMG_7433 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 2**	**Main aisle**	
Tie-beam			
Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints	Weak on the north side (intervention necessary)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	30 x 25 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Slightly deviation of the fibre direction
		Deformations	Slightly deformed
Other characteristics	The truss shows more buckling than truss one. On the south side the tie beam is divided into two elements and joined with a bar which is fixed on the inferior part of the beam with three spanner nuts. According to the executed tests no particular problems have been found (no drills accomplished)		
Rafter	**North Side**		
Biological decay	From fungi	Fungi is present in the superficial part of the element.	
	From insects	Absent	
Defects	Joints	Moderate (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	

	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	The joint is ventilated and the timber elements fit perfectly into each other so that the forces can flow easily threw the wooden beams, over a timber element (important for the ventilation), into the wall. This is the reason why the whole timber structure is in a perfect condition (joint tie beam-rafter).		
Rafter	**South Side**		
Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints	**Moderate (connection tie beam) Better (connection king beam) The heads of the beams on the south side are generally in a better condition, mainly because they are better ventilated in the external wall.**	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	**On the lower part of the rafter next to the baring on the wall the element is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated.** The final part of the beam seems to plunge and there is a fracture which does not continue up to the bearing of the wall. - Necessary intervention: next to the bearing on the wall the tie beam should be hardened.		
King Post			
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a moderate condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted). The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king post), are very interesting (unusual).	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	33 x 25 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	Knots and wane, but generally in a moderate condition		
PHOTO	 		

n. Photo	IMG_0509 Truss 2	IMG_7405 Knot (king post – rafter)
PHOTO		
n. Photo	IMG_7402 / IMG_ 7431 Knot (king post – chord member)	IMG_0513 / IMG_0514 Knot (rafter – chord member)
PHOTO		
n. Photo	IMG_0510 / IMG_0511 Knot (rafter – tie beam) South side	IMG_4736/ IMG_0515 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

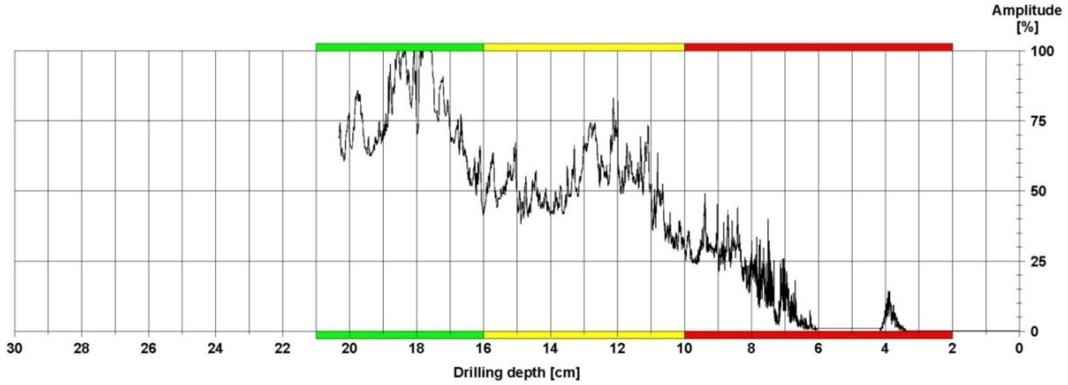
IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 3**	**Main aisle**		
Tie-beam				
Biological decay	From fungi	Rot is present.		
	From insects	Holes		
Defects	Joints	Moderate to Weak (intervention necessary)		
	Ring-shakes	No signs (absent)		
	Twist	No signs (absent)		
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	30 x 28 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Wane and deviation of the fibre direction	
		Deformations	Slightly deformed	
Other characteristics	A huge knot which has already fallen out is reducing the effective cross section of the timber element significantly (6-8cm). On the north side: At the inner parts of the tie beam buckling and flattening is visible. The degradation occurred because of water infiltrations at the dormer (roof light). About 1900 the beam has already been supported. A cotter in combination with metal pieces helped to ensure the stability of the structure. Further a strut has been added in between the bottom and top chord of the truss.			

Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
12.12.08	R 2	front end north side	underside to top side inclination 45° (ref. exterior wall)	Drill 2 (okay in the central part) the first part doesn't result, because the sap wood is missing in some parts.

Measuring / object data

Measurement no.	: 2	Time	: 12:33:23	Location	: Dome Vercelli
Drilling depth	: 20,32 cm	Avg. curve	: off	Name	: Tie beam
Wood species	: Soft (1)	Diameter	:	Length of cavities	: ---
ID number	: 10	Level	:	Min. width / height	: ---
Advance	: 14,4 cm/min	Direction	: Bottom to top	Start of detecting	: ---
Date	: 12.12.2008	Object species	: Oak	Detect last cavity	: ---



Assessment

From	0,0 cm	to	0,0 cm	:	
From	2,0 cm	to	10,0 cm	:	weak
From	10,0 cm	to	16,0 cm	:	moderate conditions
From	16,0 cm	to	21,0 cm	:	good conditions
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	

Comment

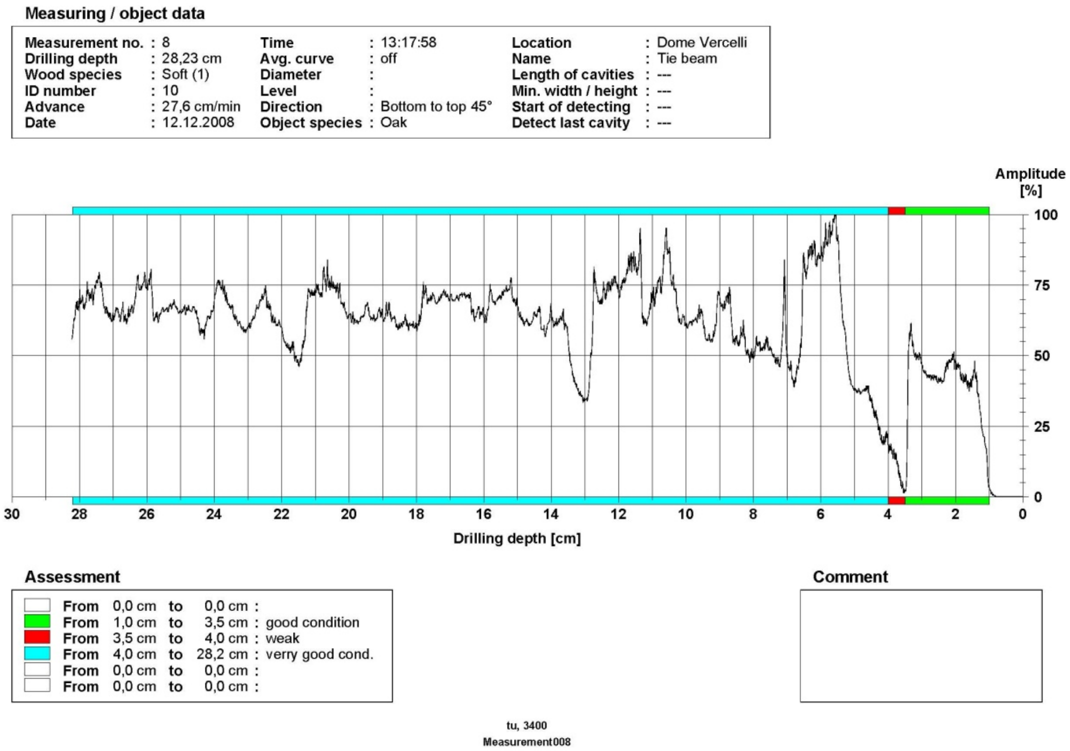
tu, 3400
Measurement002

Rafter	**North Side**		
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	Weak (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	35 x 35 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing found
		Deformations	
Other characteristics	The rafter has been brought into place with two stacked wooden elements to maintain the original roof inclination. Necessary intervention: Introduce two collateral supporting elements		

Rafter	**South Side**		
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	**The joint tie beam rafter on the south side is in a better condition, but water infiltrations weakened the connection as well.**	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	35 x 35 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane and deformation
		Deformations	
Other characteristics	**On the lower part of the rafter next to the baring on the wall the element is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated.** The final part of the beam seems to plunge and there is a fracture which does not continue up to the bearing of the wall. - Necessary intervention: next to the bearing on the wall the tie beam should be hardened.		

Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**

12.12.08	R 8	front end north side	underside to top side inclination 45° (ref. exterior wall)	The test was executed on firm timber. It shows the perfect condition of the timber element.



King Post			
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a moderate condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted). The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king post), are very interesting (unusual).	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	26 x 23 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	The post isn't perfectly lined up with the tie beam. The upper part of the post seams slightly wet. Knots and wane, but the post is generally in a moderate condition.		

PHOTO		
n. Photo	IMG_0517 Truss 3	IMG_0522 Knot (king post – rafter)
PHOTO		
n. Photo	IMG_0520 Knot (king post – chord member)	IMG_0521 / IMG_0523 Knot (rafter – chord member)

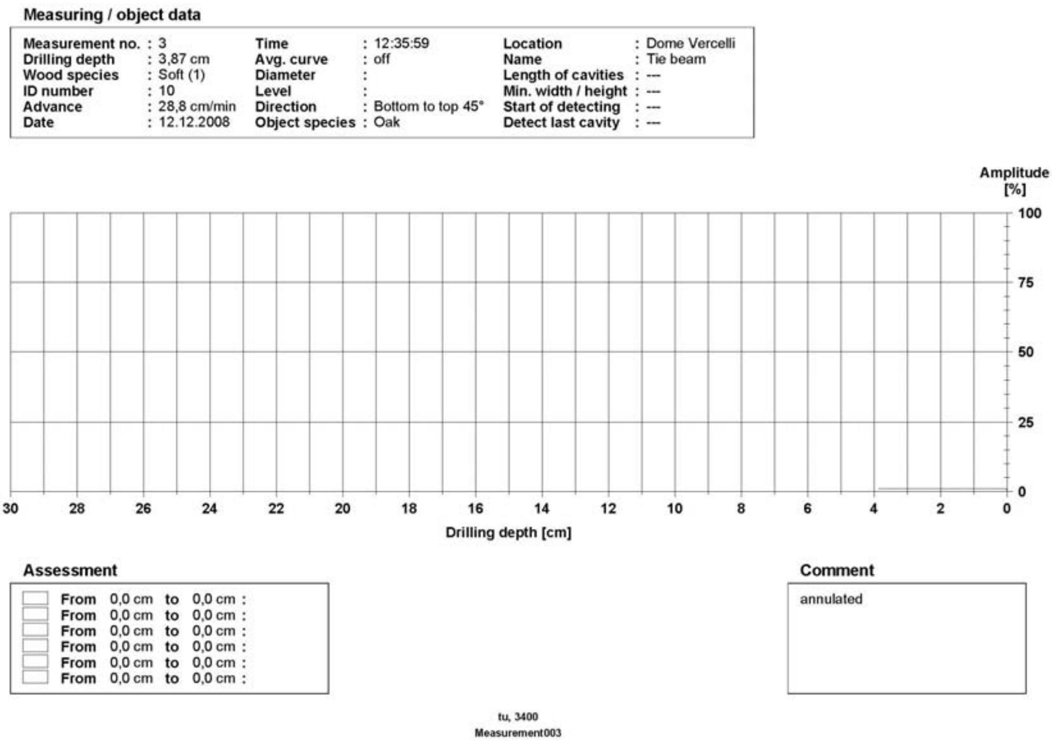
PHOTO	

n. Photo	IMG_0518 / IMG_0519 Knot (rafter – tie beam) South side	IMG_0525/ IMG_0524 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

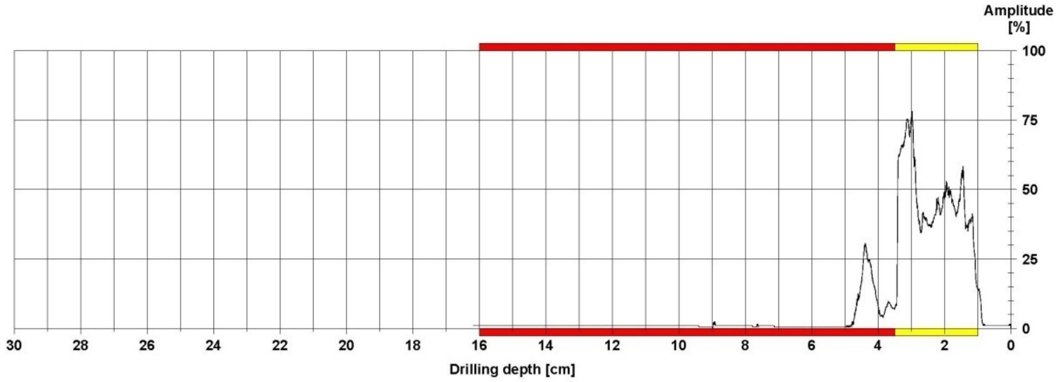
Truss	**N. 4**	**Main aisle**		
Tie-beam				
Biological decay	From fungi	Fungi was present (Not active). It interests the superficial part of the element for about 1cm depth on each side.		
	From insects	Have been present before the tree has been cut. Now not active.		
Defects	Joints	Moderate (intervention necessary)		
	Ring-shakes	No signs (absent)		
	Twist	deviation of the fibre direction		
Wooden species	Oak			
Moisture content	High			
Average dimensions of the element	29 x 28 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Wane and deviation of the fibre direction	
		Deformations	Slightly deformed	
Other characteristics	Two chord members are missing. Knots and the weak condition of the beam is reducing the efficient cross section significantly (6 to7 cm).			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
12.12.08	R 3	front end north side	-	The test had to be annulated because of the weak conditions of the timber element.



12.12.08	R 4	front end south side	underside to top side Inclination 45° (ref. exterior wall)	The test was executed on soft timber on the trus s4. The drill shows the insufficient situation and the bad condition. - Necessary intervention: Reconstruction of the head of the tie beam and the introduction of two collateral supporting elements on the rafter.

Measuring / object data

Measurement no.	4	Time	12:37:38	Location	Dome Vercelli
Drilling depth	16,20 cm	Avg. curve	off	Name	Tie beam
Wood species	Soft (1)	Diameter		Length of cavities	---
ID number	10	Level		Min. width / height	---
Advance	28,8 cm/min	Direction	Bottom to top	Start of detecting	---
Date	12.12.2008	Object species	Oak	Detect last cavity	---



Assessment

From	0,0 cm	to	0,0 cm	:	
From	1,0 cm	to	3,5 cm	:	moderate condition
From	3,5 cm	to	16,0 cm	:	insufficient
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	

Comment

tu, 3400
Measurement004

Rafter	**North Side**		
Biological decay	From fungi	Fungi is present in the superficial part of the element.	
	From insects	Absent	
Defects	Joints	The joint is in a weak condition. (further intervention)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	There is a big problem at the head of the beam with obvious signs of degradation and weakness of the material. The end of the beam has already been supported in the past. An antic method has been chosen to do the reinforcement. To support the construction between rafter and tie beam a wooden triangular piece has been introduced and two slim and long metal pieces ensure the connection between rafter and tie beam.		

Rafter	**South Side**		
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	Moderate (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane, knots
		Deformations	

Other characteristics	On the lower part of the rafter next to the baring on the wall the element is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated. The final part of the beam seems to plunge and there is a fracture which does not continue up to the bearing of the wall. - Necessary intervention: next to the bearing on the wall the tie beam should be hardened.		
King Post			
Biological decay	From fungi	Present in the part inside the masonry. Discolouration	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a moderate condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted). The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king post), are very interesting (unusual).	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	20 x 30 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	Knots and wane, but generally in a moderate condition		
PHOTO			
n. Photo	IMG_0535 Knot (king post – chord member)	IMG_0536 Knot (king post – rafter)	

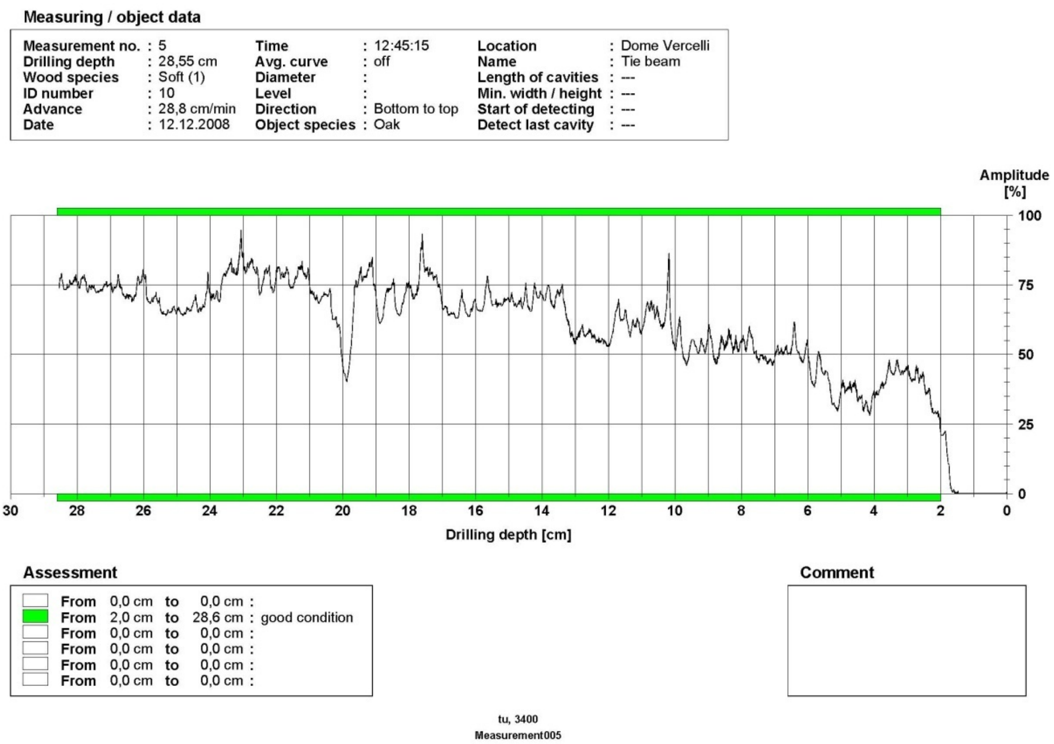
PHOTO		
n. Photo	IMG_7426 Truss 4	IMG_0534 / IMG_04537 Knot (rafter – chord member)
PHOTO		
n. Photo	IMG_0538 Knot (rafter – tie beam) South side	IMG_0527/ IMG_0533 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE

Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 5**		**Main aisle**	
Tie-beam				
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.		
	From insects	Absent		
Defects	Joints	moderate , (former intervention at the joint tie beam- king post)		
	Ring-shakes	No signs (absent)		
	Twist	deviation of the fibre direction		
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	32 x 33 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	Wane	
		Deformations	Slightly curved	
Other characteristics	The tie beam is supported by various struts, which bear on the cupola.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**
12.12.08	R 5	front end north side	underside to top side inclination 45° (ref. exterior wall)	The drill shows the good conditions of the timber element.



Rafter	**North Side**	
Biological decay	From fungi	Fungi is present in the superficial part of the element.
	From insects	Absent
Defects	Joints	Weak (connection tie beam) Better (connection king beam)
	Ring-shakes	No signs (absent)

	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	35 x 35 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Nothing found
		Deformations	
Other characteristics	Knots, but generally in a good condition		
Rafter	**South Side**		
Biological decay	From fungi	Present in the part inside the masonry.	
	From insects	Absent	
Defects	Joints	Moderate (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	35 x 35 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	On the lower part of the rafter next to the baring on the wall the element is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated. The final part of the beam seems to plunge and there is a fracture which does not continue up to the bearing of the wall. - Necessary intervention: next to the bearing on the wall the tie beam should be hardened.		
King Post			
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a moderate condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted). That for two timber pieces have been placed on each side of the post (connecting the post with the tie-beam) to maintain it in the right position and to transmit loads. The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king post), are very interesting (unusual).	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	26 x 23 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane, slightly curved
		Deformations	
Other characteristics	generally in a moderate condition		
PHOTO			
n. Photo	IMG_7424 Truss 5	IMG_0544 Knot (king post – rafter)	

PHOTO		
n. Photo	IMG_7425 Knot (king post – chord member)	IMG_0543 / IMG_0545 Knot (rafter – chord member)
PHOTO		
n. Photo	IMG_7440 Knot (rafter – tie beam) South side	IMG_7414 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 6**	**Main aisle**
Tie-beam		
Biological decay	From fungi	Absent
	From insects	Absent
Defects	Joints	Moderate – good condition

	Ring-shakes	No signs (absent)	
	Twist	deviation of the fibre direction	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	30 x 29 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane and deviation of the fibre direction
		Deformations	Absent
Other characteristics	On the truss 6 a chord member is missing it would be useful to reconstruct it to ensure the symmetry of the structure. The tie beam is supported by various struts, which bear on the cupola.		
Rafter	**North Side**		
Biological decay	From fungi	Absent	
	From insects	Absent	
Defects	Joints	Moderate (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	Knots, but generally in a good condition		
Rafter	**South Side**		
Biological decay	From fungi	Fungi is present in the superficial part of the element.	
	From insects	Absent	
Defects	Joints	Moderate- good (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	On the lower part of the rafter next to the baring on the wall the element is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated. The final part of the beam seems to plunge and there is a fracture which does not continue up to the bearing of the wall. - Necessary intervention: next to the bearing on the wall the tie beam should be hardened.		
King Post			
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king post-rafter), are very interesting (unusual). The connection between the tie beam and the post hasn´t been working anymore, that fore two timber pieces have been placed on each side of the post (connecting the post with the tie-beam) to maintain it in the right position and to transmit loads.	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	20 x 22 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	generally in a moderate condition		

PHOTO		
n. Photo	IMG_7422 Truss 6	IMG_0552 Knot (king post – rafter)
PHOTO		
n. Photo	IMG_0550 Knot (king post – chord member)	IMG_0554 / IMG_0551 Knot (rafter – chord member)

PHOTO		
n. Photo	IMG_7441 / IMG_7423 Knot (rafter – tie beam) South side	IMG_7415/ IMG_7420 Knot (rafter – tie beam) Nord side

Diagnosis of the timber joints rafter/ tie-beam /chord member

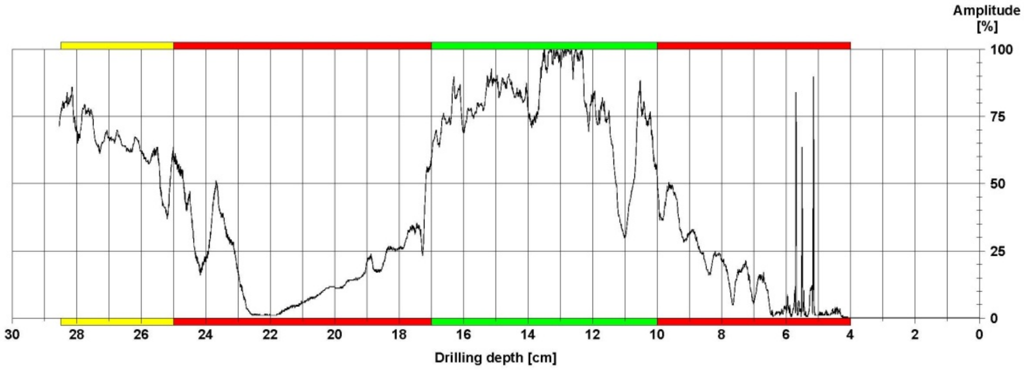
IDENTIFICATION DATA OF THE STRUCTURE	
Date of inspection	3rd/4th /12th Dec. 08, 6th/9th Mar. 09, 6th/12th May 09
Place	Vercelli - Italy
Site	Dome Vercelli
Team	Prof. Clara Bertolini Cestari (Co-ordinatore), Arch. Gianoreste Biglione, Dott. Alan Crivellaro (CNR-IVALSA), Luciana Cestari (restauratrice), DI. Pia Panosch, Arch. Daniele De Luca
	Evaluation of the conservation state of the wooden material and of timber joints

Truss	**N. 7**	**Main aisle**		
Tie-beam				
Biological decay	From fungi	No active fungi is visible.		
	From insects	Absent		
Defects	Joints	Weak (intervention necessary)		
	Ring-shakes	No signs (absent)		
	Twist	deviation of the fibre direction		
Wooden species	Oak			
Moisture content	According to the surrounding air about 16%			
Average dimensions of the element	25 x 25 cm			
	Section	Rectangular		
	Geometric peculiarity	Wane	deviation of the fibre direction	
		Deformations	Slightly deformed	
Other characteristics	The drilling test confirmed the problem on the frontend of the truss, the element sagged severely and the part where the rafter should transmit the load to the structure doesn't bear mainly on the beam but on the exterior wall. On the north side: Necessary interventions: replacement of the head of the tie beam. Furthermore until such time as the definite intervention takes place, it would be very useful to protect the truss with a guard without stressing the construction, but only to prevent further descent of the truss. On the south side: Necessary intervention: next to the bearing on the wall the tie beam should be hardened.			
Resistographic profiles				
Data	**Profile N°**	**from**	**Direction**	**Observations**

12.12.08	R 6	front end north side	underside to top side inclination 45° (ref. exterior wall)	Drill 6 (insufficient – bad condition) There are high values for 2 cm around the 13th cm. This doesn't influence the result significantly.

Measuring / object data

Measurement no.	: 6	**Time**	: 12:51:25	**Location**	: Dome Vercelli		
Drilling depth	: 28,55 cm	**Avg. curve**	: off	**Name**	: Tie beam		
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---		
ID number	: 10	**Level**	:	**Min. width / height**	: ---		
Advance	: 28,8 cm/min	**Direction**	: Bottom to top 45°	**Start of detecting**	: ---		
Date	: 12.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---		



Assessment

From	0,0 cm	to	0,0 cm	:	
From	4,0 cm	to	10,0 cm	:	weak
From	10,0 cm	to	17,0 cm	:	good condition
From	17,0 cm	to	25,0 cm	:	weak
From	25,0 cm	to	28,5 cm	:	moderate condition
From	0,0 cm	to	0,0 cm	:	

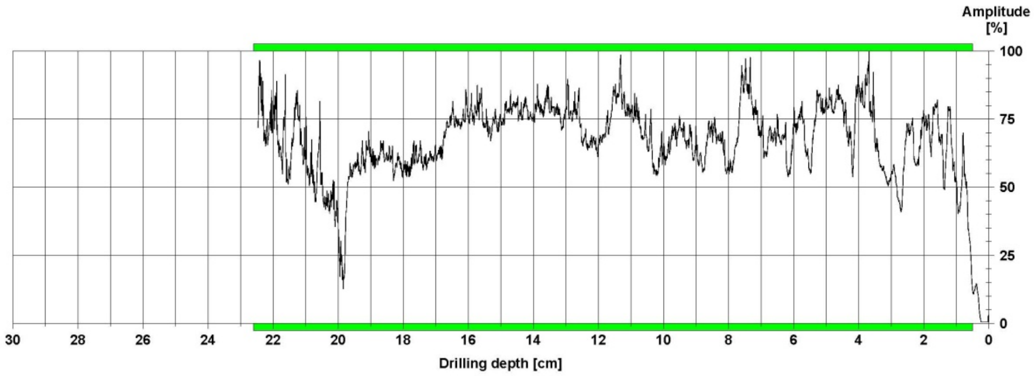
Comment

tu, 3400
Measurement006

12.12.08	R 9	front end south side	underside to top side Inclination 45° (ref. exterior wall)	The test was executed on soft timber on the truss 7. The drill 9 shows that after the weakened bearing the element is in good conditions.

Measuring / object data

Measurement no.	: 9	**Time**	: 13:28:04	**Location**	: Dome Vercelli
Drilling depth	: 22,47 cm	**Avg. curve**	: off	**Name**	:
Wood species	: Soft (1)	**Diameter**	:	**Length of cavities**	: ---
ID number	: 10	**Level**	:	**Min. width / height**	: ---
Advance	: 27,6 cm/min	**Direction**	:	**Start of detecting**	: ---
Date	: 12.12.2008	**Object species**	: Oak	**Detect last cavity**	: ---



Assessment

From	0,0 cm	to	0,0 cm	:	
From	0,5 cm	to	22,6 cm	:	good condition
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	
From	0,0 cm	to	0,0 cm	:	

Comment

tu, 3400
Measurement009

Rafter	**North Side**

Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	Weak (connection tie beam) previous intervention Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	No problem found		
Rafter	**South Side**		
Biological decay	From fungi	No active fungi is visible. Some biological attack may have caused de-colourations.	
	From insects	Absent	
Defects	Joints	Weak (connection tie beam) Better (connection king beam)	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	34 x 34 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	On the lower part of the rafter next to the baring on the wall the element is drenched from constant water infiltrations. It is not a major problem because the area is well ventilated. The final part of the beam seems to plunge and there is a fracture which does not continue up to the bearing of the wall.		
King Post			
Biological decay	From fungi	Some biological attack has caused de-colourations.	
	From insects	Absent	
Defects	Joints	The connection with the rafters seems to be in a moderate condition. The metal connection with the tie beam doesn't work anymore. The metal lengthened and doesn't support the tie beam anymore (no tension forces can be transmitted).	
	Ring-shakes	No signs (absent)	
	Twist	No signs (absent)	
Wooden species	Oak		
Moisture content	According to the surrounding air about 16%		
Average dimensions of the element	25 x 20 cm		
	Section	Rectangular	
	Geometric peculiarity	Wane	Wane
		Deformations	
Other characteristics	Knots and wane, but generally in a moderate condition		
PHOTO			

n. Photo	IMG_7417 Truss 7	IMG_0561 Knot (king post – rafter)
PHOTO		 
n. Photo	IMG_0553 Knot (king post – chord member)	IMG_0560/ IMG_0562 Knot (rafter – chord member)
PHOTO		 
n. Photo	IMG_7442 Knot (rafter – tie beam) South side	IMG_0564 Knot (rafter – tie beam) Nord side

The heads of the beams on the south side are generally in a better condition, mainly because they are better ventilated in the external wall.

The king posts are better lined up with the tie beams than in the choir, mainly because they the forces aren't transmitted directly and the posts do not have to deal with big movements. The horizontal connections, which are present in the other aisle and which connect one king post with the next, are missing.

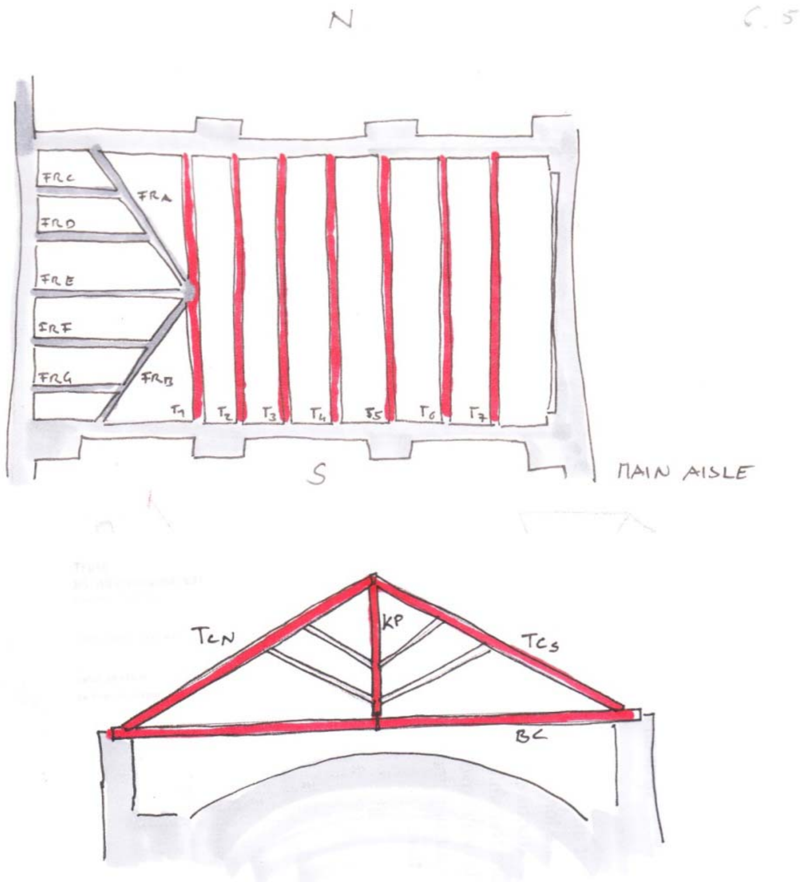
The two fragile metal elements which are positioned on two sides to reinforce the connection between the two rafters (joint king post), are very interesting (unusual).

The doubled chord members (4 instead of the normal two for every truss) are connected with the king post with a face staggered joint system (tenon - mortise) and the joint with the rafter is done with the help with the con with an external screw and a supporting wooden element on which helps to maintain the chord member in the right angle (position).

On the truss 6 a chord member is missing it would be useful to reconstruct it to ensure the symmetry of the structure.

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.1 Appendix, data of the maximal tensile force of oak) categorised.
For the classification only the visible parts were taken into consideration. The hidden areas (wall- bottom chord, top chord) have not been analysed. (see point 4.7.1. What was analysed?)



sketch 27

Table 1. Results of the resistance qualification for the examined timber elements of the trusses.

Identification		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Efficient Cross-section b x h [cm]	Category according UNI 11119
T1*	Bc1	30 x 30	\	Slightly curved at the south end, wane and deviation of the grain direction	Bearing north side has to be freed	=	//
	Tc N-1	35 x 35	\	Knot, deviation of the fibre	\	=	II
	Tc S-1	35 x 35	\	Slight wane	constant water infiltrations	=	II
	KP-1	35 x 25	\	\	Fungi, water infiltrations	=	III
	W-1n1	18 x 15	\	\	\	=	N.V.
	W-1n2	\	\	\	\	\	\
	W-1s1	16 x 15	\	Slightly curved	\	=	N.V.
	W-1s2	\	\	\	\	\	\

T2*	Bc -2	30 x 25	\	Buckling, Single deviation of the grain direction, slightly deformed	South side former intervention	=	//
	Tc N-2	35 x 35	\	Slight wane Timber piece added on rafter to change slop of roof	\	=	//
	Tc S-2	35 x 35	\	Slight wane	constant water infiltrations	=	//
	KP-2	33 x 25	\	Wane and knots	\	=	///
	W-2n1	17 x 16	\	Knots	\	=	N.V.
	W-2n2	\	\	\	\	\	\
	W-2s1	15 x 15	\	\	\	=	N.V.
	W-2s2	\	\	\	\	\	\
T3*	Bc -3	30 x 28	\	Big single knot in the middle of the beam, deviation of the grain direction, buckling, flattening	Rot	Not determinable	N.I.
	Tc N-3	35 x 35	\	Knots, Single deviation of the grain direction Timber piece added on rafter to change slop of roof	Intervention 19th cent. fungi	=	III
	Tc S-3	35 x 35	\	Knot and wane Timber piece added on rafter to change slop of roof	\	=	II
	KP-3	26 x 23	\	Displacement, Knot and wane	\	=	II
	W-3n1	14 x 15	\	\	\	=	N.V.
	W-3n2	12 x 10	\	new	\	=	N.V.
	W-3s1	15 x 13	\	\	\	=	N.V.
	W-3s2	13 x 13	\	\	\	=	N.V.
T4*	Bc -4	29 x 28	\	Knots, wane, rot	Extremely bad conditions especially on the north side ev. Insect attack	Not determinable	N.I.
	Tc N-4	35 x 35	> 30%	degradation and weakness near bearing Timber piece added on rafter to change slop of roof	Previous intervention	30 x 30	N.I.
	Tc S-4	35 x 35	\	Wane Timber piece added on rafter to change slop of roof	constant water infiltrations	=	III
	KP-4	20 x 30	\	Knot and wane	Discoloration (fungi)	=	III
	W-4n1	18 x 15	\	Single deviation of the grain direction	\	=	II
	W-4n2	\	\	\	\	\	\
	W-4s1	20 x 16	\	Knot	\	=	N.V.
	W-4s2	\	\	\	\	\	\
T5*	Bc -5	32 x 33	\	small knots, Single deviation of the grain direction	\	=	N.V.
	Tc N-5	35 x 35	\	Knot and wane Timber piece added on rafter to change slop of roof	\	=	II
	Tc S-5	35 x 35		Knot and wane Timber piece added on rafter to change slop of roof	\	=	II
	KP-5	26 x 25	\	Curved	Discoloration (fungi) Intervention(king post -tie beam)	=	III

	W-5n1	13 x 15	\	\	\	=	II
	W-5n2	10 x 10	\	\	\	=	II
	W-5s1	16 x 14	\	wane	\	=	N.V.
	W-5s2	10 x 10	\	new	\	=	N.V.
T6*	Bc -6	30 x 29	\	Deviation of the fibre, knots	\	=	III
	Tc N-6	35 x 35	\	Knot and wane Timber piece added on rafter to change slop of roof	Discoloration (fungi)	=	II
	Tc S-6	35 x 35	\	Knots and wane Timber piece added on rafter to change slop of roof	\	=	II
	KP-6	20 x 22	\	Knot and wane, slightly curved	Intervention(king post -tie beam)	=	II
	W-6n1	16 x 16	\	\	\	=	N.V.
	W-6n2	\	\	\	\	\	\
	W-6s1	16 x 12	\	\	\	=	N.V.
	W-6s2	10 x 10	\	\	\	=	N.V.
T7*	Bc -7	25 x 25	wet	Deviation of the grain direction	\	=	III
	Tc N-7	35 x 35	\	Buckling, knots Timber piece added on rafter to change slop of roof (extream)	Discoloration (fungi)	=	III
	Tc S-7	35 x 35	\	Single knot Timber piece added on rafter to change slop of roof	Discoloration (fungi)	=	III
	KP-7	33 x 25	wet	Knots	Discoloration (fungi)	=	II
	W-7n1	15 x 13	\	\	\	=	N.V.
	W-7n2	\	\	\	\	\	\
	W-7s1	16 x 15	\	\	\	=	N.V.
	W-7s2	\	\	\	\	\	\
FR	FR-A	28 x 28	\	\	\	=	II
	FR-B	28 x 28	\	\	\	=	II
	FR-C	22 x 22	\	\	\	=	II
	FR-D	28 x 28	\	\	\	=	II
	FR-E	22 x 22	\	\	\	=	II
	FR-F	21 x 21	\	\	\	=	II
	FR-G	22 x 22	\	\	\	=	II
	FR-G1	22 x 22	\	\	\	=	II
	B	8 x 8	\	heavy degrade	\	=	N.I.
	CB	4 x 4	\	heavy degrade	\	=	N.I.

T= Truss; Bc = bottom chord; Tc = top chord; N = north; S = south; KP=King post; W= web member; FR= False rafter;
B=Battens; CB=Contra-battens.
N. I. = not qualified (adequate); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

Static model RPLAN defects

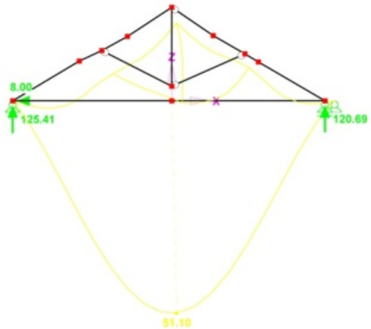
Deformations

Truss1

ERGEBNISSE

LG 4 - summe_lasten_D-C
Verschiebungen
Auflagerreaktionen

In Y-Richtung



Max u: 51.10 mm
Faktor für Verschiebungen: 200

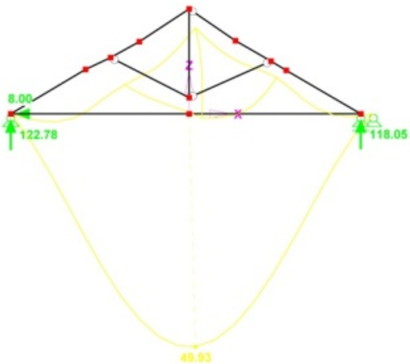
2.747 m

Truss2

ERGEBNISSE

LG 4 - summe_lasten_D-C
Verschiebungen
Auflagerreaktionen

In Y-Richtung



Max u: 49.93 mm
Faktor für Verschiebungen: 200

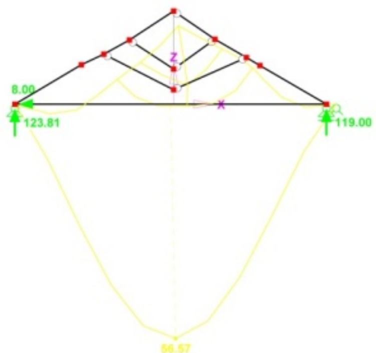
2.703 m

Truss3

ERGEBNISSE

LG 4 - summe_lasten_D-C
Verschiebungen
Auflagerreaktionen

In Y-Richtung



Max u: 56.57 mm
Faktor für Verschiebungen: 200

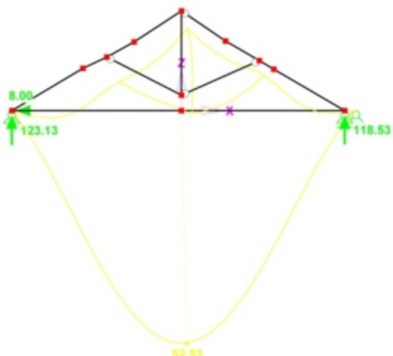
2.951 m

Truss4

ERGEBNISSE

LG 4 - summe_lasten_D-C
Verschiebungen
Auflagerreaktionen

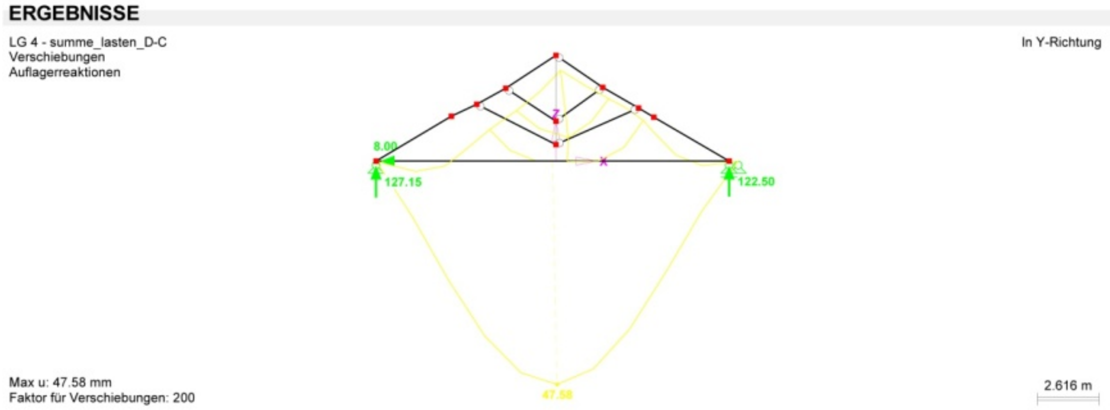
In Y-Richtung



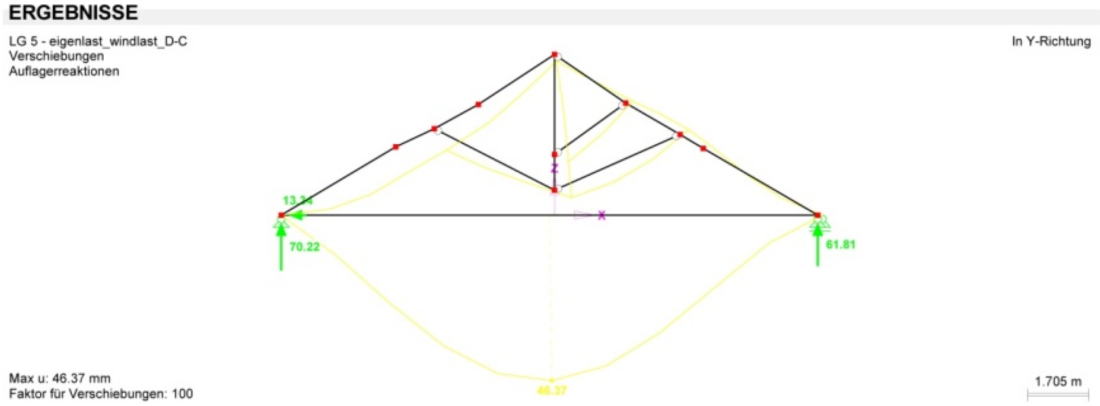
Max u: 52.53 mm
Faktor für Verschiebungen: 200

2.801 m

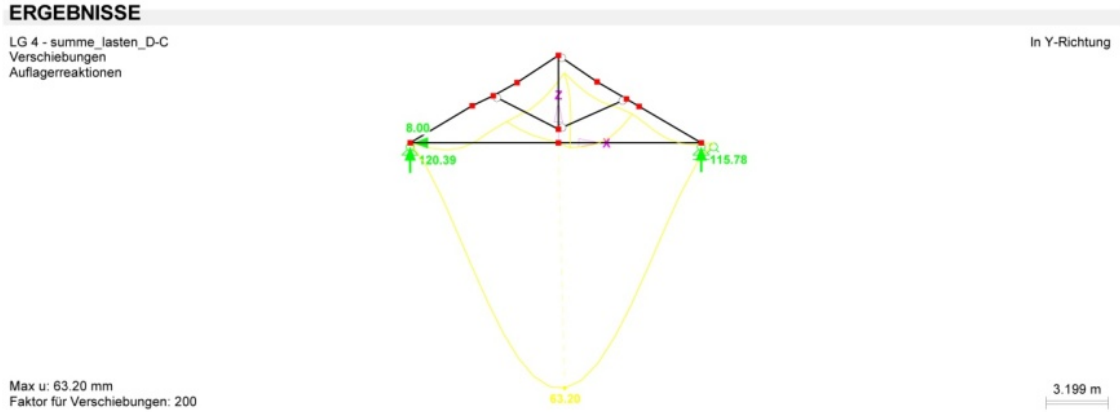
Truss5



Truss6



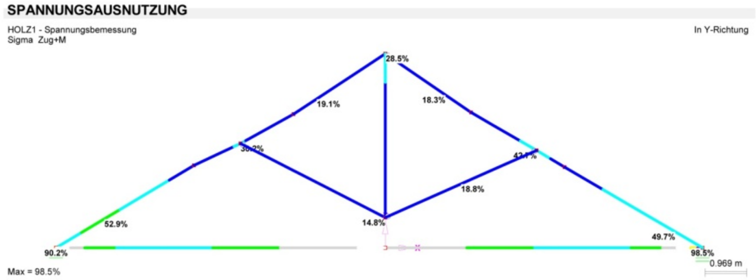
Truss7



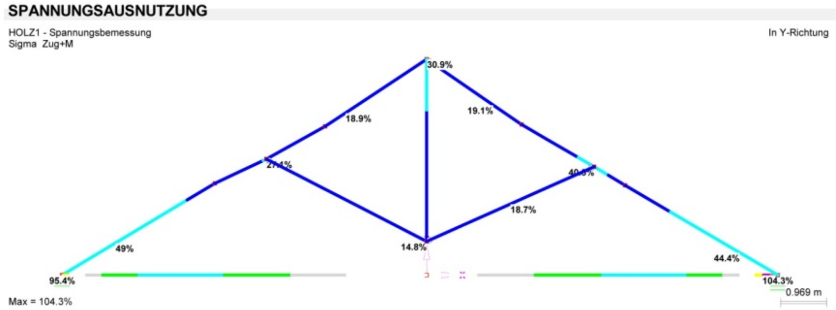
Deformation: 15000mm/300 = 50mm (l/300)
The worsted point is the midpoint of the tie beam. The deformations lay in between 60 to 100 mm!
This is too high. Reason: The metal tension elements connecting the tie beam with the king post do not work anymore. They have to be substituted.

Stress:

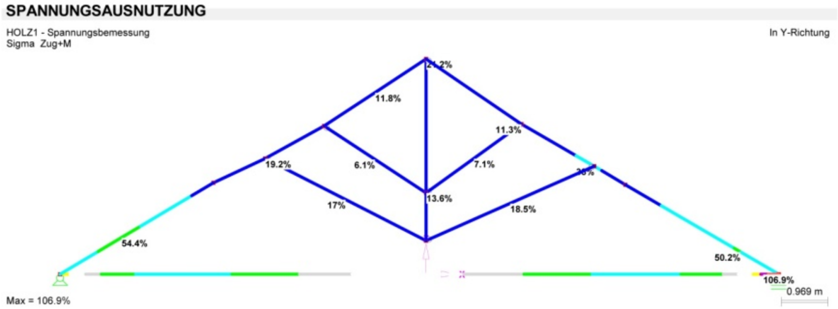
Truss1



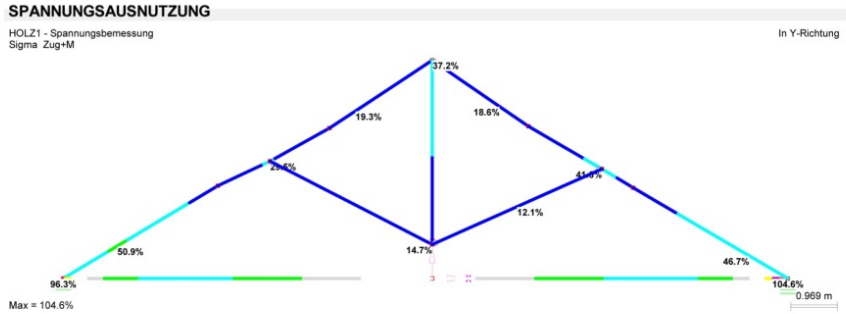
Truss2



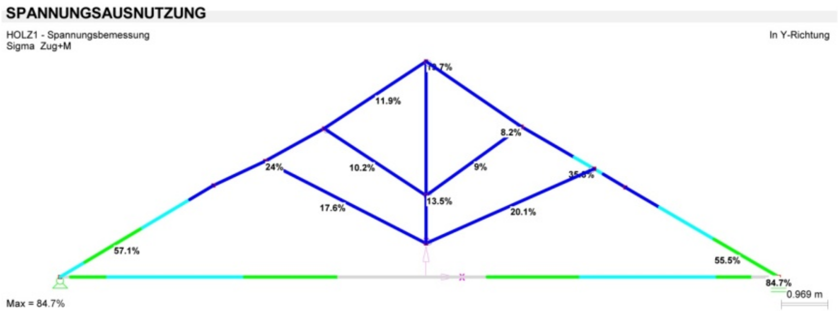
Truss3



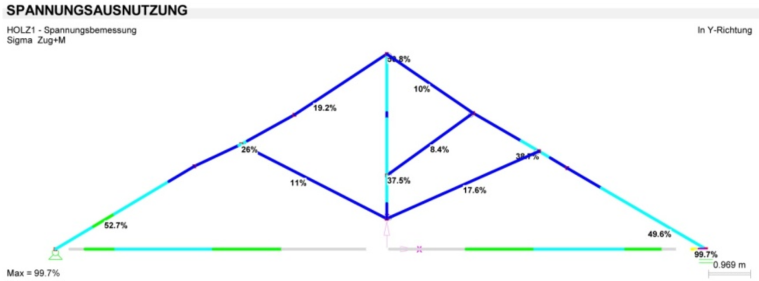
Truss4



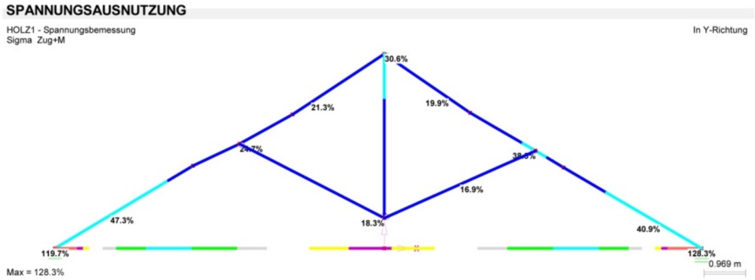
Truss5



Truss6



Truss7



The stress analyses show that the elements seem to be generally in a better condition than in the choir. The maximum values lay in between 98 and 128% of the load capacity.

Aisles left

3

What was analysed?

None of the points of support have been visible during the inspection. The false rafters and the girders have been inspected on 3 sides. The upper parts haven't been taken into consideration, because it was not directly visible. The heads of the girders were visible and could be taken into consideration, but the bearings of the false rafters are in positions difficult to reach and haven't been checked. The web members have been checked on 4 sides.
Added chords with a cross-section smaller than 9x9cm have not been analysed.

Used methods

The standard: UNI 11119 (*Beni culturali – Manufatti lignei – Strutture portanti degli edifici – Ispezioni in situ per la valutazione dello stato di conservazione e la stima delle prestazioni degli elementi in opera*) includes the operative methods to classify the timber structure and was used to categorise the resistance of the roof structure of the Dome of Vercelli.
Additionally to a visual inspection no special tools were used. The visits on the roof often under bad lighting conditions made the inspection difficult.
Additionally, regarding the results the view surveys have to be considered. To get detailed information about the conditions further expert's surveys are necessary. Further instrumental inspection to estimate the presence of decay of the internal part of the beams, accomplished by a Resistograph, and measurements of the wood moisture content with a Pin-type meter would be useful.

General state of conservation

The heads of the rafters couldn't be valued because of their difficult position, but the heads of the girders are generally in a good condition, mainly because they are ventilated, but the beam of the timber structure one has to be checked, because of it's eventually dangerous conditions caused by ring shake.
The rest of the primary and secondary structure seems to be in quite good conditions. The battens are quite degraded and should be changed.

Photos of every single element

T1

4 False rafters

5Main Beam


FR1
FR1
FR1
Side beams
FR2
FR2
FR3
FR3
FR4
FR4
T1
T1

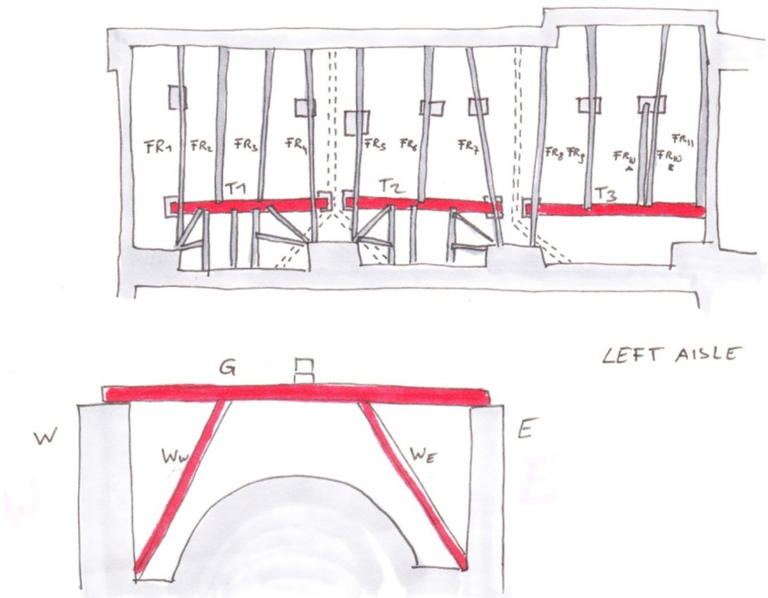

FR5
FR5
FR6
FR6
T2
FR7
FR7
Side beams
T2
T2
Side beams


FR8
FR8
FR8
T3
FR9
FR9
FR9
FR10
T3
T3
T3
Side beams

6

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.2) categorised.
For the classification only the visible parts were taken into consideration. The hidden areas have not been analysed. (see point What was analysed?)



sketch 28

Table 2. Results of the resistance qualification for the examined timber elements of the trusses.

Identification		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Category according UNI 11119
T1*	G 1	32 x 35	\	big knots, ring shake?	\	N. I.
	W E-1	\	\	\	\	\
	W w-1	\	\	\	\	\
T2*	G -2	28 x 30	\	small cracks	\	II
	W E-2	\	\	\	\	\
	W w-2	8 x 12	\	small cracks	Sapwood: fungi attack	II
T3*	G -3	28 x 33	\	heavy degrade, displacement	Sapwood: fungi attack	III
	W E-3	17 x 15	> 30%	big cracks	ev. water infiltration	III
	W w-3	14 x 15	\	small cracks	insect attack	III
T4*	FR 1	26 x 28	> 30%	joint (S) heavy degrade,	fungi (water infiltration)	N. I.
	FR 2	26 x 28	\	big knots	\	II

	FR 3	26 x 28	\	small cracks	\	II
	FR 4	26 x 28	\	big cracks	\	III
	FR 5	35 x 35	\	big knots, small cracks	\	III
	FR 6	36 x 28	\	\	above joint (S) missing tile -> water infiltration	III
	FR 7	30 x 30	\	big knots	\	II
	FR 8	27 x 23	\	small knots	insect attack	III
	FR 9	24 x 25	\	knots	Sapwood: fungi attack	III
	FR 10	22 x 25	\	big knot-> whole, small cracks	\	III
	FR 10a	25 x 24		small cracks	Sapwood: fungi attack	III
	FR 11	9 x 9	\	heavy degrade	water infiltration	N. I.
	S	15 x 15		mostly heavy degrade	fungi, insects	N. I.

T= Timber structure; G = girder; W = web member; E = east; W = west; FR= False rafter; S= Side beams
N. I. = not qualified (adequate); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

Aisles right

7 right aisle

What was analysed?
See left aisle

Used methods
See main aisle

General state of conservation
The right aisle has nearly the same amount of fungi attack as the aisle on the left side, although viewer water infiltrations occur. Generally it has similar problems for example a ridge with a ring shake…
Most of the timber elements are in worse conditions, also because of the amount of elements with insect attack, which generally occurs rarely in the structures of the dome of Vercelli. The insects however are not active anymore and haven't caused mayor damage. Additionally it is to say that the elements in the worst conditions are not of great importance for the whole timber structure and some of them are missing entirely in the aisle on the left side.
This means that the general condition of the right aisle is quite fine, but should be controlled frequently.

Photos of every single element


8 T1


T1
T1
T1
T1
FR1
FR1
FR1
Side beams
FR2
FR2
FR3
FR3


FR4
FR4
FR5
FR5
FR6
FR6
Side beams
T2
T2
T2
T2
T2

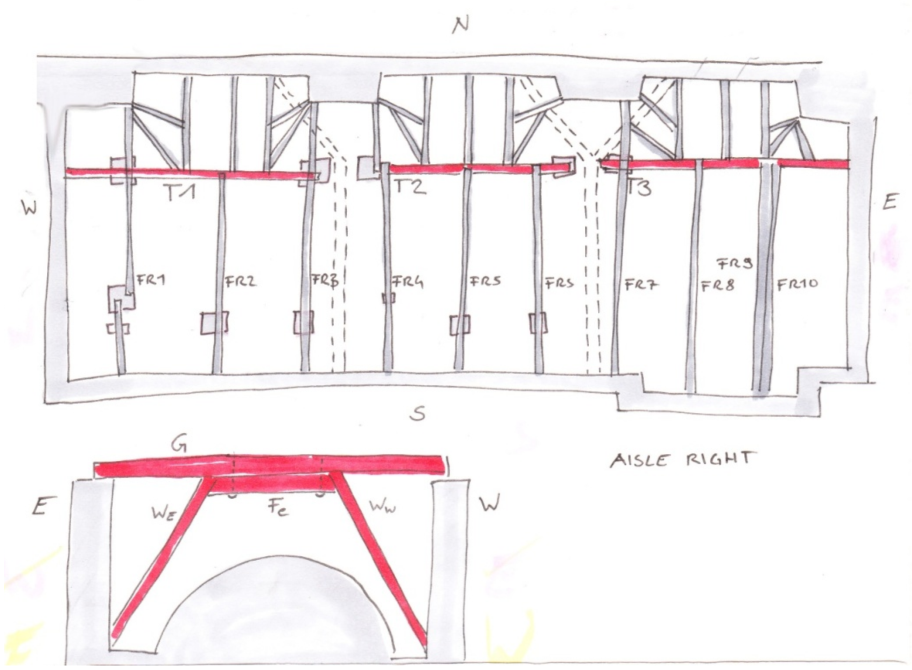

FR7
FR7
FR7
Side beams
FR8
FR8
FR9
FR9
FR10
T3
T3
T3

9

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.2) categorised.

For the classification only the visible parts were taken into consideration. The hidden areas have not been analysed. (see point What was analysed?)



sketch 29

Table 3. Results of the resistance qualification for the examined timber elements of the trusses.

Identification		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Category according UNI 11119
T1*	G 1	28 x 23	\	knots	insect attacks	III
	Fe 1	8 x 12	\	\	insect attacks	III
	W E-1	15x 10	\	death	insect attacks	N. I.
	W w-1	12 x 13	\	heavy degrade (photo)	N.V.	N. I.
T2*	G -2	28 x 30	\	lots of knots, ring shake, crack not parallel to fibre!!!	Sapwood: fungi attack	N. I.
	Fe 2	10 x 13	\	\	Sapwood: fungi attack	III
	W E-2	13 x 13	\	\	\	II
	W w-2	13 x 12	\	small cracks	insect attacks	II
T3*	G -3	28 x 29	\	big knots, small cracks	\	III
	Fe 3	8 x 12	\	\	\	-
	W E-3	12 x 12	\	knots, curved	\	II

	W w-3	13 x 13	\	knots, curved	\	//
T4*	FR 1	23 x 20	\	small knots and cracks		//
	FR 2	23 x 23	\	\	insect attacks	II
	FR 3	27 x 27	\	\	active fungi (joint wall)	II
	FR 4	28 x 18	\	big knots	insect attacks	III
	FR 5	25 x 20	\	small knots and cracks	\	II
	FR 6	23 x 20	\	small knots and cracks	\	II
	FR 7	26 x 25	\	knots	\	II
	FR 8	20 x 20	\	\	\	II
	FR 9	20 x 20	\	crack 15mm	Sapwood: fungi attack	III
	FR 10	20 x 20	\	big wholes	insect attacks	III
	S	15 x 15		mostly heavy degrade	fungi, insects	N. I.

T= Timber structure; G = girder; W = web member; E = east; w = west; Fe= False edge; FR= False rafter; S= Side beams
N. I. = not qualified (adequate); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

Transept left

10 transept truss

What was analysed?

None of the points of support have been visible during the inspection. The primary structure of the timber roof of the transept on the right side is composed out of tree wrong beams and a truss which play a principal part. Together with the main beam they work like portals, which carry the 3 long rafters and maintain the free span.
Nearly all of the elements have been inspected on 3 sides. The upper parts haven’t been taken into consideration, because it was not directly visible. Only the king post and the tie beam of the truss and all the web members have been analysed on 4 sides. The bearings of the timber structure are in positions difficult to reach and haven’t been checked.

Used methods

See main aisle

General state of conservation

Some of the diagonal timber elements are drenched with water and therefore the general condition is mediocre. The timber structure has some gaps and problems, an intervention to maintain the whole structure has to be carried out fast to avoid further amplified damage which can quicken and if the water infiltrations continue.
The major part of the beams (structurally tertiary order) has to be substituted.

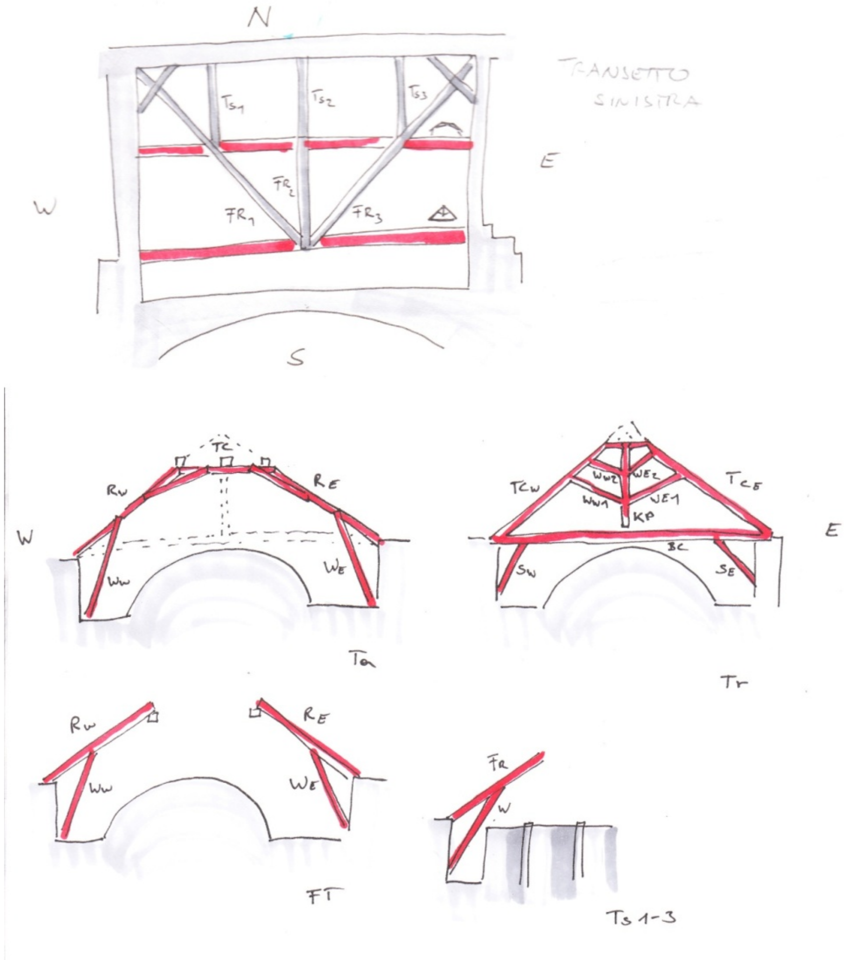
Description of every single element

11 transept

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.2) categorised.

For the classification only the visible parts were taken into consideration. The hidden areas have not been analysed. (see point What was analysed?)



sketch 30

Table 4. Results of the resistance qualification for the examined timber elements of the trusses.

Identification		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Category according UNI 11119
Tr*	Bc1	25 x 26	\	seems newer because very square, small fractures, Problem: knot (former intervention)	\	*III*
	Tc w-1	30x 30	\	first half (wall), false edge ca. 20cm	\	III
	Tc e-1	30 x 30	\	first half (wall), false edge ca. 20cm	\	III
	KP-1	27 x 27	\	\	\	II
	W-1w1	14 x 8	\	\	\	II
	W-1w2	12 x 8	\	\	\	II
	W-1e1	14 x 8	\	\	\	II
	W-1e2	12 x 8	\	\	\	II
	S-1w	15 x 15	\	\	\	II
	S-1e	10 x 12	\	\	\	II

FT*	R - w	30 x 30	\	\	\	III
	R - e	30 x 30	\	small cracks	\	III
	W - w	14 x 12	\	small knots	\	II
	W - e	17 x 14	\	curved	insect attacks	II
Ta*	TC	33 x 33	\	\	\	N.V.
	R - w	15 x 20	high moisture content	heavy degrade	Sapwood: fungi attack	III
	R - e	21 x 18	\	cracks (30mm), knots	insect attacks	III
	W - w	10 x 20	\	\	\	II
	W - e	10 x 20	\	\	Sapwood: fungi attack	III
FR1 *	Fr	30 x 30	\	shrinkage fractures	\	III
FR2 *	Fr	30 x 40	\	shrinkage fractures	\	II
FR3 *	Fr	30 x 30	\	knots	\	III
Ts1*	Fr	25 x 25	\	small fractures	\	III
	W	18 x 18	\	deformation, big knots	insect attacks	III
Ts2*	Fr	27 x 23	slightly wet	crack (23mm)	fungi (joint wall)	III
	W	15 x 15	\	curved, small cracks (13mm)	\	II
Ts3*	Fr	19 x 22	\	big cracks, intervention visible (False edge)	\	III
	W1	12 x 10	\	bad quality of working progress some parts have only 10x8cm cross-section, small cracks	insect attack	III

Tr=Truss; FT= False truss; Ta= arch timber structure; Ts= secondary timber structure; W = web member; e = east; w = west; S=Strut (wall/tie-beam), FR= Main false rafter; Fr= False rafter; Sb= Side beams
N. I. = not qualified (insufficient); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

Transept right

12 transept

What was analysed?

The primary structure of the timber roof of the transept on the right side is composed out of tree wrong beams which play the principal part. Together with the main beam they work like a portal, which carries the long rafters and maintains the free span.
Nearly all of the elements have been inspected on 3 sides. The upper parts haven't been taken into consideration, because it was not directly visible. Only

the web members have been checked on 4 sides. The bearings of the structure are in positions difficult to reach and haven't been analysed.

Used methods

See main aisle

General state of conservation

The dimensions of the wooden elements are small and that for many small interrupted wooden elements are introduced to arrive at the desired pitching of the roof.
Some of the diagonal timber elements are drenched and the general condition is alarming. The timber structure has many gaps and problems, an intervention to maintain the whole structure has to be carried out fast to avoid further amplified damage which can quicken and if the water infiltrations continue.
The major part of the beams (structurally tertiary order) has to be substituted.
The material is mainly not classifiable some may enter in the forth category, only some elements can be recycled and reused.

Description of every single element

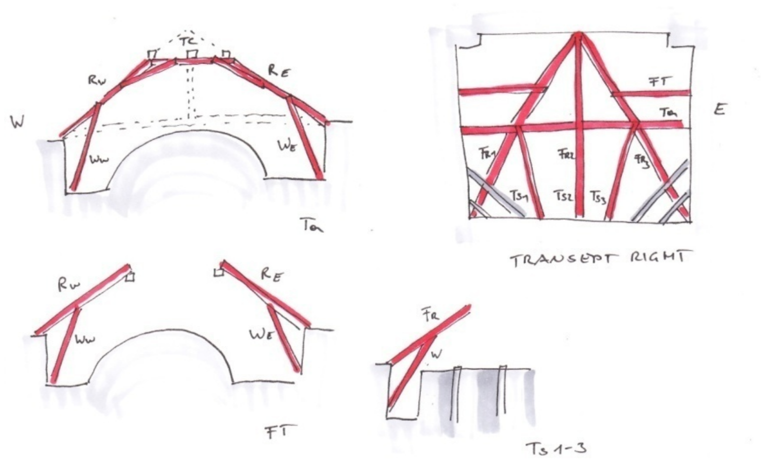
13 transept

The roof structure consists of a main porting beam on which lie two apex beams and further tree rafters (orthogonal to the main porting beam) which bear on the other side of the wall and form the roof covering of the pavilion.
The apex beam on the south side is supported by a small vertical timber piece and a bolt.
On the surface the beam is slightly softened, where the timber piece lies on the wall there is no huge problem because of its big dimensions, but the other side

the beam has lost a lot of substance and is too slim to carry the loads. An intervention would be useful (cravatta).
The fist rafter on the south side (next to the entrance) is very long and shows caries (softening only on the sapwood and not on the heart wood) on both sides. The beam can be categorised in the third category and is supported by a wooden element.
The second rafter, the one in the middle, has bigger dimensions than the first and the third rafter. The beam shows shrinkage fractures, but in general it seems to be in a good condition. It is the only element in this area which can be classified in the second category.
The third rafter (the one on the north side) is moderately dimensioned and it is backed by a bolt, which has been substituted because it is not bungled with an axe but sawn.
The beam shows 50cm from the bedding on the wall extended to a third of the dimensions a false edge with a softened wooden element fixed with four turnbuckles. In correspondence to the added bar the beam suffered breakage on the intrados part of the structural element where the horizontal spacing of the fibres is enlarged. Only the lower part of the beam is affected by the fracture, an intervention including an iron cramp and a longish metal piece should be foreseen.
The apex beam on the north side is of big dimensions and is slightly weakened and softened only in the zone of the sap wood.
On the extrados of the beam a huge timber plate has been positioned to ensure the displacement and the pitch of the roof.
A part of the main supporting beam, which is plating on the north side has been recently substituted.
The two principal rafters, which are positioned parallel to the main beam and are bedded on the north side of the external wall, have smaller dimensions and the two beams seem to be recycled because they show the typical fluting, which rafters used for timber roofs normally exhibit.

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.2) categorised.
For the classification only the visible parts were taken into consideration. The hidden areas have not been analysed. (see point What was analysed?)



sketch 31

Table 5. Results of the resistance qualification for the examined timber elements of the structure.

Identification		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Category according UNI 11119
FT1*	R - w	30 x 30	\	N. V.	\	N. V.
	R - e	25x 30	\	N. V.	\	N. V.
	W - w	16 x 12	\	\	\	II
	W - e	19 x 16	\	heavy degrade	fungi and insect attacks	III
FT2*	R - w	30 x 30	\	recycled	\	N. V.
	R - e	25 x 30	\		\	N. V.
	W - w	15 x 15	\	heavy degrade, knots	fungi and insect attacks	III
	W - e	20 x 15	\	heavy degrade, knots	fungi and insect attacks	III
Ta*	TC	30 x 25	\	slightly softened	Intervention necessary	N. V.
	R - w	30 x 25	high moisture content	Recycled, cracks, knots	Sapwood: insect attack	III
	R - e	30 x 25	high moisture content	recycled , heavy degrade, Knots, wholes	fungi and insect attacks	III
	W - w	10 x 20	\	\	\	II
	W - e	10 x 20	\	\	Sapwood: fungi attack	III
FR1 *	Fr	33 x 33	\	caries	\	III
FR2 *	Fr	30 x 40	\	shrinkage fractures	\	II
FR3 *	Fr	33 x 33	\	breakage	Former intervention	N. I.
Ts1*	Fr	20 x 20	high moisture content	heavy degradation	fungi	II
	W1	18 x 18	\	deformation, (huge wholes)	fungi and insect attacks	III
	W2	r = 10cm round	\	\	insect attacks	III
Ts2*	Fr	25 x 25	slightly wet	knots	\	III
	W	r = 14cm round	\	curved, small cracks	\	II
Ts3*	Fr	20 x 20	\	big cracks, intervention visible (False edge)	Sapwood: fungi attack	III
	W1	12 x 12	\	recently exchanged (new)	\	III

Tr=Truss; FT= False truss; Ta= arch timber structure; Ts= secondary timber structure; W = web member; e = east; w = west; S=Strut (wall/tie-beam), FR= Main false rafter; Fr= False rafter; Sb= Side beams
N. I. = not qualified (insufficient); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

Attic

14 attic

What was analysed?

The twenty big joists (west east) have been inspected on 3 sides. The struts have been analyzed on four sides. The little timber elements, which are positioned above the joists to balance eventual deformations or differences in the cross - sections have not been valued.
The bearings of the structure are in positions difficult to reach and haven't been analysed.

Used methods

See Main aisle

General state of conservation

The environment is very wet. This is influencing the timber structure in a negative way. Already some fungi started to grow and it is necessary to repair the roof covering immediately to avoid water infiltrations and further damage. The windows/doors of the attic should be kept open to ensure ventilation which can help the structure to dry. Some of the bearings were the web members are connected with the wall have been filled with concrete. This may cause damage in future, because eventually water infiltrations are going to be locked in the timber element and will cause damage.
Anyhow the structure is still in a quite moderate condition.

Photos of every single element

Timber element 3

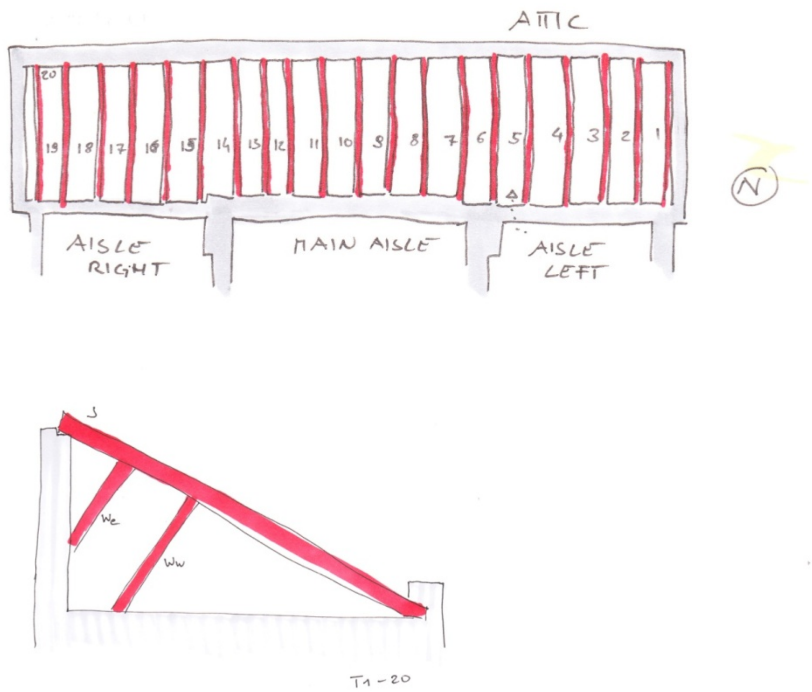
15 Timber element 3


FR1
FR2
FR3
FR4
FR5
FR6
FR7
FR8
FR9
FR10
FR11
FR12
FR13
FR14
FR15
FR16
FR17
FR18
FR19
FR20

16

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.2) categorised.
For the classification only the visible parts were taken into consideration. The hidden areas have not been analysed. (see point What was analysed?)



sketch 32

Table 6. Results of the resistance qualification for the examined timber elements of the structure.

Identification		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Category according UNI 11119
T1*	J	29 x 29	\	Caries upper part	Water infiltrations	III
	W1w	20 x 20	\	Curved, deviation of the fibre	\	II
	W2e	15 x 15	\	Buckling fractures	\	II
T2*	J	29 x 29	\	Knot, caries bearing bottom	\	III
	W1w	20 x 20	\	\	Part bottom drenched with water	N. I.
	W2e	15 x 15	wet	Knots	\	II
T3*	J	29 x 29	wet	Knots	\	II
	W1w	20 x 20	\	Knots, buckling, displacement	\	II
	W2e	15 x 15	\	Small cracks	\	II
T4*	J	29 x 29	wet	Knots	Sapwood: fungi attack	III
	W1w	20 x 20	\	Small knots	\	II
	W2e	15 x 15	\	\	\	II

T5*	J	29 x 29	wet	Knots	Water infiltration bearing	III
	W1w	20 x 20	\	Buckling	\	II
	W2e	15 x 15	\	Small cracks	\	II
T6*	J	29 x 29	wet	Deviation of the fibre, cracks	\	II
	W1w	20 x 20	\	Crack	\	II
	W2e	15 x 15	\	Small single knot	\	II
T7*	J	29 x 29	wet	Deviation of the fibre, cracks	Caries	III
	W1w	20 x 20	\	Curved buckling	\	II
	W2e	15 x 15	\	Curved, looses cross-section in the upper part	\	II
T8*	J	29 x 29	\	N. V.	\	N. V.
	W1w	20 x 20	\	N. V.	\	N. V.
	W2e	15 x 15	\	\	\	II
T9*	J	29 x 29	wet	Knots, deviation of the fibre, cracks	\	II
	W1w	20 x 20	\	Curved, buckling	\	II
	W2e	15 x 15	\	Crack	\	II
T10*	J	29 x 29	wet	Big knots	Sapwood: fungi attack	III
	W1w	20 x 20	\	Small cracks	\	II
	W2e	15 x 15	\	Deviation of the fibre, buckling	\	III
T11*	J	29 x 29	wet	\	Active Fungi	N. I.
	W1w	20 x 20	wet	Small knots	\	II
	W2e	15 x 15	wet	Curved	\	II
T12*	J	29 x 29	\	Knots	\	II
	W1w	20 x 20	\	Small knots	\	II
	W2e	15 x 15	\	Slight torsion	\	II
T13*	J	29 x 29	wet	Rot, caries	Sapwood: fungi attack	N. I.
	W1w	20 x 20	\	\	\	II
	W2e	10 x 10	\	Small cracks, diminution of the cross-section	\	II
T14*	J	29 x 29	wet	Small cracks, fibre deviation	Discolouration (fungi)	III
	W1w	20 x 20	\	Buckling.	\	II
	W2e	15 x 15	\	Small cracks	\	II
T15*	J	29 x 29	\	Curved, deviation of fibre, cracks	\	II
	W1w	20 x 20	\	Knots, bad condition	Caries, fungi attack	III
	W2e	15 x 15	\	\	\	II
T16*	J	29 x 29	\	Knots, cracks	Water infiltrations	III
	W1w	20 x 20	\	Curved, buckling, knots	\	II
	W2e	15 x 15	\	\	Water infiltrations	II
T17*	J	29 x 29	\	Deviation of the fibre, cracks	Caries	III
	W1w	20 x 20	\	Crack	\	II
	W2e	15 x 15	\	Displacement	\	II
T18*	J	29 x 29	wet	Buckling, knots	Sapwood: fungi attack	III
	W1w	20 x 20	wet	\	\	II
	W2e	15 x 15	\	Small cracks	\	II
T19*	J	29 x 29	wet	Extremely degraded	Caries	N. I.
	W1w	20 x 20	\	Slight deviation of the fibre	\	II
	W2e	15 x 15	\	\	\	II
T20*	J	29 x 29	wet	Cracks, Knots	Caries	III
	W1w	20 x 20	\	\	\	II
	W2e	15 x 15	\	Curved, buckling	\	II

T= timber structure; W = web member; e = east; w = west; J=Joist
N. I. = not qualified (insufficient); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

Chapel right “Capella del Crocifisso”

What was analysed?

The joists and the false rafters of the timber structure have been inspected on three sides, because the upper parts of the inclined beams are not directly visible. The struts have been analysed on all four sides. The bearings of the structure are as always, in positions difficult to reach and haven’t been taken into consideration. The little timber elements, which are positioned above the false rafters to balance eventual deformations or the differences in the cross sections of the rafters, have not been analysed.

Used methods

See Main aisle

General state of conservation

The environment is quite wet. Especially the false rafter bearing on the exterior wall is in a dangerous condition and should be protected from further water infiltrations. The openings of the attic should be kept open to ensure ventilation which can help the structure to dry. The struts are fixed directly in the pavements and the water can’t escape in any point, this already caused some damage in the lower parts of the elements.
The other elements of the structure are still in a quite good condition.

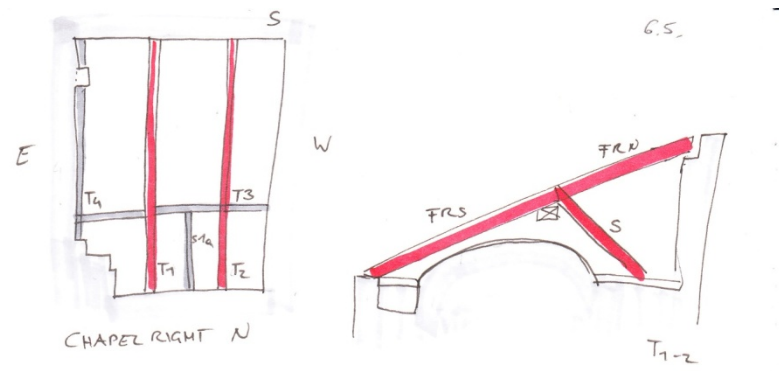
Photos of every single element

17 chapel

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.2) categorised.

For the classification only the visible parts were taken into consideration. The hidden areas have not been analysed. (see point What was analysed?)



sketch 33

Table 7. Results of the resistance qualification for the examined timber elements of the structure.

Identificat		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Catego UNI 11
T1*	Fr1-l	25 x 22	\	small cracks, grain direction	\	II
	Fr 1-s	20 x 22	\	\	Sapwood: fungi attack	III
	S1	15 x 20	\	small cracks	\	II
	S1a	20 x 20	\	small cracks, slightly bended, curved	\	II
T2*	Fr 2-l	25 x 22	\	small cracks	insect attacks	III
	Fr 2-s	15 x 22	\	small cracks		II
	S2	20 x 22	\	small cracks	insect attacks	III
	Fe	18 x 18	\	heavy degrade especially connection pavement	Sapwood: fungi attack	N.I.
T3*	J3	30 x 30	\	huge cross section, cracks, grain direction	\	II
T4*	J4	15 x 15	wet	heavy degrade	Sapwood: fungi attack, insect attacks	N.I.
	B	8 x 8	\	heavy degrade	\	N. V.
	CB	4 x 4	\	heavy degrade	\	N. V.

T= timber structure; S = strut; J=Joist; Fr=false rafter;l=long (north); s=short (south); B= Battens; CB= Contra Battens; Fe= False edge
N. I. = not qualified (insufficient); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

Cupola Chapel of S. Eusebio

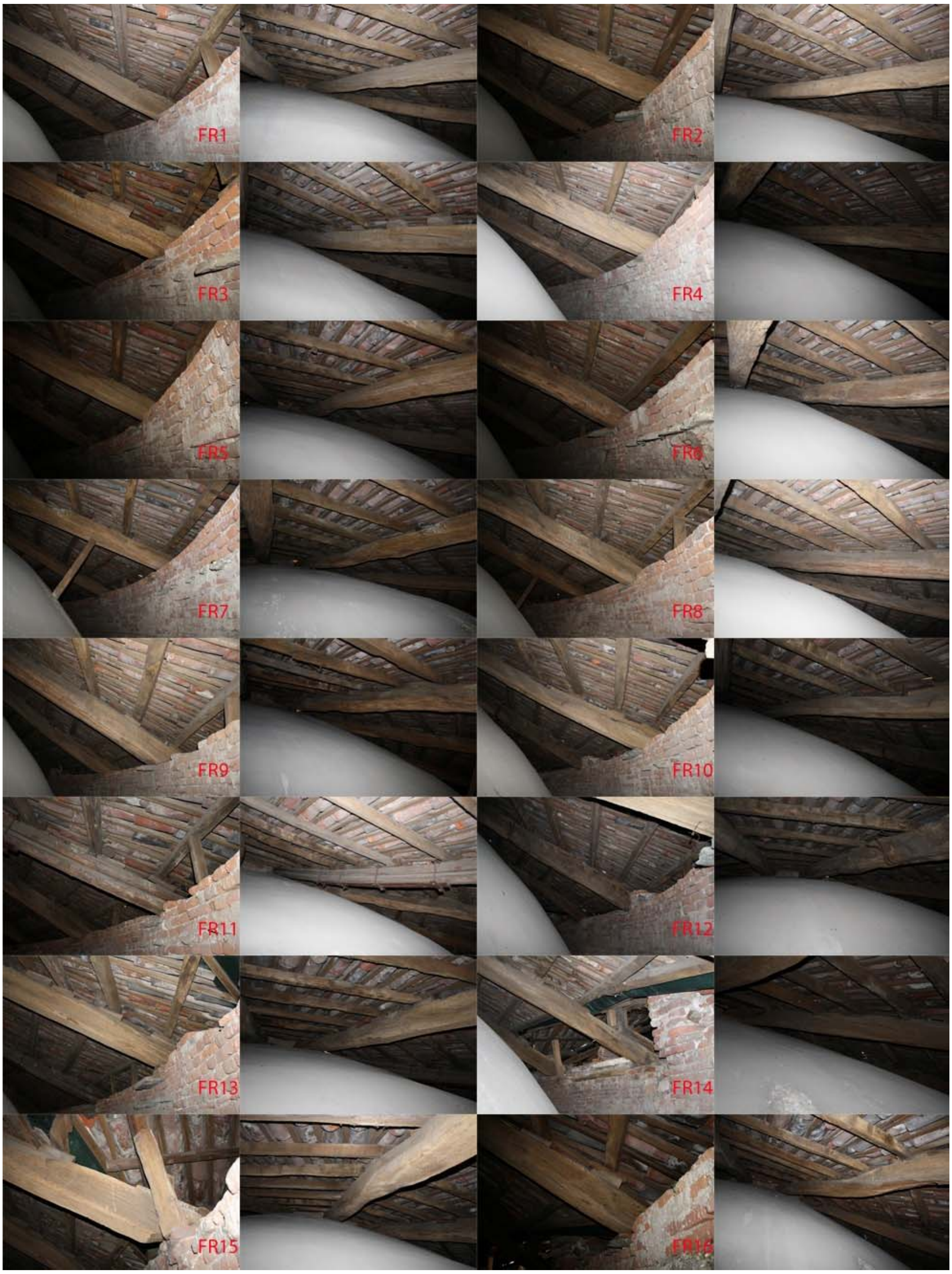
What was analysed?
The eight structural timber elements have been inspected on three sides, because the upper parts of the inclined beams are not directly visible. The bearings of the structure are in positions difficult to reach and haven't been analysed. Also the upper parts of the chords have not been visible (next to the bearing of the centre of the cupola) during the inspection.

Used methods
See main aisle

General state of conservation
The bearings are all well ventilated (at least the visible ones) and that for the structure seems to be in good conditions.

Photos of every single element
Fr 1

18 chapel

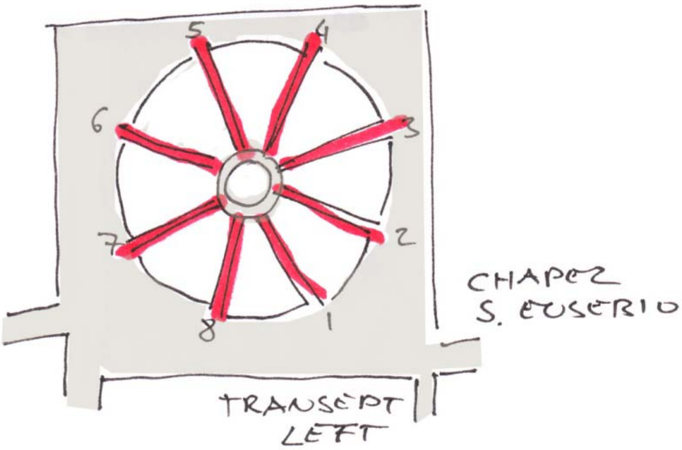


19

Grading table

The results of the classification of the single elements can be seen in the following table. Every element is listed with its characteristics and according to the standard (UNI 11119) (Tab.2) categorised.

For the classification only the visible parts were taken into consideration. The hidden areas have not been analysed. (see point What was analysed?)



sketch 34

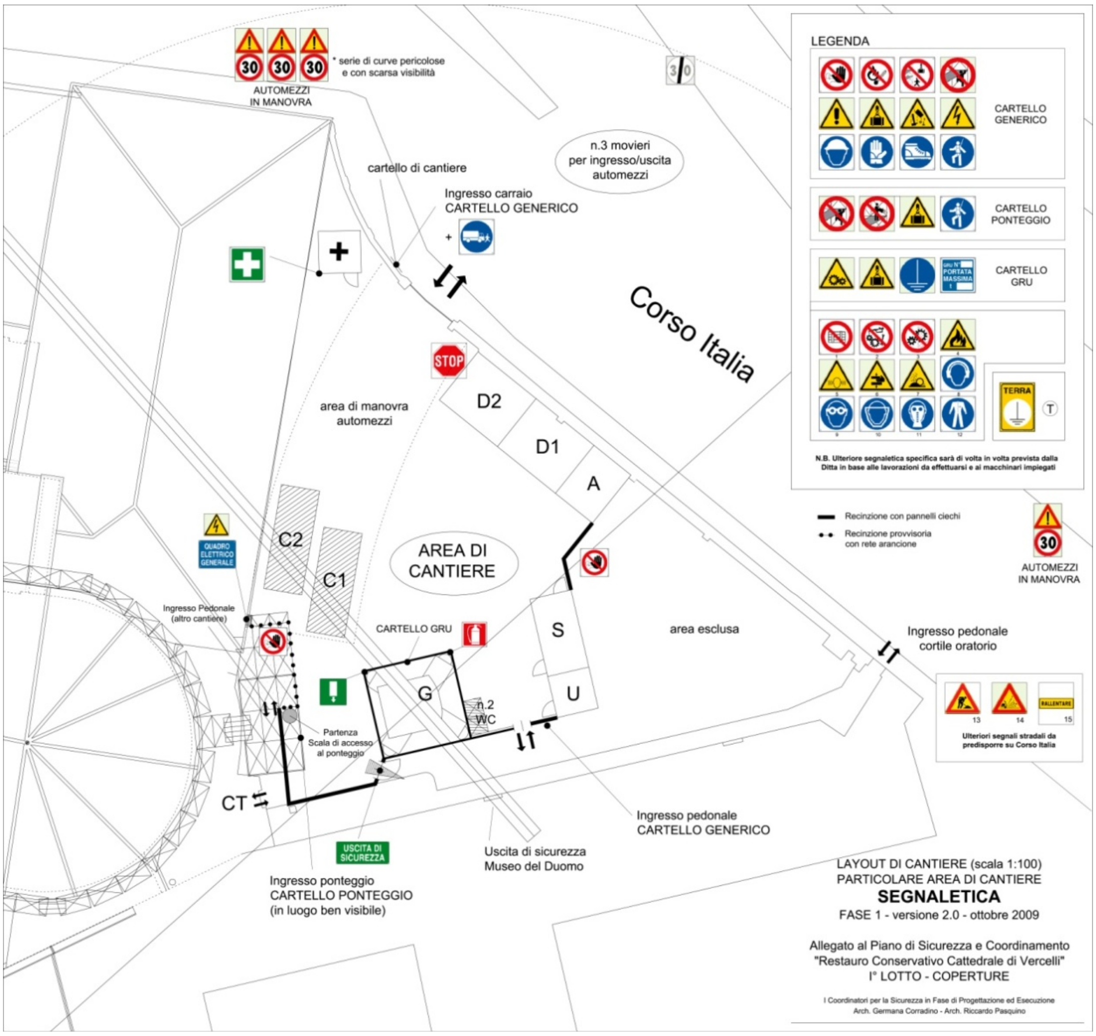
Table 8. Results of the resistance qualification for the examined timber elements of the structure.

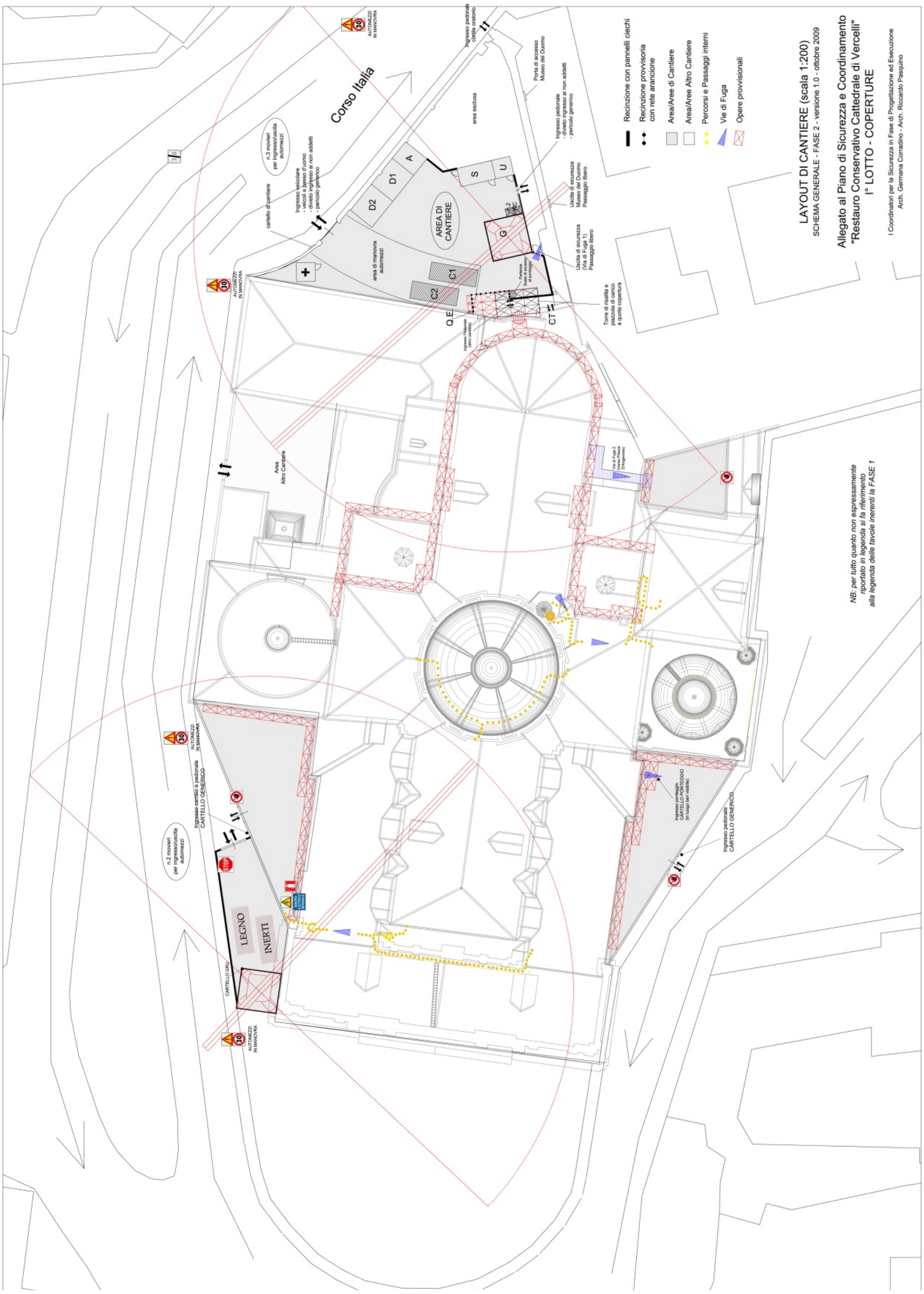
Identification		Minimum measured cross-section b x h [cm]	Average moisture content of the connections [%]	Defects, disconnections, fractions which have determinate the classification	Note	Category according UNI 11119
T*	R1	21 x 21	\	Buckling fractures	\	N.I.
	R1	21 x 21	\	Small cracks, small knots	\	II
	R3	21 x 21	\	Alteration of the timber	Former intervention	II
	R4	21 x 21	\	Inclination of the fibres, knots, badly worked	\	II
	R5	21 x 21	\	Knot, buckling	Former intervention	II
	R6	21 x 21	\	Small cracks , curved	\	II
	R7	21 x 21	\	cracks, deviation of the fibre	Alteration (colour)	N.I.
	R8	21 x 21	\	Slightly curved, fracture	\	N.I.
	R1_side2	21 x 21	\	Fracture	\	II
	R2_side2	21 x 21	\	Small cracks, deviation of the fibre	\	II
	R3_side2	21 x 21	\	Small cracks, small knots	\	II
	R4_side2	21 x 21	\	Curved	\	II
	R5_side2	21 x 21	\		\	II
	R6_side2	21 x 21	\	Small cracks, small knots	Alteration (colour), fungi	II
	R7_side2	21 x 21	\	Small cracks	\	II
	R8_side2	21 x 21	\	Slightly curved, fracture	Sapwood fell of	N.I.

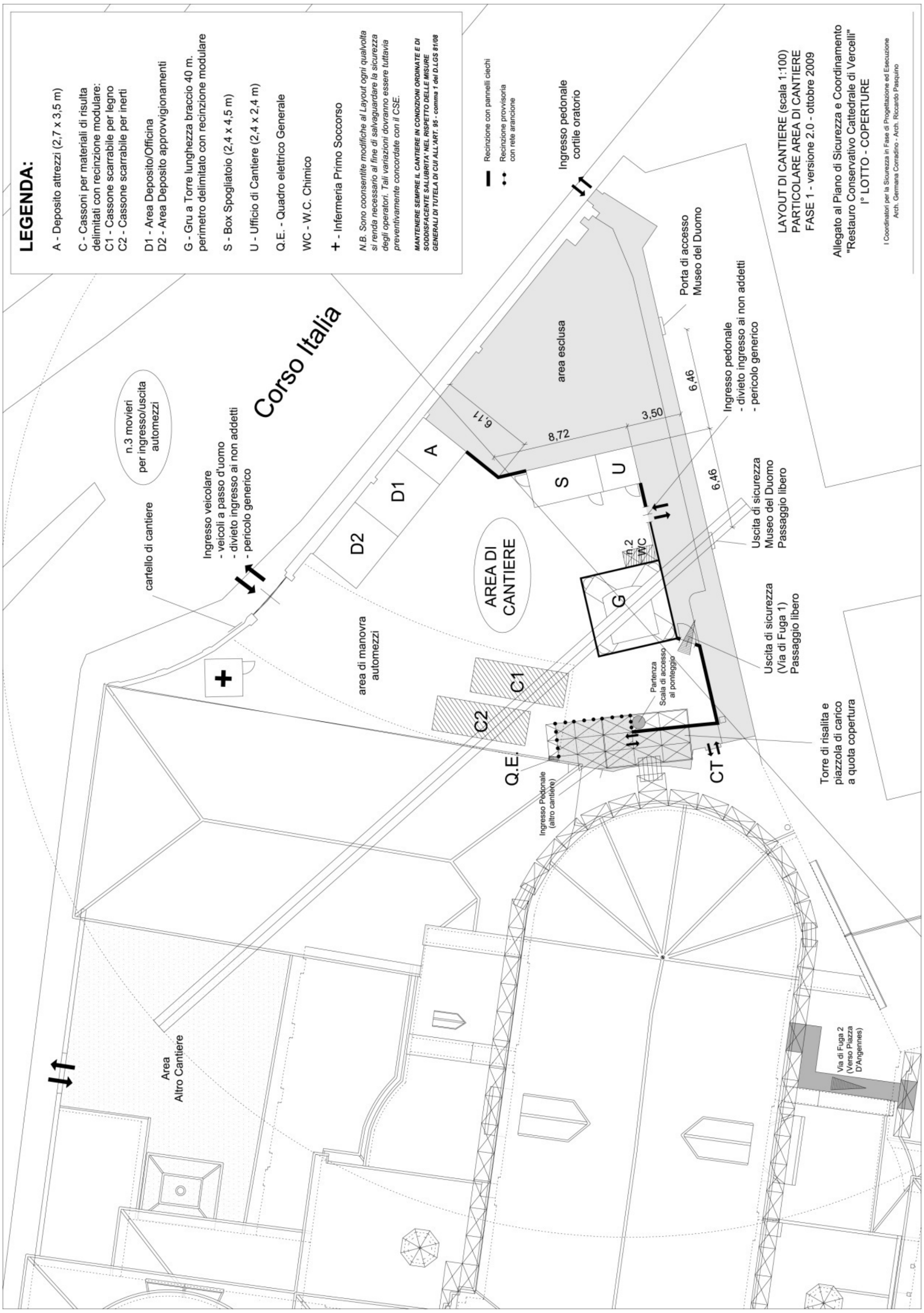
T= timber structure; R=rafter
N. I. = not qualified (insufficient); N. V. = not evaluated
* Defects and relevant alterations are commentated in the chapter description of every single element.

11.4. Plans Manuale di sicurezza

Arch. D. De Luca, Arch. G. Corradino, and Arch. R. Paquino

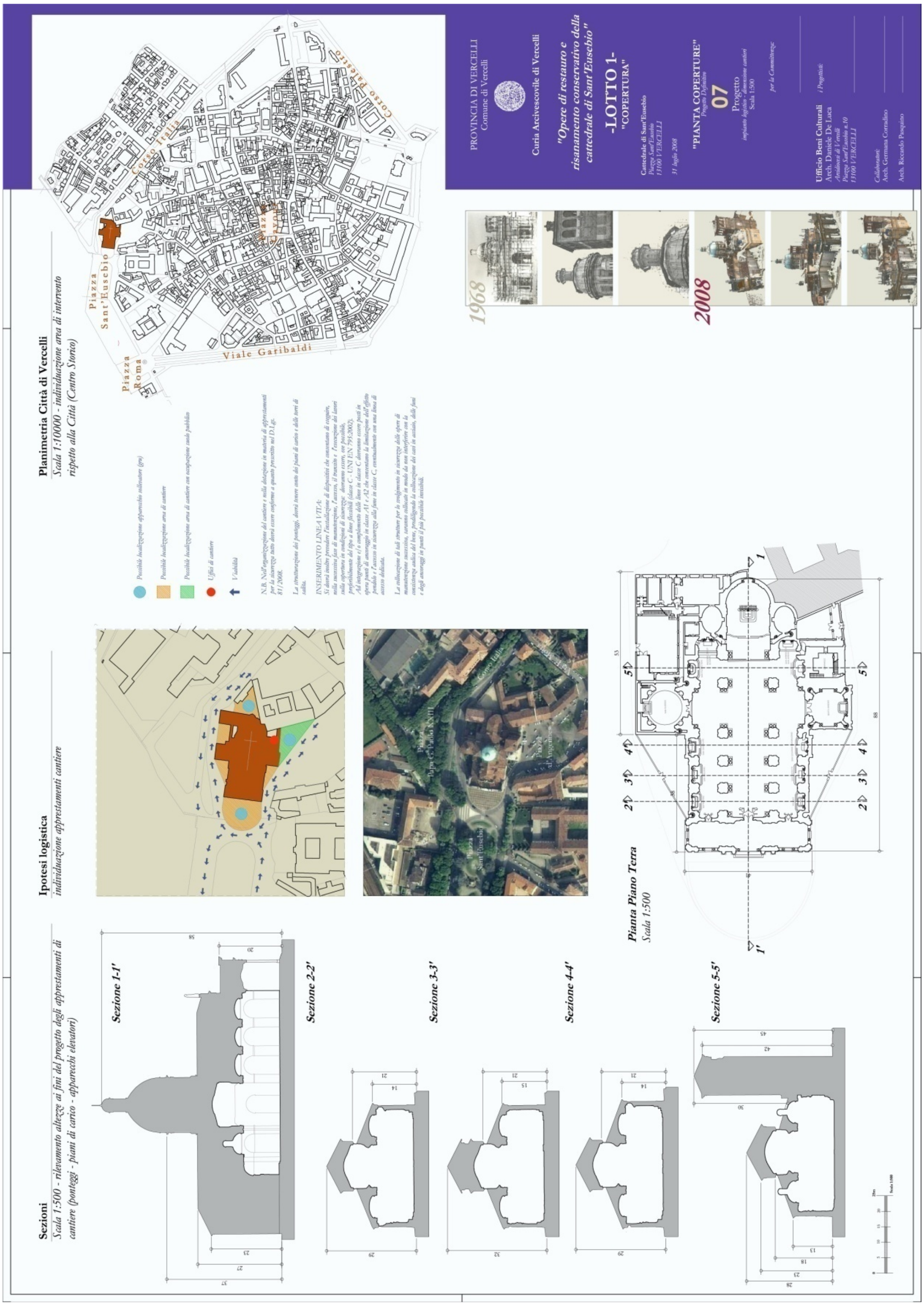


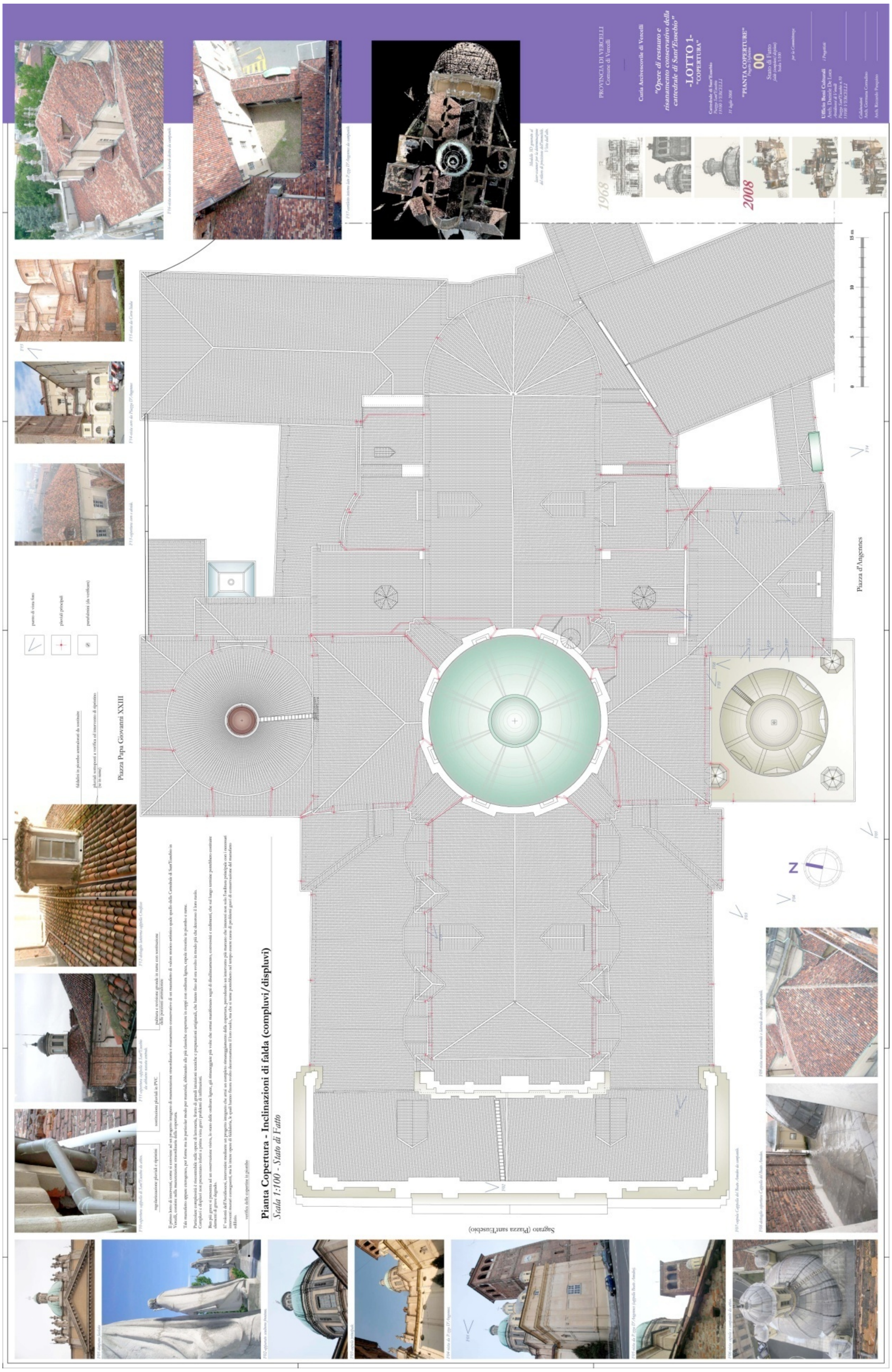

LAYOUT DI CANTIERE (scala 1:200)
SCHEMA GENERALE - FASE 2 - versione 1.0 - ottobre 2009
Allegato al Piano di Sicurezza e Coordinamento
"Restauro Conservativo Cattedrale di Vercelli"
I° LOTTO - COPERTURE
I Coordinatori per la Sicurezza in Fase di Progettazione ed Esecuzione
Arch. Germana Corradino - Arch. Riccardo Pasquino
Recinzione con pannelli ciechi
Recinzione provvisoria con rete arancione
Area/Aree di Cantiere
Area/Aree Altro Cantiere
Percorsi e Passaggi interni
Vie di Fuga
Opere provvisionali
Corso Italia
AREA DI CANTIERE
LEGNO
INERTI
NB: per tutto quanto non espressamente riportato in legenda si fa riferimento alla legenda delle tavole inerenti la FASE 1

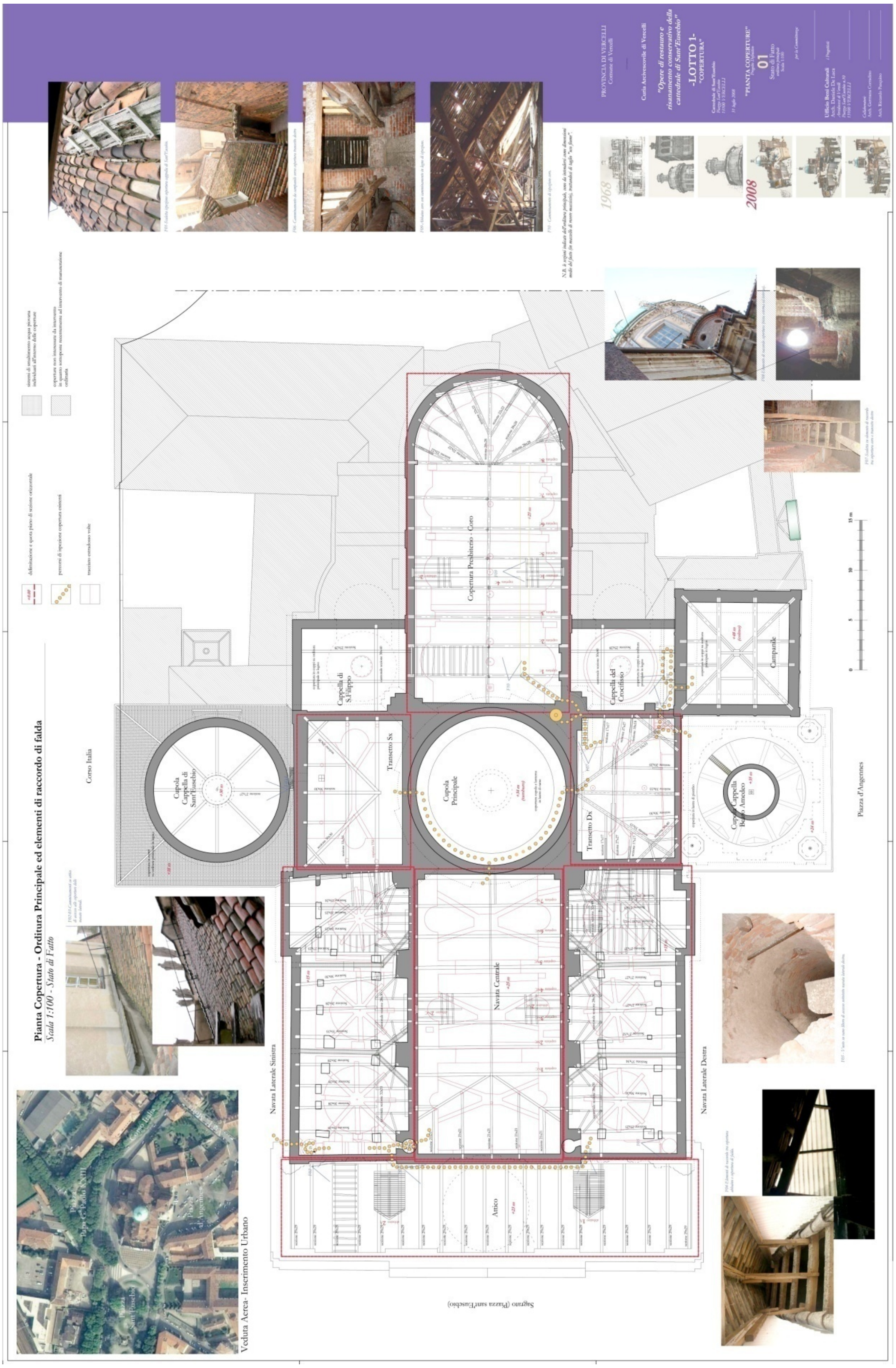


LEGENDA:
A - Deposito attrezzi (2,7 x 3,5 m)
C - Cassoni per materiali di risulta delimitati con recinzione modulare:
C1 - Cassone scarrabile per legno
C2 - Cassone scarrabile per inerti
D1 - Area Deposito/Officina
D2 - Area Deposito approvvigionamenti
G - Gru a Torre lunghezza braccio 40 m. perimetro delimitato con recinzione modulare
S - Box Spogliatoio (2,4 x 4,5 m)
U - Ufficio di Cantiere (2,4 x 2,4 m)
Q.E. - Quadro elettrico Generale
WC - W.C. Chimico
+ - Infermeria Primo Soccorso
N.B. Sono coonsentite modifiche al Layout ogni qualvolta si renda necessario al fine di salvaguardare la sicurezza degli operatori. Tali variazioni dovranno essere tuttavia preventivamente concordate con il CSE.
MANTENERE SEMPRE IL CANTIERE IN CONDIZIONI ORDINATE E DI SODDISFACENTE SALUBRITA' NEL RISPETTO DELLE MISURE GENERALI DI TUTELA DI CUI ALL'ART. 95 - comma 1 del D.LGS 81/08
Recinzione con pannelli ciechi
Recinzione provvisoria con rete arancione
Ingresso pedonale cortile oratorio
Corso Italia
n.3 movieri per ingresso/uscita automezzi
Ingresso veicolare
- veicoli a passo d'uomo
- divieto ingresso ai non addetti
- pericolo generico
cartello di cantiere
area esclusa
Porta di accesso Museo del Duomo
Ingresso pedonale
- divieto ingresso ai non addetti
- pericolo generico
6,11
8,72
3,50
6,46
6,46
A
D1
D2
S
U
AREA DI CANTIERE
n.2 WC
G
Uscita di sicurezza Museo del Duomo Passaggio libero
Uscita di sicurezza (Via di Fuga 1) Passaggio libero
area di manovra automezzi
C1
C2
Partenza Scala di accesso al ponteggio
Q.E.
CT
Torre di risalita e piazzola di carico a quota copertura
Ingresso Pedonale (altro cantiere)
Area Altro Cantiere
Via di Fuga 2 (Verso Piazza D'Angennes)
LAYOUT DI CANTIERE (scala 1:100)
PARTICOLARE AREA DI CANTIERE
FASE 1 - versione 2.0 - ottobre 2009
Allegato al Piano di Sicurezza e Coordinamento
"Restauro Conservativo Cattedrale di Vercelli"
I° LOTTO - COPERTURE
I Coordinatori per la Sicurezza in Fase di Progettazione ed Esecuzione
Arch. Germana Corradino - Arch. Riccardo Pasquino

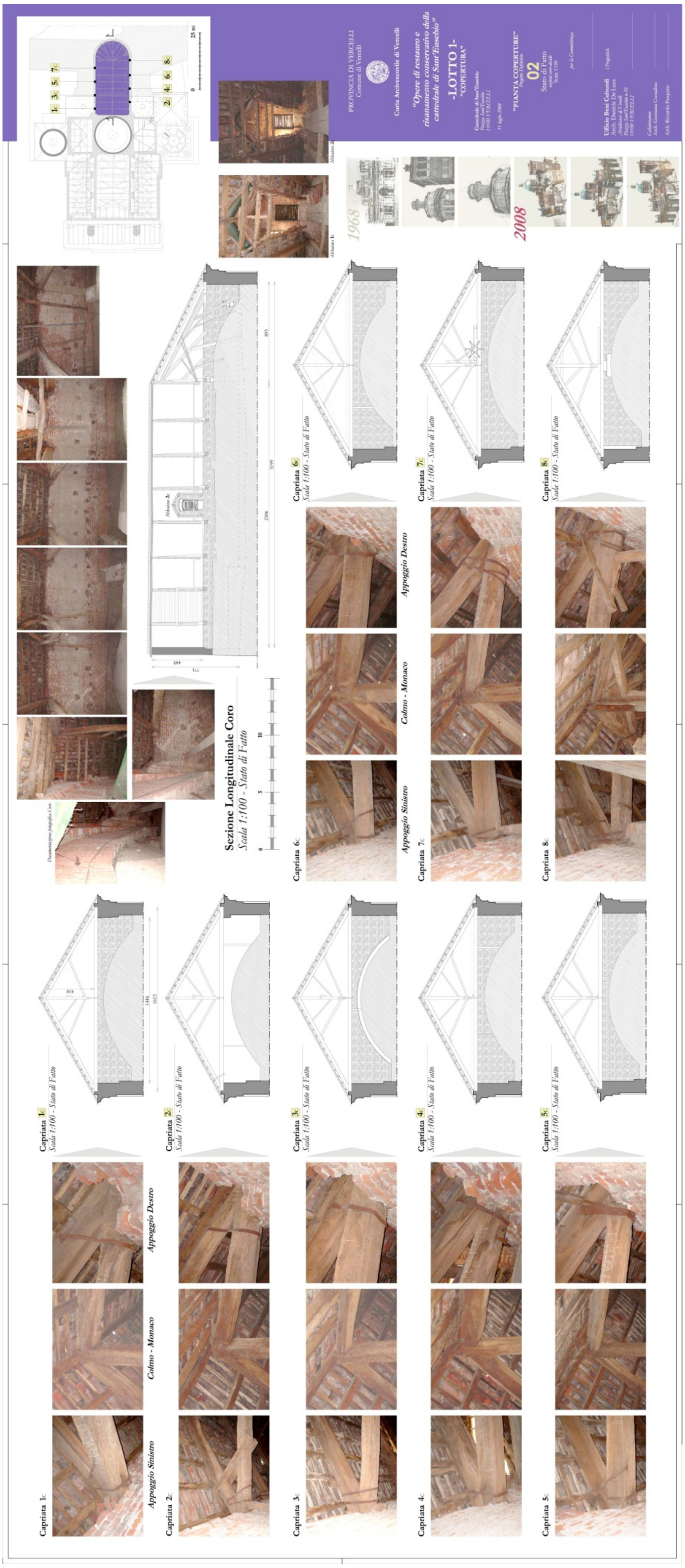
11.5. Plans Arch. De Luca

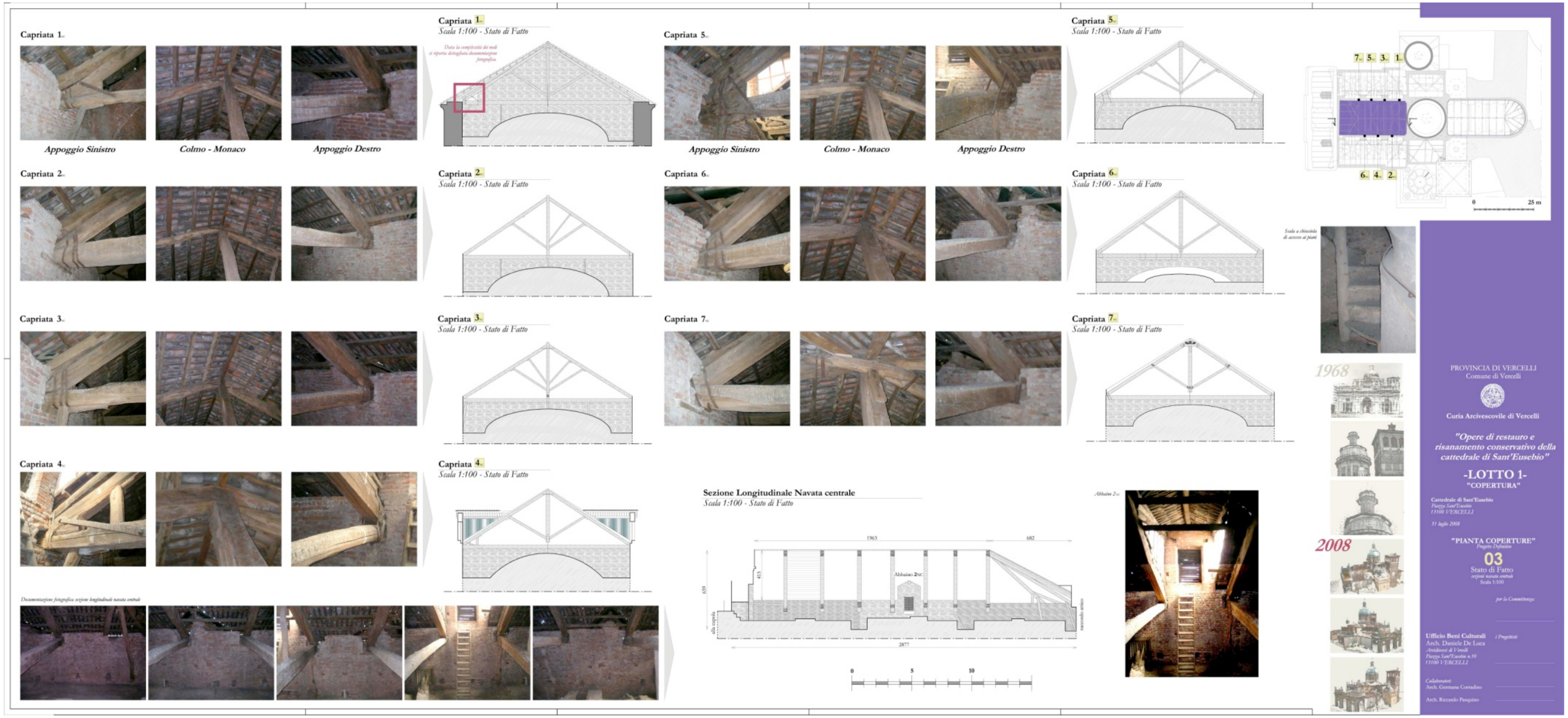



Pianta Copertura - Inclinazioni di falda (compluvi/displuvi)
Scala 1:100 - Stato di Fatto
Piazza Papa Giovanni XXIII
Piazza d'Angennes
Sagrato (Piazza sant'Eusebio)
PROVINCIA DI VERCELLI
1968
2008
N



Pianta Copertura - Orditura Principale ed elementi di raccordo di falda
Scala 1:100 - Stato di Fatto
PROVINCIA DI VERCELLI
Curia Arcivescovile di Vercelli
-LOTTO 1-
1968
2008
Copertura Presbiterio - Coro
Cappella di S.Filippo
Cappella del Crocefisso
Campanile
Cupola Cappella di Sant'Eusebio
Transetto Sx
Cupola Principale
Transetto Dx
Cupola Cappella Beato Amedeo
Navata Centrale
Navata Laterale Sinistra
Navata Laterale Destra
Attico
Corso Italia
Piazza d'Angennes
Sagrato (Piazza sant'Eusebio)
Veduta Aerea- Inserimento Urbano


PROVINCIA DI VERCELLI
Comune di Vercelli
Curia Arcivescovile di Vercelli
"Opere di restauro e risanamento conservativo della cattedrale di Sant'Eusebio"
-LOTTO 1-
"COPERTURA"
"PIANTA COPERTURE"
02
Stato di Fatto
1968
2008
Sezione Longitudinale Coro
Scala 1:100 - Stato di Fatto
Capriata 1
Capriata 2
Capriata 3
Capriata 4
Capriata 5
Capriata 6
Capriata 7
Capriata 8
Appoggio Sinistro
Colmo - Monaco
Appoggio Destro



Capriata 1.
Appoggio Sinistro
Colmo - Monaco
Appoggio Destro
Capriata 1.
Scala 1:100 - Stato di Fatto
Capriata 5.
Appoggio Sinistro
Colmo - Monaco
Appoggio Destro
Capriata 5.
Scala 1:100 - Stato di Fatto
Capriata 2.
Capriata 2.
Scala 1:100 - Stato di Fatto
Capriata 6.
Capriata 6.
Scala 1:100 - Stato di Fatto
Capriata 3.
Capriata 3.
Scala 1:100 - Stato di Fatto
Capriata 7.
Capriata 7.
Scala 1:100 - Stato di Fatto
Capriata 4.
Capriata 4.
Scala 1:100 - Stato di Fatto
Sezione Longitudinale Navata centrale
Scala 1:100 - Stato di Fatto
1963
682
2877
Abbaino 2
0
5
10
7. 5. 3. 1.
6. 4. 2.
0
25 m
1968
2008
PROVINCIA DI VERCELLI
Comune di Vercelli
Curia Arcivescovile di Vercelli
"Opere di restauro e risanamento conservativo della cattedrale di Sant'Eusebio"
-LOTTO 1-
"COPERTURA"
Cattedrale di Sant'Eusebio
Piazza Sant'Eusebio
13100 VERCELLI
31 luglio 2008
"PIANTA COPERTURE"
Progetto Definitivo
03
Stato di Fatto
sezioni navata centrale
Scala 1:100
per la Committenza:
Ufficio Beni Culturali
Arch. Daniele De Luca
Arcidiocesi di Vercelli
Piazza Sant'Eusebio n.10
13100 VERCELLI
i Progettisti:
Collaboratori:
Arch. Germana Corradino
Arch. Riccardo Pasquino

Principali interventi di consolidamento

Prima di mettere in pratica qualsiasi risoluzione che, di seguito, verrà enunciata si renderà necessario seguire delle procedure preliminari indirizzate, sia alla salvaguardia dell'integrità di ogni singolo elemento che compone la struttura del tetto, sia per creare le condizioni atte a garantire una corretta esecuzione dell'intervento. Le operazioni sotto elencate, per fasi successive, costituiranno le accortezze da prendere quando si effettuerà il cauto smontaggio del tetto (in questo frangente lo smontaggio non comprenderà anche gli elementi lignei che costituiscono l'orditura primaria per la quale l'intervento di manutenzione sarà previsto, dove le condizioni conservative lo consentiranno, in loco):

- puntellamento e/o sbatacchiamento con appropriati ritti regolabili da cantiere della struttura portante del tetto;
- rimozione dei canali di gronda delle canne fumarie, dei comignoli, delle antenne, delle scossaline e quant'altro sia presente sulla copertura;
- verifica della stabilità dei cornicioni e, nel caso siano direttamente connessi con la struttura del tetto, provvedere ad idonei puntellamenti;
- rimozione del manto di copertura ed accatastamento all'interno del cantiere od in altro luogo sicuro (in ogni caso non in modo da gravare sulla struttura dell'edificio);
- verifica di ogni singolo elemento che compone il manto di copertura (presenza di eventuali rotture e/o criccature) al fine di accertarne l'eventuale riutilizzabilità e, in tal caso, procedere con la rimozione dalla superficie di ogni genere di deposito (muschi, licheni ecc.) per mezzo di una pulitura manuale tramite bruschinaggio con spazzole di saggina e successiva battitura;
- totale o parziale rimozione della piccola orditura lignea, e loro eventuale, accatastamento in luogo sicuro ed esterno alla struttura, facendo cura di selezionare gli elementi ancora efficienti e riutilizzabili ed effettuare eventuali interventi di pulitura che dovranno essere di tipo manuale con l'ausilio di spazzole di saggina.

Collegamento tra le strutture della copertura e la muratura

Particolare attenzione si dovrà porre nel valutare l'effettiva capacità meccanica delle murature d'imposta, sovente soggette ad infiltrazioni d'acqua, ad oscillazioni termiche (con conseguente disgregazione dei giunti di malta e degrado del materiale costituente l'apparecchio) e, appunto, alle sollecitazioni degli appoggi delle strutture lignee.

Nel caso si valuterà la possibilità di "bonificare", ovvero consolidare preventivamente le murature sommitali mediante il ripristino dell'imposta con elementi di laterizio pieno ben apparecchiati con malta idraulica.

Cordolo in legno
Ove necessario si valuterà l'inserimento di un cordolo avente funzione di "cappello strutturale" tramite l'inserimento, in sommità alle murature portanti, di travi di legno, adeguatamente dimensionate seguendo le prescrizioni di progetto Tutte le travi di cordolo saranno preventivamente trattate con specifici prodotti anti-fungo e anti-tarlo.

Connessione tra i diversi elementi costituenti l'orditura

Connessione mediante staffe e/o piastre metalliche
Al fine di migliorare o creare collegamenti tra i vari elementi lignei costituenti l'orditura primaria e secondaria, si potranno posizionare delle piastrine in lamierino zincato (sezione minima 2x40 mm) ancorate sull'intradosso delle orditure minori (per es. travicelli o mezzanelle) e in seguito ripiegate sulla superficie di appoggio di terzere o travi di colmo. Queste piastre saranno ancorate alle strutture lignee attraverso viti autofilettanti o chiodi inox (minimo 3 f 4 mm per ogni elemento). Se il progetto prevedrà il collegamento, in corrispondenza dell'orditura principale (tramite tavola di legno o piatto metallico), di tutti i travicelli non si renderà necessario collegarli tutti ma sarà sufficiente vincolarne uno su tre; in caso contrario occorrerà effettuare l'intervento su tutta l'orditura minuta. I correnti potranno anche essere collegati all'orditura principale mediante vaschette metalliche zincate a doppio vano oppure attraverso angolari di lamiera di acciaio (spessore minimo 5 mm) muniti eventualmente, di squadretta di irrigidimento; entrambi i dispositivi di ancoraggio saranno opportunamente fissati alle strutture lignee attraverso chiodi inox o viti autofilettanti.
Sarà sempre consigliabile (nei casi in cui si renderà possibile) realizzare il collegamento tra puntoni contrapposti, attraverso l'inserimento di doppio bullone in acciaio zincato a sezione circolare (minimo f 14 mm su foro di f 15 mm) e testa esagonale vincolato al legno con dado e rosetta in acciaio poggiata sul legno per tutta la sua superficie.

Irrigidimento e controventatura delle falde di copertura

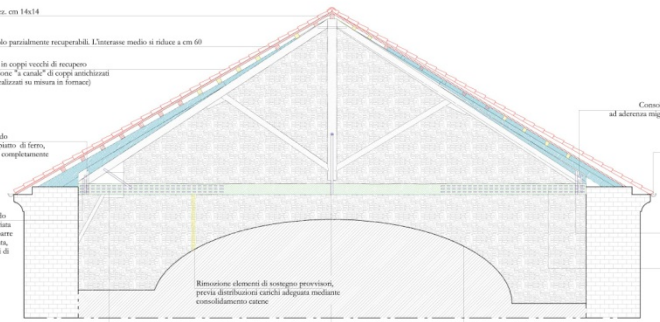
Irrigidimento e controventatura mediante tavolato ligneo
Si intende realizzare solo nelle coperture nelle quali il piano di appoggio del manto di copertura si rilevi visibilmente deformato, in uno stato avanzato di degrado e male, o per niente, ancorato all'orditura sottostante. E solo dopo accurata valutazione della D.L.
Tale intervento risulta di facile esecuzione (non richiede, infatti, manodopera specializzata), veloce ed a secco.
Dopo aver eseguito le operazioni preliminari di smontaggio della copertura si procederà alla posa in opera del tavolato ligneo perfettamente stagionato (ad es. abete o larice), di spessore indicato dai disegni di progetto (comunque non inferiore a 25 mm) ed in funzione dell'interasse dei morali o correnti, piallato, fissato a perfetto contatto e posizionato ortogonalmente alla pendenza di falda. Il tavolato, che presenterà una maschiettatura da entrambi i bordi, sarà ancorato alla sottostante struttura attraverso viti autofilettanti di acciaio inossidabile o chiodi inox filettati o scanalati (minimo f 4 mm inseriti con trapani per chiodature oppure manualmente) cominciando dalla linea di gronda e proseguendo, per corsi rigorosamente paralleli, fino a quella di colmo.
Si ricorda che tutto il legno che andrà posato in opera dovrà essere preventivamente trattato con prodotti fungicidi e/o tarlicidi (per maggiori dettagli si rimanda a quanto detto all'articolo specifico).

Rigenerazione di testate di travi e nodi di incavallature

L'intervento verrà eseguito allorché la testa di una trave risulti deteriorata in modo avanzato (tanto da compromettere la stabilità dell'intera unità strutturale con il rischio di coinvolgere, per l'azione che le strutture ausiliari esercitano, quelle adiacenti) e, pur non garantendo un adeguato appoggio, non si ritiene opportuno operare la sostituzione totale della struttura, sia per ragioni estetiche, sia economiche che logistiche (difficoltà della procedura di sostituzione). Prima di eseguire qualsiasi operazione sostitutiva e/o consolidante parziale o integrale, sarà effettuata una scrupolosa campagna di indagine del manufatto al fine di verificare lo stato conservativo della trave, e la sua reale efficienza statica. La tecnica da utilizzare verrà via via scelta in funzione dello stato di degrado.

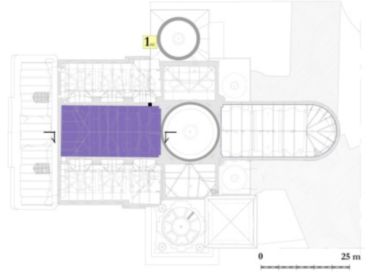
Dettaglio tipo - interventi in progetto - copertura

Capriata 1
Scala 1:50 - Stato di Fatto



- Elementi da rimuovere con eventuale recupero del materiale idoneo e reimpiego su indicazione della D.L.
- Parti di orditura da sostituire con travi di recupero e/o elementi uso Fiume.
- Elementi oggetto di restauro e consolidamento strutturale.
- Parti di orditura da rimuovere e riposizionare in modo complanare all'orditura esistente.
- Parti di orditura di nuova collocazione ad integrazione dell'esistente.

Selezione longitudinale
Scala 1:50 - Stato di Fatto



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PROVINCIA DI VERCELLI
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Curia Arcivescovile di Vercelli

"Opere di restauro e risanamento conservativo della cattedrale di Sant'Eusebio"

-LOTTO 1-
"COPERTURA"

Cattedrale di Sant'Eusebio
Piazza Sant'Eusebio
13100 VERCELLI

31 luglio 2008

"PIANTA COPERTURE"
Progetto Definitivo

04p
Progetto
dettaglio tipo - interventi in copertura
Scala 1:50

per la Committenza

Ufficio Beni Culturali — *i Progettisti*
Arch. Daniele De Luca
Arcidiocesi di Vercelli
Piazza Sant'Eusebio n.10
13100 VERCELLI

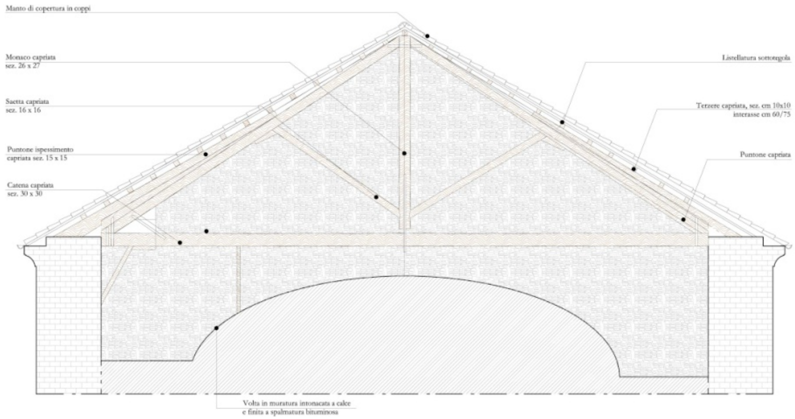
Collaboratori
Arch. Germana Corradino

Arch. Riccardo Pasquino

Dettaglio tipo - stato di consistenza - orditura lignea copertura

Elementi	Materiale costituente	Stato di conservazione
Capriate	*Legno di rovere*	*Generalmente buono*
Puntoni/ispessimenti	*Legno di rovere*	*Degradati*
Listellature	*Rovere/abete*	*Degradati*
Ferramenta	*Ferro*	*Degradati*

Capriata 1
Scala 1:50 - Stato di Fatto



Lo stato delle **orditure lignee**, già rimaneggiate più volte negli anni, manifestano ormai forti segni di disallineamento, convessità e cedimenti, che costituiscono elementi di grave degrado.

La tipologia maggiormente incidente presente sulla copertura della Cattedrale risulta essere il tetto a padiglione, che risulta essere sicuramente la struttura architettonica che ha conservato più di ogni altra immutate nel tempo la forma e la tecnica costruttiva.

Le forme rintracciabili, sono le classiche a quattro o più falde, con orditura lignea maggiore formata da travi e/o capriate e da cantonali lignei disposti sulle bisettrici degli angoli della fabbrica.

La forma degli elementi lignei dell'orditura maggiore e di quella minore denotano differenze nelle tecniche di taglio e lavorazione.
Ai coppi in laterizio tradizionali, si abbinano (sulla copertura dell'artio di ingresso) coppi di dimensione fuori standard, che sicuramente incideranno sulla realizzazione dell'intervento.

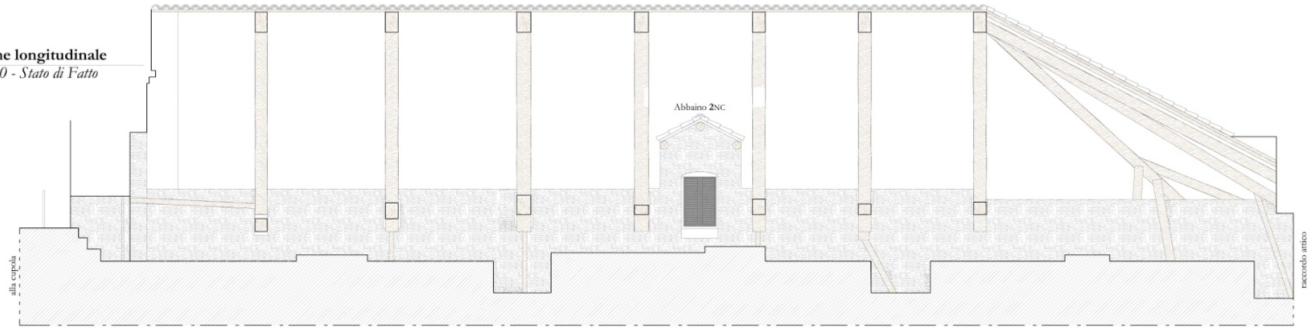
Difetti di costruzione e degrado dei materiali

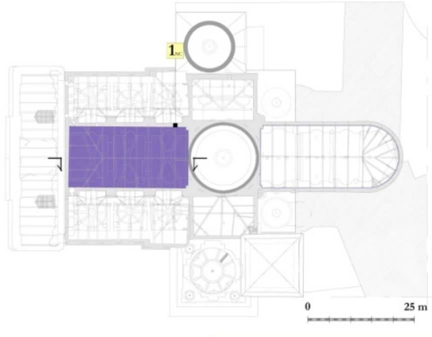
Oltre a quelli che sono i difetti naturali ed i fenomeni di degrado relativi al tipo di materiale utilizzato per la realizzazione delle coperture (in particolare legno e ferro) in alcuni punti le condizioni del tetto sono rese precarie da imprecisione e difetti nella costruzione: la testata delle travi in alcuni punti a contatto con le malte o con la muratura, manifesta fenomeni di marcescenza per umidità, così come sono intelleggebili in alcuni punti deformazioni derivanti da eccessivo carico permanente .
Sono identificabili, in particolare sulle navate laterali deformazioni non uniformi di travi, arcarecci e correnti a causa di sollecitazioni differenziate.

E' necessario tenere presente che il normale degrado di una fabbrica parte dal tetto, la parte più esposta agli agenti atmosferici.
Ad oggi gli interventi di manutenzione attuati hanno riguardato principalmente l'orditura lignea minore e il manto di copertura.

L'intervento in progetto mira al recupero della tradizione manutentiva, senza rinunciare al ricorso, ove opportuno e principalmente al fine di evitare interventi più invasivi o più estese sostituzioni, a tecniche avanzate utili a garantire il consolidamento e la protezione degli elementi lignei e/o metallici posti in opera.

Selezione longitudinale
Scala 1:50 - Stato di Fatto





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Curia Arcivescovile di Vercelli

"Opere di restauro e risanamento conservativo della cattedrale di Sant'Eusebio"

-LOTTO 1-
"COPERTURA"

Cattedrale di Sant'Eusebio
Piazza Sant'Eusebio
13100 VERCELLI

31 luglio 2008

"PIANTA COPERTURE"
Progetto Definitivo

04
Stato di Fatto
dettaglio tipo
consistenza orditura lignea
Scala 1:50

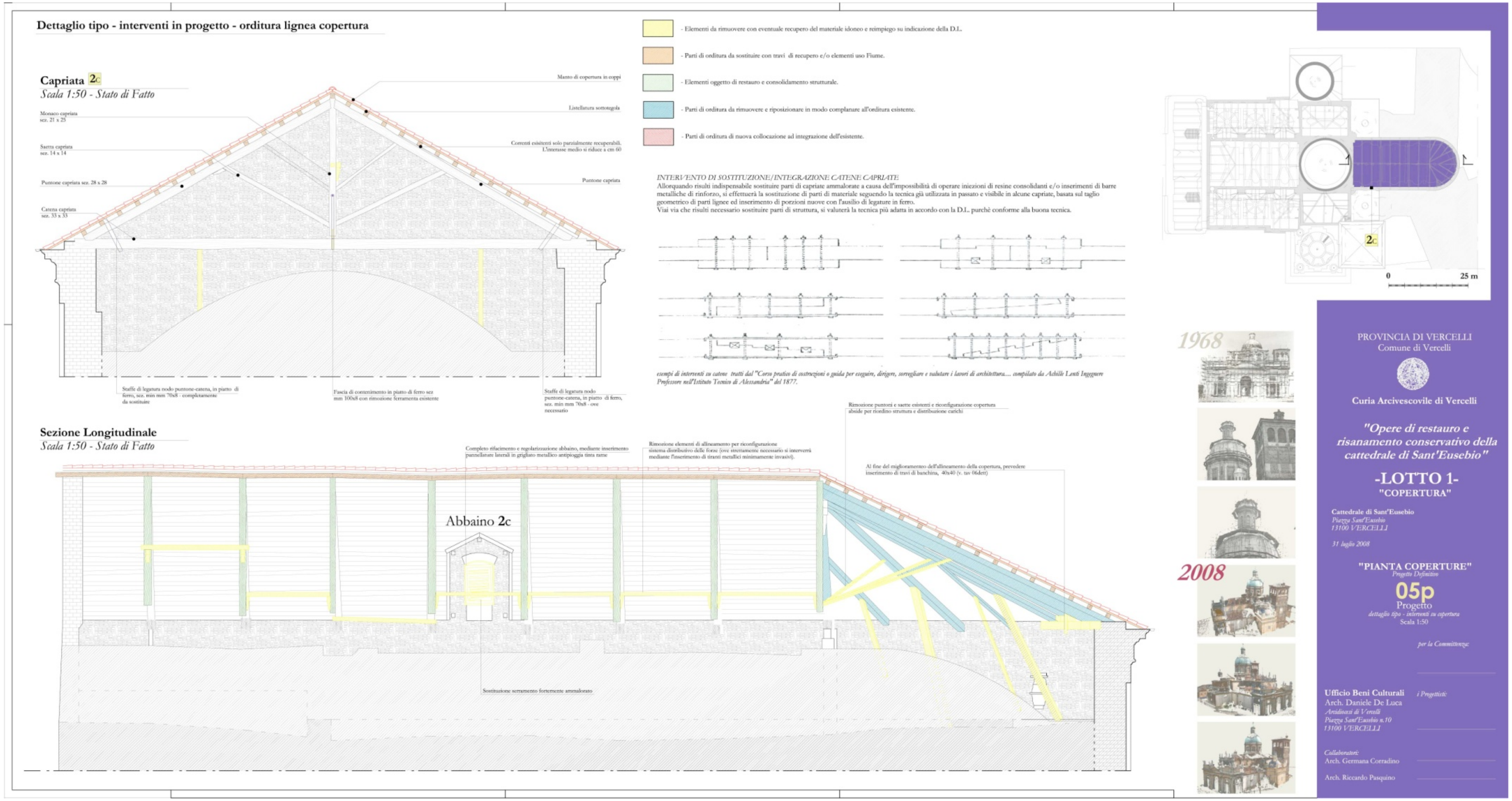
per la Committenza:

Ufficio Beni Culturali
Arch. Daniele De Luca
Arcidiocesi di Vercelli
Piazza Sant'Eusebio n.10
13100 VERCELLI

i Progettisti:

Collaboratori:
Arch. Germana Corradino

Arch. Riccardo Pasquino


Dettaglio tipo - interventi in progetto - orditura lignea copertura
Capriata 2c
Scala 1:50 - Stato di Fatto
Sezione Longitudinale
Scala 1:50 - Stato di Fatto
Abbaino 2c
- Elementi da rimuovere con eventuale recupero del materiale idoneo e reimpiego su indicazione della D.L.
- Parti di orditura da sostituire con travi di recupero e/o elementi uso Fiume.
- Elementi oggetto di restauro e consolidamento strutturale.
- Parti di orditura da rimuovere e riposizionare in modo complanare all'orditura esistente.
- Parti di orditura di nuova collocazione ad integrazione dell'esistente.
INTERVENTO DI SOSTITUZIONE/INTEGRAZIONE CATENE CAPRIATE
Allorquando risulti indispensabile sostituire parti di capriate ammalorate a causa dell'impossibilità di operare iniezioni di resine consolidanti e/o inserimenti di barre metalliche di rinforzo, si effettuerà la sostituzione di parti di materiale seguendo la tecnica già utilizzata in passato e visibile in alcune capriate, basata sul taglio geometrico di parti lignee ed inserimento di porzioni nuove con l'ausilio di legature in ferro.
Viai via che risulti necessario sostituire parti di struttura, si valuterà la tecnica più adatta in accordo con la D.L. purchè conforme alla buona tecnica.
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PROVINCIA DI VERCELLI
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"Opere di restauro e risanamento conservativo della cattedrale di Sant'Eusebio"
-LOTTO 1-
"COPERTURA"
Cattedrale di Sant'Eusebio
31 luglio 2008
"PIANTA COPERTURE"
05p
Progetto
Scala 1:50
per la Committenza:
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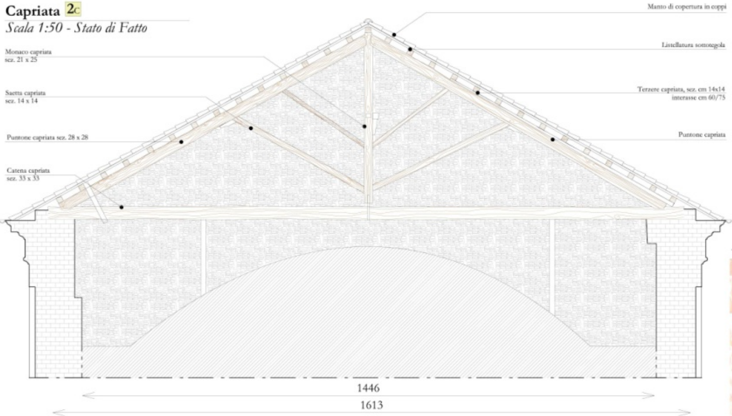
Capriata 2c
Scala 1:50 - Stato di Fatto



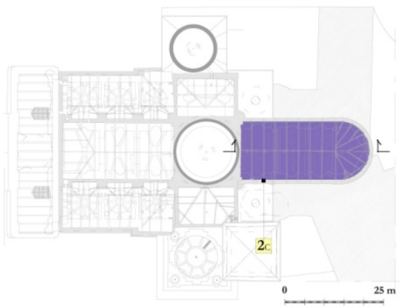
Dettaglio tipo - stato di consistenza - orditura lignea copertura

L'intera copertura si regge su di un sistema di grossa orditura, costituita da capriate e cantonali a supporto di una media struttura costituita principalmente da colmi, puntoni, terzere, disposti in modo alquanto disordinato, in particolare lungo la parte absidale della pianta. Al di sopra di esse si sono avvicendate, nel corso del tempo, diverse tipologie di listellatura.
L'orditura principale fa capo a sette capriate disposte in modo tale da risolvere l'intero assetto strutturale del tetto del coro. Con una luce libera di circa sedici metri, costituiscono gli elementi di maggior risalto dell'intera orditura. Ad esse fanno capo i cantonali di definizione delle pendenze e l'orditura lignea a forma semicircolare che copre l'Abside. In quest'ultima porzione di copertura, l'insieme delle terzere è costituito da travi piuttosto irregolari, sia per il variare delle sezioni sia per la collocazione non sempre geometrica.
L'avvicendarsi delle manutenzioni più o meno progettate, a seguito dei vari eventi metereologici, ha fatto si che in alcuni tratti la copertura presenti una doppia orditura, complanare, costituita da elementi aventi le stesse funzioni, spesso sovrapposti in modo disordinato e replicati senza necessità.
Tale situazione, pur non costituendo pregiudizio strutturale, non consente comunque agli elementi che compongono l'orditura di lavorare in modo univoco e corretto. In particolare lungo l'abside sono collocati diversi elementi di supporto staticamente poco funzionali alle esigenze collaboranti della struttura.
Nella fase preliminare di rilievo si è proceduto ad effettuare un'accurata indagine sia per quanto riguarda le condizioni dei supporti murari sui quali vanno a gravare i pesi ed i carichi dell'intero manto di copertura, sia per quanto riguarda le condizioni dell'orditura lignea vera e propria a supporto del tetto.
Complessivamente le parti murarie di supporto non presentano particolari condizioni di degrado strutturale, in particolare saranno riviste tutte le aree di appoggio della grande e media orditura. Si interverrà con la tecnica del "cuci e scuci", avendo cura di recuperare, per quanto possibile, i mattoni e gli elementi in cotto esistenti. Eventuali integrazioni saranno effettuate con materiale analogo sia per dimensione che per cromia e caratteristiche dell'impasto. Per analogia con l'esistente le parti murarie saranno realizzate con malta di calce naturale. Eventuali superfici, in prossimità degli appoggi potranno essere intonacate con egual materiale.
Si interverrà mediante una regolarizzazione delle mensole esistenti con una rivisitazione del piano di appoggio delle capriate affinchè sia congruo allo scarico della copertura per garantire il funzionamento del sistema statico (inserimento dormiente ligneo dove ritenuto necessario con la D.L.)
Interventi di dettaglio sulle capriate si renderanno necessari a causa del forte disallinemaento delle catene e della riduzione di sezione delle medesime in punti localizzati.

Appoggio Sinistro

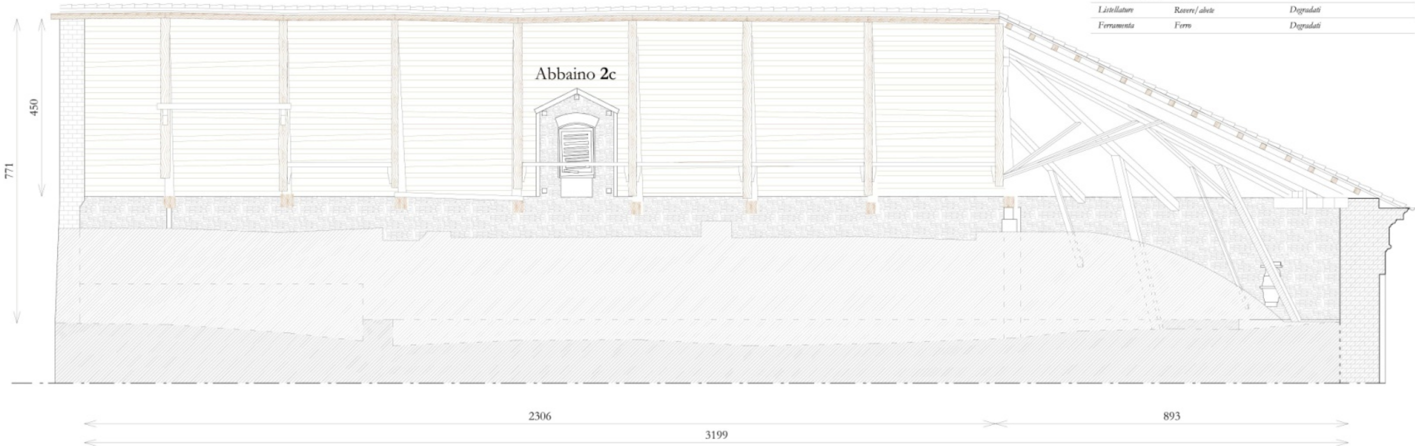
Colmo - Monaco

Appoggio Destro



Elementi	Materiale costituente	Stato di conservazione
Capriate	*Legno di rovere*	*Generalmente buono*
Puntoni/ispessimenti	*Legno di rovere*	*Degradati*
Listellature	*Rovere/abete*	*Degradati*
Ferramenta	*Ferro*	*Degradati*

Sezione Longitudinale
Scala 1:50 - Stato di Fatto



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-LOTTO 1-
"COPERTURA"

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13100 VERCELLI

31 luglio 2008

"PIANTA COPERTURE"
Progetto Definitivo
05
Stato di Fatto
dettaglio tipo - consistenza orditura lignea
Scala 1:50

per la Committenza:

Ufficio Beni Culturali
Arch. Daniele De Luca
Arcidiocesi di Vercelli
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13100 VERCELLI

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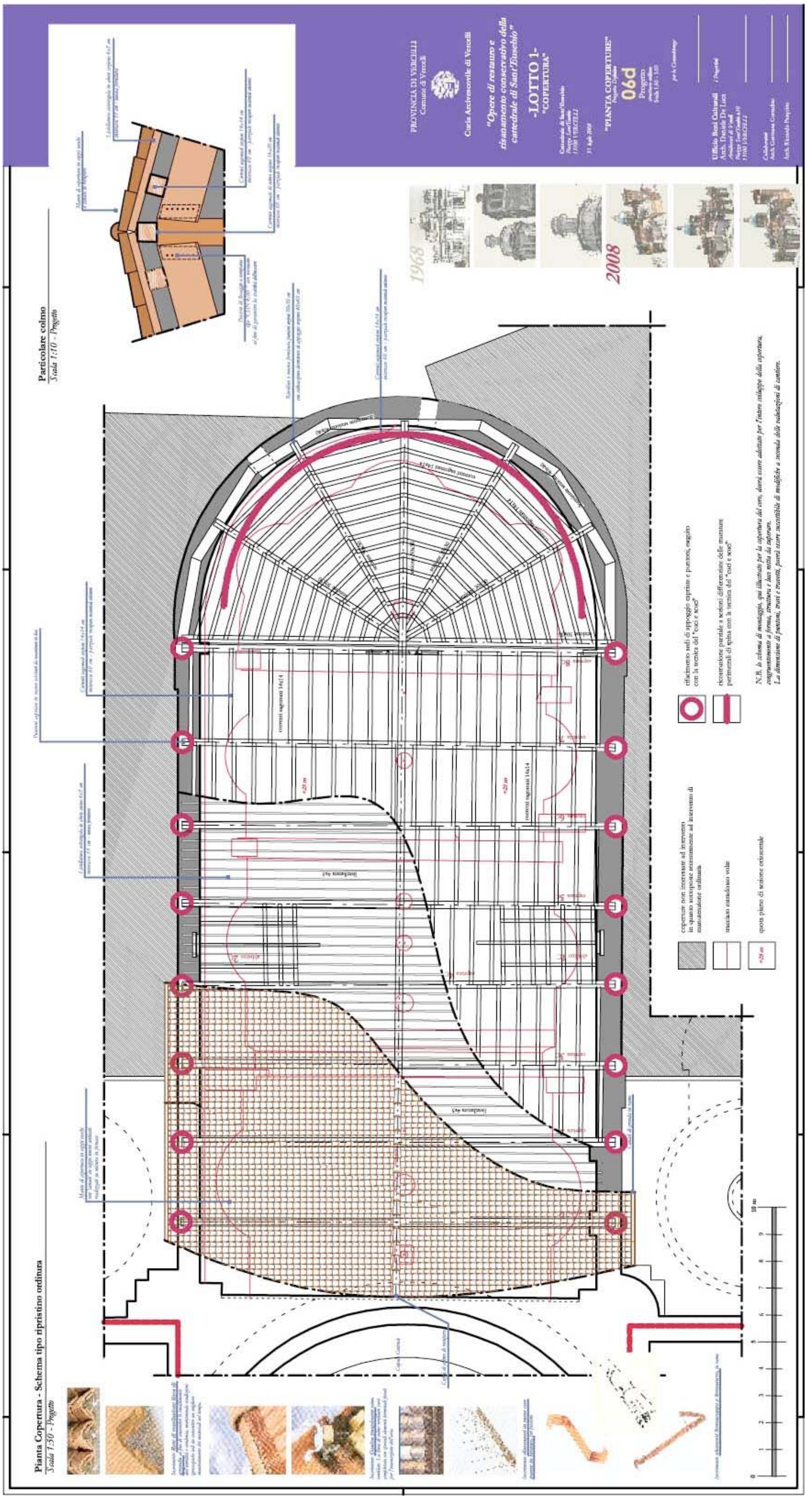
Pianta Copertura - Schema tipo ripristino orditura
Scala 1:50 - Progetto
Particolare colmo
Scala 1:10 - Progetto
1968
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PROVINCIA DI VERCELLI
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"Opere di restauro e risanamento conservativo della cattedrale di Sant'Eusebio"
-LOTTO 1-
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"PIANTA COPERTURE"
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Affidavit

I, **DI PIA THERESE PANOSCH**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Hidden Architecture - The timber roof structure of the dome of Vercelli - Inspection-Diagnostics- Interventions", 280 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 05.02.2010

Signature