Inspection, diagnosis methodologies and maintenance of ancient timber structures.

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Abstract
The paper reports a typical lesson in the frame of the Italian PhD in Conservation of Cultural Heritage.

1. Introductory considerations and topical aspects of the subject
Conservation of existing timber structures may be motivated not only by their historic, artistic or environmental value, but also by other reasons, including economy, safety and quality of life. Therefore, and especially in situations where severe decay has occurred or structural stability is insufficient, it is necessary to identify clearly which features or values should primarily be conserved (e.g. the original materials, the original construction/manufacturing techniques, parts having significant artistic value, the structural functions...). Many agents, both biological and non-biological can cause decay to timber and timber structures, but a timber structure or artwork may last several hundreds or thousands of years, provided it is adequately conceived, constructed, and, in particular, maintained.

Furthermore, in the field of building refurbishment, ancient timber structures constitute a specific class of artefacts of major importance. Their undeniable interest in the vast legacy of historic building is due to their widespread presence in the territory, to the noteworthy variety of their different types, to their technological characteristics and artistic-formal value. However, first and foremost, it must be considered that these artefacts are structures which, in most cases, have not received the same attention or consideration as the buildings of which they are an essential part. They have not been treated with their due respect, especially in our country, with many examples of unjustified alterations, replacements and demolition.

With regard to their conservation, a wide-scale, firmly-rooted conviction has recently gained ground. This belief is that structures must – as much as possible – be maintained and
rehabilitated while preserving their inherent static role. Any interventions must respect and be consistent not only with their original design but also with the material used, wood. However, even today, there are still many examples of operating methods that entail unjustified, drastic interventions: timber floors consolidated with steel and reinforced concrete vaults, partial or complete reconstruction of timber roof structures with steel or glulam elements, etc. Many of these interventions reflect mistrust in wood, as well as, in the building tradition and in the ancient skills. In addition, these interventions are often lacking for one of the typical stages in managing a structural rehabilitation project, i.e. the diagnostic survey.

2. Diagnosis methodologies on timber structures: a multi-disciplinary approach

The technological evaluation of the actual state of a timber structure is therefore of primary importance; its main objective is to provide the people in charge with reliable technological information about:
– the original quality of the timber elements and connections;
– the state of present decay, estimate of decay rates;
– the evaluation of sound cross-sections and of their load-bearing capacity;
– maintenance needs and priorities.

The results should be clearly delivered by means of written reports, preferably complemented by thematic drawings. For this task, a thorough understanding of wooden material (including its structural behaviour, decay processes and conservation requirements) is required and also of construction techniques used in the specific structures.

In recent decades, there has been a positive turnaround in the attitude towards surveys of timber structures involved in refurbishment projects. Today, specific literature proposes a new methodological approach which is the offshoot of research in different disciplinary fields. This approach is more relevant to the particular characteristics of the wood material.

The main goal of the diagnosis phase is the quantitative determination of the timber structure characteristics, accounting for the interactions with other parts of the building and the environment. The process is based on the examination of each individual structural parts and of the corresponding static scheme. In timber constructions, a prior detailed diagnostic survey is directed towards acquiring precise knowledge of the conservation and functionality of the timber elements and joints. The environmental conditions and risks of decay assessment is indispensable for the correct structural analysis and, even more so, for the design of appropriate restoration interventions. A survey of this type is even more essential in drawing up a correct restoration plan in order to avoid invasive interventions involving replacement, additions or even demolition and changes in structural original function.

Experience has also demonstrated that the “intensity” or “invasiveness” of the intervention, and also the related costs, are inversely proportional to the resources and energy dedicated to prior acquisition of knowledge regarding the structure and its materials. This is particularly true in the case of a biodegradable, non-homogenous, hygroscopic, anisotropic material with natural defects such as construction timber. Therefore, a diagnostic and analytical phase, which must comprise increasingly-refined subsequent steps until optimal compliance with reality is achieved, is absolutely essential.

This goal can be effectively achieved only by adopting a multi-disciplinary approach in which different, complementary professional figures, such as the architect, engineer, restoration expert and wood technologist, can evaluate the conditions of the artefact. The selection of the methods used to carry out the survey is never based on a single decision. The problem must be patiently calibrated and assessed, with particular attention to each individual case. In-depth knowledge of the physical, mechanical, technological and biological characteristics of the wood is essential since they affect the choice of analyses and the interpretation of results.
The assessment of the state of conservation and efficiency of timber structures is a valuable tool both for work planning and controlling, according to the priority of the interventions of possible restoration-conservation interventions. Only “possible”, because an accurate diagnosis and classification of the structural elements complying with the effective method of use of the structure, often leads to the reasonably conclusion that the structure is reliable without the need for further reinforcement. This situation can be the case, even when the necessary operating performance does exceed the one forecasted in the original design.

The technological assessment may also be very useful when carrying out maintenance, allowing to adopt specific countermeasures for any type of detected modification, anomaly or damage, and to interrupt or at least slow down the wood decay. Subsequently, monitoring and periodic inspection (several times a year) of the restored structure will be very useful in verifying how the construction has responded to the interventions. This includes the detection of any states of sufferance, damage, irregular behaviour or, vice versa, the achievement of a good level of efficiency in time.

2.1 Direct study and constructive survey
The first step in analysing the structural consistency of the work starts from the knowledge of the material and its geometric shape. Therefore, this step must be part of the survey and be directed towards the knowledge of constructive aspects (figures 1-2)

The survey must be planned and designed case by case according to not only the objectives, but also accessibility of the artefact and available measurement techniques. If possible, both conventional measurement and much more precise photogrammetric techniques are used. The investigation to be made for the diagnostic survey must be reported in plan and section views. There are often strong differences with respect to the architectural survey since damage, disconnections, re-integration of the material, deformation of the various construction elements etc. must be highlighted. As a consequence, in-depth knowledge of the original techniques used by carpenters is essential when carrying out the survey, in order to recognise any elements that may have been modified or replaced over the centuries. The survey graphical output establishes the bases for instrumental diagnostic analyses directed towards identifying structural faults and decay. In this way, the assessment of the quality and characteristics of each element and of the entire structure is made possible prior to the actual instrumental inspection. Therefore, the surveyor can concentrate on the qualitative and geometrical characteristics of these elements, formulating hypotheses and interpreting any causes of decay. Everything is gradually observed can be reported with a standard graphical representation. The survey reflects the subjective observations of whoever is responsible for it. On the other hand, if it is carried out with the correct attention and competence, the survey provides a series of information as important as that provided by other scientific instruments.
Activity necessary to acquire knowledge of mechanical aspects and, therefore, to express an opinion on stability.

Initially, the survey plan will define the following elements:

- the aim of the geometrical survey, which has to be defined by a logical system that guides collection of the measurements for structural configuration;
- the techniques to be used according to the aims of the surveys, which has to comply with the structural complexity, the accessibility and feasibility of the work;
- the integration with instrumental methods, such as non-destructive or partially destructive surveys;
- both the in-site and laboratory data collection system, which can be collected, for example, by means of the so called “thematic charts”.

Therefore, the aspects to be investigated include the dimensions of the beams of timber floors or of the members of trusses, included where these lay on the perimeter walls. The timber boards of the roof, when present, may act as a diaphragm and it is useful to know how the joints are made. The roof frame must be clearly defined both in terms of components and of reciprocal joints. This is crucial especially in complex structures and in case of difficult structural interpretation.

The methods adopted for a survey of this type are somewhat different from conventional ones. The surveyor must enhance his/her specific culture with the knowledge of the construction techniques adopted at the building time in order to distinguish – when possible – its original parts and those added or replaced in subsequent periods.

Surveying and listing the underlying construction criteria of architectural works is a new task that can no longer be disregarded, as it is more and more recognised also at international level. The most relevant disciplinary fields which are suitable to this goal are those of the survey, the history and technology of architecture.

Observation must focus on the connecting points of the structure, even if they are not visible on the surface. Among those are tenon and mortise joints, dove-tail joints. The consistency of material in relation to any degradation attack has to be considered, in order to determine the effective resistant section. For these aspects, instrumental surveys will be required – not so much with the thermographic camera – but rather with penetrometric instrumentation, as discussed below.

The above-mentioned metric survey will be suitably arranged in analytical reports of the structural elements. The reports should highlight: the geometrical characteristics of members (e.g. partialised sections), wood species, flaws in the original material (knots, sloping grain and consequent twisting) and, concerning the joints, splits, breakage of wooden pegs, imperfections of surfaces in contact, etc. The reports are referred in summary maps (thematic chart) which represent a very clear and effective documentation for planned refurbishment interventions.

The above approach makes it possible to define an analytical model for the structural survey.

 Below, a brief syllabus of the primary knowledge of the wood material is reported, taken from the disciplinary field of wood technology.

2.2 Visual inspection and data-base for data management

Technological fiches and thematic charts

Graphical output of data and results of the diagnostic investigation represents the closing phase of the survey. This phase can be considered just as delicate as the previous ones, since it governs the achievement of the main objective of the survey: i.e. allowing the designer technician to take aware decisions. In other words, it improves the quality of the designer work and the success chances of the project.

In this step, the communication of the information acquired through the diagnostic survey is crucial.
Nowadays, leading experts of the field define the technological assessment as a complex process that considers the timber structures at successive increasing levels of depth. As a consequence, the different levels of in-depth survey must be defined according to the objective to be achieved.

- **1st level survey**
  A 1st level survey comprises all the preliminary and general inspections necessary to establish the priority of interventions. A brief attempt to assess the load bearing capacity of the structure is often included. The surveys are directed towards identifying decay, damage, serious defects. The biological risk is estimated by measuring environmental characteristics (humidity and temperature of the air, the equilibrium humidity of the wood) and tracing causes of decay (points of infiltration or stagnation of water in contact with the timber, the presence of xilophagous organisms, etc.).

- **2nd Level survey**
  The aim of the so-called 2nd level inspections, more detailed than those above, is to make a technological evaluation of each individual load bearing elements of the structure. The assessment is carried out identifying critical defects and apparent or hidden decay. Special care is devoted to the cross-sections subject to the highest stress or affected by significant weakening. This requires an in-situ inspection with close visual checking of every parts of the element, possibly accompanied by drilling and complementary instrumental tests. The inspection phase is followed by processing of the data collected: the output may be a "technological fiche" of each structural element inspected. It is thus possible to deduce the resistant quality of the element and the shape of any collaborating sections, purged of any defects or alterations, and to verify the structural safety (Fig. 4).

This level of inspection also includes a technological evaluation of the joints of structural elements, which provide the forces transmission from one member to another.

- **3rd Level survey**
  3rd level surveys are carried out when previous surveys have revealed that the structures examined are unable to carry out their specific load bearing functions. Only with precise analyses and interdisciplinary comparisons, it is possible to establish whether interventions are effectively required on these structures (which, in some cases, may have to be demolished or relegated to a purely decorative role). Sometimes this solution is adopted only because of excessively prudent methods of inquiry or in the case of a verification calculation that does not sufficiently reflect the actual situation. A 3rd level survey can be carried out only through multi-disciplinary involvement of wood technologists and structural experts. In this way, the critical points of the structure are taken into account in a joint discussion, according to each
specific competences. The technological evaluation of defects, damage, anomalies and decay of the wood is viewed in a different light, as these are considered in relation to the analysis of external actions and internal stresses. In this perspective, certain defects that are considered to be highly penalising in a traditional grading based on resistance, may even be considered negligible when these are located in low stress positions, and vice versa. In some ways, this type of inspection represents a step back to the method used in the past and is often carried out ‘spontaneously’ by conscientious, competent technicians. The innovation lies in the new knowledge available regarding the load bearing behaviour of beams in use. In fact, it is nowadays possible to provide a realistic assessment of the mechanical performance of a timber element accounting for the presence of classified defects.

3.1 Fields of survey

Basically, the technological survey of timber structures can be defined as “the set of carried out operations and obtained results, in order to verify all the characteristics of the wood with a direct or indirect influence on the current or planned load bearing capacity of each single structural element, or joint between members and of the timber construction as a whole”.

The technological assessment is closely related with different type of surveys; such as: the historical evolution of the artefact, the geometrical and architectural survey, the operating conditions (macro and microclimate, external actions), the calculation of structural safety and also the design of restoration according to the future intended use of the structure.

The technological survey comprises four main lines of inquiry:
- diagnosis, i.e. the set of techniques adopted in situ and/or in laboratory to collect the original natural characteristics of the timber (wood species, physical-mechanical characteristics of flawless wood, defects and anomalies), and those acquired subsequently after construction (biological decay, splits, deformation);
- grading according to resistance, using the results of the diagnostic phase to define the structural quality of the wood elements. The values of the main physical-mechanical characteristics are given according to “categories”, that can be used when calculating structural safety;
- evaluation of the joints functionality, essential for correct functioning of traditional timber structures. In many cases, the stability of the structure stem specifically from the insufficient capacity of the joints to transfer forces from one element to another;
- evaluation of the main restoration interventions. Those can be carried out both prior and during the monitoring. The aim is to assess the compatibility between the new materials and with the wood in situ.

3.2. Diagnosis

The technological evaluation of a single load bearing timber element involves the following steps:
- evaluation of the quality of the wood for which it is necessary to recognise the wood species and identify defects and anomalies in the members;
- assessment of possible biological alterations and damage occurred in the wooden element after construction;
- evaluation of the current resistant section;
- assessment of relevant physical-mechanical characteristics such as humidity, volume mass and elasticity modulus.

To carry out the diagnosis phase, the main physical-mechanical characteristics of the wood, its defects, and agents that may cause downgrading and impair its load bearing capacity must be known.

3.2.1. Requirements

The inspection always requires the visual accessibility of the structure, with suitable illumination (especially under the roofs), equipment for inspecting the material with physical contact (scaffolding, mechanical arms, ladders… complying with safety regulations). In addition, it must be possible to inspect the inaccessible surfaces such as the heads of trusses inserted in walls, the hidden sides of false ceilings, floors or other construction elements that impede viewing and contact. In these cases, interventions to liberate the elements,
dismantling or other actions that permit
inspection, or at least sampling, of inaccessible
elements must be carried out.
Any extraneous material (dust, dirt, rubble, etc.),
which often covers the surfaces of wood
elements, must also be removed. This phase
must be carefully programmed in agreement
with the various experts in order to avoid, e.g.
the removal of decorated surfaces, of linings of
historical-artistic value or traces useful for
identifying decay. The availability of an
architectural and geometrical survey, which
should be prepared in a phase prior to the
evaluation, is absolutely essential.

4. Direct observations on the material:
defects, alterations, recalls
When inspecting in-situ timber structures the
wood species, the flaws in the wood and any
alterations that have occurred must be identified.
An extensive literature exists regarding
inspection methods to which reference should be
made.
First of all, the wood species must be identified.
The volume mass, the mechanical strength and
the in-situ durability characteristics is directly
linked to this, albeit with an intra-species
variability. In the case of a restoration
intervention, any replacements must be made
using material with similar characteristics.
As far as constitutive anomalies in wood
members is concerned, the most important are
listed below (i.e. those that cause a more or less
appreciable reduction in mechanical strength
characteristics and which can therefore be
considered defects).
Longitudinal cracks are caused by the anisotropy
of radial and tangential shrinkage in the wood.
Therefore, they are not indicators of yielding
of the beam. Nevertheless, they may reduce its
resistance both with respect to tangential stress
that accompanies deflection and to other types of
stress, such as traction, especially in the case of
sloping grain. They are unavoidable if the
considered element contains pith inside (as usual
in beams).
Ring shakes may cause complete detachment of
the various parts of a beam, especially if such
parts are liable to tangential stress and also when
the ring shakes intersect radial shrinkage cracks.
Sloping grain reduces resistance of the wood,
because the maximum mechanical strength of
wood is provided when the load is applied in the
direction of the grain. This defect is often
accompanied by twisting, also caused by the
shrinkage of the whole element.
Knots are portions of branches that have kept
embedded in the trunk of the tree. They may
cause a considerable reduction of the strength,
even when if sound and adherent. The case is
worst when they are rotten, cracked or close to
falling out.
The wood is weakened both by the gap caused
by the knot and the fact that the grain of the
wood tends to deviate and bend around the knot.
Bio-organisms may cause biodeterioration of in-
situ wood and the environmental conditions can
favour this. Reference should be made to the
specific literature.
Concerning the observation of any yielding or
structural faults, the points to be checked with
greatest attention are the joints between the
wood elements and between these and walls.
Particular importance is devoted to these points
also according to Della Giustina’s, who analyzes
some of the most significant cases of failures
involving timber structures. After examining
800 of these, on behalf of the French Bureau
Securitas, it came out that 30% of structural
faults were to be ascribed to insufficient project
studies, 30% to imperfect joints between
structural elements (incorrect design, weak
links), 10% to fungi, 9% to insects (of which 7%
to the Capricorn beetle); 1% to different types of
attack, 19% to deformation and dimensional
variations in the wood, 1% to flaws in the wood.
Although these examples do not directly refer to
ancient structures, they are relevant, as ageing of
the wood is not, by itself, a cause of structural
weakening.

4.1. Evaluation of defects and anomalies
In order to define the extent of the defects
(useful for grading) the diameter and position of
the knots, the depth and direction of shrinkage
cracks must be measured (using thin instruments
such as millimetre rulers, flexible rods, etc.). In
addition, also shape defects (deformations and
warping) and deviation of the grain (the angle
formed by the direction of the gain in relation to the longitudinal axis of the member is assessed), ring shakes and the position of the pith inside the beam (observing the shape and position of the knots) must be recorded.

4.2. Evaluation of biological decay
Decay caused by fungi is generally found in areas where the relative humidity of the wood is above 20%. This condition may occur where construction details favour the accumulation of humidity in the wood, like at heads of trusses enclosed in supporting walls characterised by insufficient ventilation. Other critical situations may occur in areas of rainwater infiltration or in correspondence of the formation and accumulation of condensation, e.g. wood-metal elements contact areas.

Stains, haloes, changes in the colour of the wood indicate possible infiltration or percolation of water and may be a sign of past fungi attack. Therefore they reveal possible weakening of the material.

In species with differentiated heartwood (such as larch, bay oak, elm), it is important to record the extension of any sapwood. This region is generally less resistant to fungi attack compared with heartwood. Therefore, its presence has to be accounted for in the estimate of the residual durability of the element.

When zones characterised by favourable conditions for present or past development of fungi are present, the structural integrity of the wood can be evaluated by sampling its consistency with simple instruments, as listed in the tables below.

![fig. 5 Grades of timber members](image)

5. NDT diagnosis and instrumental survey techniques
Nowadays, NDT diagnosis of buildings is a very topical subject in the field of civil engineering for two main reasons. First, in order to draw up a structural survey of a building and to draft a correct project for consolidation and restoration of existing structures, it is essential to know, with a sufficiently high level of reliability, the mechanical characteristics of the materials in situ. Second, to construct a realistic model of the whole structure behaviour in its effective condition under actual acting load. In addition, in the structural consolidation project emerges an increasingly marked need to use suitable diagnostic techniques in order to identify where and how interventions must be carried out to consolidate a building. This is accompanied by the need to check the effectiveness of refurbishment interventions.

The above needs are accompanied by an ever more pressing demand for precise indications from sector operators, also in the light of the vast number of experiments carried out in recent decades. Similarly, in view of the increasing use of destructive and non-destructive surveys, and the spreading of increasingly technologically advanced instruments and equipment, there is a strong demand from practitioners for simplification of all the above techniques. In
fact, the difficulties frequently encountered in interpreting the abundance of available diagnostic data, implies that operators are often unable to use the specialists’ surveys. As they are professional restorers, they are not aware a priori of the limits or advantages of each particular method of survey. Therefore, they are often unable to use the related results in a profitable manner. Hence, the need to follow precise selection criteria for correct interpretation of the diagnostic survey project. Very often, the data required cannot be obtained with destructive type surveys as these would cause irreparable damage to the architectural work. In these cases, non-destructive testing techniques represent an excellent opportunity for providing the necessary information, without any noticeable repercussions on the structure.

In recent years, there has been a considerable increase in application of NDT techniques to timber using instrumental methods. As far as evaluation of the resistance of in-situ timber beams is concerned, most of these techniques are still at the experimental stage and may be adopted to integrate visual inspection but never, in any case, to replace this. The attitude of relying entirely on instrumentation, on indirect investigation, reflects an illusory confidence in the equipment and often generates very poor diagnostic results. Thus, the results of the experiment cannot be used by the professional figure responsible for the intervention. In other words, it is advisable to entrust instrumental investigations to specialist personnel only if a correctly-formulated, fully-articulated diagnosis has been drawn according to clearly-defined objectives to be achieved. However, and this is the second important suggestion, instrumental investigation can never replace visual inspection.

A number of non-destructive and/or almost non-destructive diagnostic techniques that have now reached a good level of effectiveness and reliability, as regards management of experimental results, are outlined below. Division of the techniques into non-destructive or partially destructive, such as for example micro-drilling, is not so significant for in-situ timber structures. However, as a first general classification can be attempted according to different objectives:
- surveys of elements for mechanical characterisation of the material;
- detailed surveys of sections of timber to assess their state of conservation;
- surveys of the entire structure.

Certain instrumental techniques are able to provide further indications regarding the state of the material, and can be applied where and when the technician involved in the inspection considers this advisable. These can provide, case by case, quantitative indications regarding the mechanical characteristics of the element, identifying for example the presence of disconnections, hidden defects, diseases, etc. Some of these can be considered as well-established in view of the number of experiments carried out and the results obtained. Others are more innovative with most of the applications still at the experimental stage, and usable only by specialist personnel. Theoretically, the simplest method for evaluating the mechanical characteristics of a timber element, if binding conditions and geometrical characteristics are known is to carry out a load tests with given loads and measurement of the elastic deformations. However, although the problem is elementary from a theoretical point of view (such as, e.g. determining the elasticity modulus of a beam according to its deflection under known loads), from a practical point of view, it is not always easy. It may even be impossible to apply the test loads, measuring the related deflections and applying stress to the element in the same conditions in which it operates. In addition, the influence of the defects varies according to the face of the beam on which the load is applied. In recent years, ultrasonic surveys are increasingly used in many industrial sectors. Ultrasonic prospecting applications has been applied in the characterisation of many construction materials, included timber. Some difficulties arise in coupling the transducers and the surface of the wood. Therefore, the effective path followed inside the wood and the influence of the various factors on speed of propagation in the wood is still uncertain. This method cannot as yet be considered sufficiently reliable. The various
applications available at the moment, both those
designed originally for other materials and
subsequently applied to wood, and those
specifically developed for the mechanical
qualification of wood, are equipped with two
transducers. The transmitter and the receiver are
applied at two specifically selected points of the
beam at a known distance, and the time taken by
the ultrasonic vibrations to travel from one
transducer to the other is measured. The speed of
propagation V (conventional, since the effective
path of the vibrations is not known) is calculated
according to time and the distance between the
transducers. From this value, and from
the volume mass of the wood, it is possible to
obtain, with a specific formula, the "dynamic
elastic modulus" Edin.

The optimal operating condition is when the two
transducers are applied to the heads of the beam.
Unfortunately, as these are seldom accessible
and sound, the transducers must be applied in a
specular manner, i.e. on the same face of the
beam or opposite each other on two opposed
sides. In this way, the propagation time through
the width of the beam is measured.

Despite the uncertainties outlined above,
according to various Authors, this method has
demonstrated effective on certain wood species
both as a predictive instrument for evaluation of
mechanical characteristics and for identification
of zones attached by fungi.

Vibratory methods can also be used to obtain an
elastic modulus Evibr with a certain degree of
approximation. However, at the moment, very
little experience exists of application of this
technique to in-situ beams (in particular because
it is difficult to schematize the constraints in a
simple manner). On the other hand, the method
is widely used in laboratory for mechanical
grading of sawn elements.

Another useful method of analysis is based on
in-situ measurement of the hardness of the wood
of a beam. This mechanical characteristic is
closely linked to the volume mass of a material.
Subsequent application of suitable corrective
coefficients, according to wood species, the
defects of a single beam etc., allows for a good
estimation of certain properties of the "default-
free" wood. Various application exploiting this
technique have been developed for in-situ
measurement, such as the Pilodyn or the
impression test of Turrini and Piazza.

The endoscope analysis permits the direct
examination of the inside of the wood. Therefore,
its permits to detect areas of rotted
wood, discontinuities in portions of wood not
directly examinable “de visu”. On the other
hand, this technique cannot provide indications
regarding the mechanical characteristics of the
material. Moreover, this technique cannot be
defined as completely non-destructive as, in
surveys of timber, it is necessary to drill an at
least 12-mm diameter hole. In addition, the
cutting of cellular elements is not very clean and
the sawdust that remains attached to the edges of
the walls makes it difficult to interpret the
images.

Although apparently similar to the previous
method, the resistograph has peculiar aspects
that make it more effective. It is based on
Resistograph®, an instrument available on the
market. The instrument assesses the density of
the wood by measuring its resistance to
penetration of a very thin needle using a specific
drill (which makes a 3-mm diameter hole). The
drill is equipped with two electric motors, one of
which controls the rotary movement of the
needle while the other moves this forward at
constant speed (adjustable to 7, 14, 28 cm/min).
The density of the wood is assessed by
measuring the current absorbed by the two
motors in drilling the hole and in moving
forward. Thereby the measurement of the
resistance to penetration can be correlated to the
density of the drilled material. The data recorded by this tool are transmitted continuously, during the test, to a printer. The graphical output reports, on the X axis, the depth of the hole in 1:1 scale and, on the Y axis, the resistance to penetration. It is also possible to save the data (25 measurements every millimetre of thrust) on a computer. Theoretically, such instrument is able to assess the internal discontinuities in the wood, to provide indications on resistant section and to measure the thickness of the growth rings. Anyway, certain restrictions exist. Various methods of application of this instrument for mechanical assessment of defect-free wood have nowadays been considered.

The application to wood of the thermograph method appears to be not very realistic, since it is usually difficult to place it in a useful way. Although it works at different wavelengths, a similar method is that of NIR spectroscopy based on quantifying absorption by the material of near infrared light (700 - 2500 nm). It has proven to be an excellent technique for non-destructive assessment of humidity, density, resistance to compression and chemical downgrading on specimens of red pine. At the same time, the method provides indications regarding the surface layer of the material examined. However, it must be stressed that application of this method to ancient timber structures, affected by photo degradation or surface oxidation, is still to be investigated.

Radiographic analysis techniques (x, y rays, computerised tomography) are indicated for completeness, since their possible applications are well known. These techniques not only permit identification of organisms, discontinuities, bio-downgrading inside the elements examined but also measurement of their density. Nevertheless, at the moment, their application is restricted to small, easily transportable, objects due to the high costs involved and to the hazardous nature of certain applications.

6. Conclusions
A brief overview of various instrumental methods (stemming from recent technological innovation) for non-destructive diagnosis has been presented. The above notes, trace an initial reference framework that highlights the main available survey techniques at present time. Some of those approaches can be readily used in the project. Others are less efficient or are not entirely reliable since they have not yet been sufficiently tested on timber structures.

A possible guideline for the diagnostic process must take into account two different phases: “first level” surveys, without using instrumentation (or with simple instrumentation) that comprises construction surveys, visual inspections, the drafting of protocols and of thematic charts. A “second level” survey, performed using instrumentation such as ultrasonic techniques, endoscopes, thermography, etc. The two levels of analysis may be combined together to provide a quantitative assessment of mechanical strength, of decay of the material and of the structures in their entirety.

The main distinction between the two types of survey is that the first provides qualitative type evaluations and the second qualitative and quantitative analyses.

The current trend, according to which designers ask for increasing instrumental diagnostic surveys, cannot and must not justify replacement of what is the most reliable “instrument”, i.e. direct observation.
7. Bibliography


