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Juniper structures in Western Mediterranean vernacular architecture: ongoing research

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Abstract.

This research highlights the constructive features of *Juniperus thurifera* timber visible in the Western Mediterranean (from the island of Sardinia to Morocco). The use of this material is above all related to vernacular and traditional architecture, in the coastal areas as well as in the interior of the analyzed countries. An initial taxonomy of its use presents us with the issue of understanding the main structural performance of this type of timber, focusing in particular on its structural use and behavior. The results, visible throughout the research, are related to the resistance of the timber and its performance. On the other hand, this raw material is valued in vernacular architecture because of its strength when exposed to sea water or harsh weather conditions. Juniper beams and pillars are the most frequent solutions, but the use of branches and roots is also common, as the research demonstrates. In this framework, the text underlines the results of the research based on a geographical survey of juniper as a construction material, and on the first attempts to study its mechanical performance.

Featuring: juniper timber

Juniper timber has been employed throughout the centuries in several examples of traditional architecture, visible all over the Mediterranean basin; it has also sometimes been confused with cedar timber, due to the similar qualities and properties that these timbers share.

"The cedar and the juniperus trees possess the same qualities as the two latter names (note: referring to pines);but just as the cypress and pine yield a resin, the cedar tree yields an oil called cedrium, with which, whatever is rubbed, such as books, for instance, will be preserved from worm. The leaves of this tree resemble those of the cypress, and its fibers are very straight. The statue of the goddess, and also the ceiling of the temple of Diana at Ephesns, are made of this material, and it is used in many other celebrated temples, on account of its great durability."[1]

It is worth highlighting that, in the constructive tradition of ancient Greece, the name for aromatic timber with straight and thin fibers was *Kedrós*, a word which was used for *Juniperus, Cedrus, Tetraclinis*...for this reason there's some confusion in terms of the timber definition, a confusion that continues through the roman constructive traditions.

If we review the names of timber throughout the Iberian Peninsula at that time we find some curious references such as: *Spanish Cedrus, Juniperus* (in the north- central-regions of Spain), *Sabina Albar* or *Albarra, Roma, Tejo* (or white juniper in the central- eastern regions), *Intzentsu Miterra or Intzentsu Sabina* (in the north eastern regions) [2].

Outside of the Iberian Peninsula the distribution of these woods is quite scarce but visible in some regions; yet it's possible to find translations of the name of the tree, such as in Southern France (*Vrier de l'encens*), and in Southern Portugal (*Sabina Turifera*) and Central/Southern Italy (*Ginepro Turifero*).

Within this framework the research started with the identification of the type of tree, the features and the classification of the species. Thanks to this it's possible to chart an evolution in the history of its classification; Linnaeus (1707-1778) was one of the first that defined the *Juniperus thurifera*, followed by Lamarck (1744-1829) and Miller (1691-1771), who called the species *Juniperus hispanicus*; later S. L. Endlincher (1804-1849) classified the tree as *Juniperus sabinoide*, and Antoine F. (1815-1886) again as *Juniperus thurifera* [3].

Thanks to this short journey through Botanical history we can appreciate the link between the Juniper's name, and Spanish geography, as well as Mediterranean geography in general.

It's Latin name, *thurifera*, may also be useful in understanding one of the most significant features of the timber, the oleoresin that the wood contains; the name *Juniperus* comes from the Latin "IENIPERUS", meaning juniper, meanwhile *thurifera* comes from "THURIS", meaning incense and "FERO", to carry; in other words "juniper that carries incense".

Juniper timber structures in the Western Mediterranean

Different traditional buildings, built using *Juniperus thurifera* timber structures, are visible throughout the Mediterranean (above all in the West, from the island of Sardinia to Morocco). The timber is used in a hierarchical system organized by pillars, beams, purlins, rafters and branches. Frequently these structures are supported by thick perimeter walls and stones, often associated with thatched or tiled roofs.

The use of *Juniperus thurifera* timber is linked to the shaky economy of these areas, seasonal migration of livestock and the employment of proximate natural resources from the inner areas of Mediterranean Basin [4].

This type of juniper tree has an incredibly slow growth and although the trunk can reach 20 m in height this is of course not as common as examples of "just" 4 or 8 m high. The slow growth process (the trunk only increases 1-3mm in diameter each year...) guarantees a good density of the timber, especially in some of the oldest special trunks of 1 or 2 m in diameter. These trunks are used in the interior of Spain and North Morocco as beams and pillars in residential vernacular architecture. On the other hand shortest elements, like the branches or roots, of just 0.7 or 1 m in length, are useful above all for lintels, in openings like windows, doors or porches (in this case the examples are visible from Spain to Italy, passing through the South of France, Fig.1). Undoubtedly, this raw material, irrespective of the length of the trunks, is valued in vernacular architecture for its strength in when exposed to sea water or harsh humid conditions. Juniper beams and pillars are the most frequent solutions, but the use of branches and roots is also common.

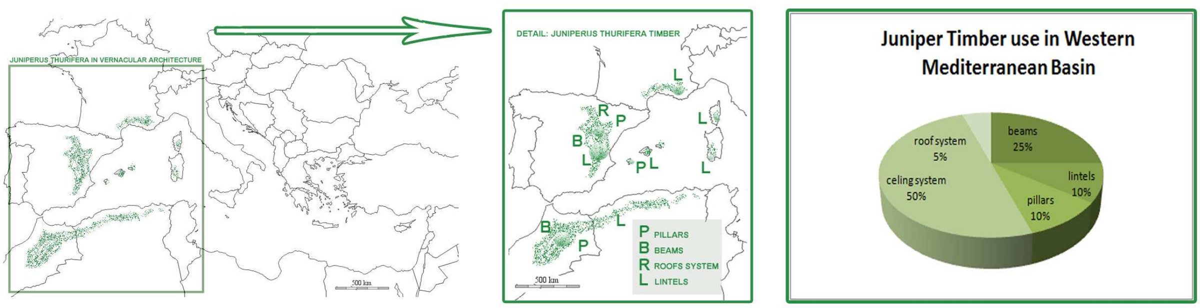

Fig. 1. Juniper Timber use in West Mediterranean Basin

In general the trunk is characterised by grey bark that is scarcely scored by waved grooves along the whole tree, just like the common Juniper species. If we analyzing the tree we discover a conical, irregular trunk, ash-brown in colour, fibrous and with deep cracks that break off into splinters; in addition the base of the trunk has an aged and scored system of roots, due to the slow growth process[5]. The *Juniperus thurifera* also has shoots that are broken into enlarged galls. The main branches are very thick and developed. The top is more or less conical in shape, especially during the early stages of the tree's life.

Xylophages’ resistance: performance of the timber

The heartwood of the juniper tree is strongly scented and displays contrasting growth rings marked by darker dense areas of latewood. Although grain disturbance around the knots in the timber may be visible, the selected specimens are smooth grained with a medium to fine texture. Thank to these features the timber is durable, resistant to attack from Mediterranean timber borers and termites. These features are made possible thanks to two different factors. On the one hand the timber has its own defense mechanism in the form of repellent chemicals (such as resins) which are contained in the woody cell walls. On the other hand, this raw material, due to the buildup of these resins, boasts an extremely dense heartwood. In this framework the surveys [10] have shown that the timber is frequently used in contact with sea water (Balearic Islands) with soil, or cattle and agricultural waste material (above all in the mountainous inner areas of Sardinia, Spain and Morocco Fig.2). In the Balearic Islands, for example, the timber is frequently used in contact with sea water, in ship shelter structures; meanwhile in inner rural areas of Spain or Morocco these timber structures are in particular used for shepherds’ shelters [5].

Fig. 2. Different use of Juniper Timber in the vernacular architecture of Western Mediterranean

The analysis has shown that 10% of the old structures (type 1&2 samples) have been attacked, just superficially, by Anobidae beetles (with circular perforations/diameter between 1-2 mm). No presence of Curculionidae larva (usually characterised by elliptic perforations/diameter between 3-4 mm) cerambycidae larva or termites have been detected. On the other hand the possible presence of bark beetles (Scolytidae- Coleoptera) was detected in young logs (1 trunk identified during the selection of samples). The attack is visible thanks to the engraving on the surface of the wood (Fig.3). The presence of these xylophages could be caused by warmer winters in the inner regions of Spain, a characteristic that allows this species to expand its range and proliferate.

Fig. 3. Xylophages attack (bark beetle) visible during the selection, obtained from young logs

Mechanical performance: studies and analysis

The authors have taken into account a few specific characteristics in order to study in depth this type of timber [10]. On the one hand the proposal of the research was to respect the historical juniper timber architecture, the concentration and quality of which has been highlighted in some of the case studies. In order to reconcile all these factors the study has been developed above all with non destructive tests, and only occasionally, with analyses of tension and compression along the grain.

The research has been carried using three main groups of timber samples for study and analysis, depending on the different environmental conditions, humidity, temperature and conservation circumstances.

The study has been structured both in terms of old timber [6] and new raw material (Fig.4), taking into account the fact that the protected status of this timber (*Decreto autonómico 12/87, de 3-2-87, Protección de la Sabina Albar*), means that carrying out campaigns with large numbers of samples is complex, due to the fact this would involve the felling of many specimens (in this case only in specific cases under the strict supervision of a specialist forestry surveyor).

As such it was proposed that non destructive methods should be used (NDT - non destructive testing) for the mechanical characterisation and determination of the old wood, as have been employed in previous studies [4]. Nevertheless, using parts of the unused material from the non destructive tests, we proceeded to carry out destructive mechanical testing (parallel compression and simple flexion).

Fig. 4. Three group of samples: indoor timber/mixed timber/ outdoor timber

The first group (type 1) included 20 timber samples proceeding from 5 beams, obtained from a ceiling of a disassembled private house structure, built in the 50s. This collection of samples would be termed as having a low risk of biological assault (class 2, according to Spanish technical building code, CTE DB SE-M, RD 314/2006). In this case the timber is classified as part of a well maintained indoor structure. Overall, the samples came from a timber that has always been protected from bad weather conditions, and only occasionally exposed to high environmental moisture that could lead to superficial, non-persistent moistening.

The second group of samples (type 2), included 20 timber samples, proceeding from 5 beams obtained from a roof structure of a shepherds' shelter built in the 70s. In this case the timber has been defined as part of an indoor/outdoor environment, with a medium risk of biological attack (class 3, according to Spanish building technical code, CTE DB SE-M, RD 314/2006). These juniper timber samples have been partially protected from bad weather conditions, and frequently the environmental moisture conditions would be higher than 20%.

Finally the third group of samples (type 3) was obtained from 20 timber samples, proceeding from 5 juniper trunks, recently been felled and dried naturally. Each sample was prepared and standardized, according to UNE EN 408: 2011+A1 (Table2).

Table 1. Dimensional features

DIMENSIONAL FEATURES	SAMPLES (type 1)	SAMPLES (type 2)	SAMPLES (type 3)
AVERAGE SIZE ORIGINAL TRUNK (Ø+length)	182 mm Ø 2,5 m	210 mm Ø 2,20 m	195 mm Ø 2,10 m
SPECIMEN DIMENSION FOR BENDING TEST (mm)	20x20x300	20x20x300	20x20x300
SPECIMEN DIMENSION FOR COMPRESSION TEST (mm)	20x20x60	20x20x60	20x20x60
ANATOMICAL DIRECTION	Parallel to the fibres	Parallel to the fibres	Parallel to the fibres

Table 2. Samples features

FEATURES	SAMPLES (type 1)	SAMPLES (type 2)	SAMPLES (type 3)
AVERAGE WEIGHT/ NON DRIED SAMPLE (g)	13,6	12,5	15,5
AVERAGE WEIGHT/DRIED SAMPLE (dried to reduce the moisture content to less than 1%,)	12	11,1	12
AVERAGE TIMBER MOISTURE (%) (according EN 13183-1/AC:2004 procedures)	11,59% (11%-12,20%)	14% (13%-15%)	16% (15%-17%)
AVERAGE TIMBER DENSITY (kg/dm3)	0,57	0,52	0,55

Later, all the elements were tested using ND tests[7], in particular the resistograph test (Fig.5 IML RESI B300® model, Wood Testing System), ultrasonic test (SYLVATEST DUO®) and sclerometer test (PYLODIN®).

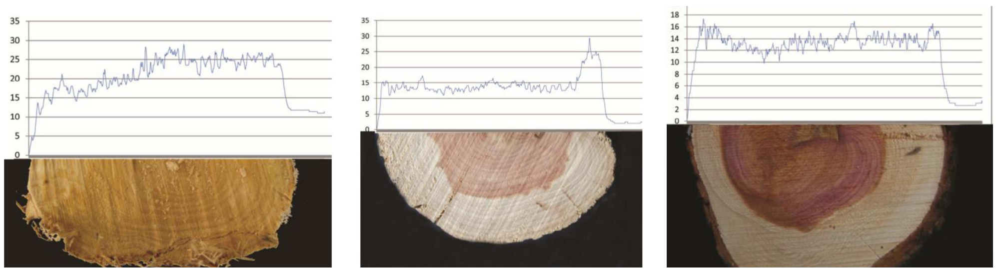

Fig.5. Resistograph test results: examples of samples from group 1, 2 and 3

The first test, carried out on 60 different timber samples (from groups 1, 2 and 3) in the laboratories of the UPV University in Spain, established different profiles of density in relation to conservation and mechanical features [8]. The second, an ultrasonic waves test, where a straight line pulse is emitted parallel to the grain, defined the density performances of 60 samples of juniper timber. In this case, the length of time (µs), that the wave takes to cross the timber (between the pulse receiver and the sender) depends on the density of the timber and its possible imperfections [9]. Finally, thanks to the third test, made by a sclerometer, it has been possible to define the relationship between surface hardness and compression strength of the 60 samples analyzed.

The instrument made it possible to establish the depth of penetration in the timber samples, through a device with an adjustable weight and spring (Table 5.). Finally mechanical tests were used for the analysis of compression/bending along the grain according to UNE 56528:1978 guidelines. An electromechanical testing machine (L IBERTEST STIB-200) was used for two stages of tension/compression tests, with maximum loads of 200 kN and 100kN, respectively (Table 3-4).

Table 3. Bending test results

BENDING	**SAMPLES (TYPE1)**	**SAMPLES (TYPE 2)**	**SAMPLES (TYPE 3)**
BENDING TEST (N/mm2)	38,51	20,16	57,24
AVERAGE VALUE OF BENDING STRENGTH (N/mm2)	53,68	25,01	64,75
STANDARD DEVIATION (N/mm^2)	2,1	1,5	2,53
DEFORMATION (mm)	5,1	4,46	9,12
CHARACTERISTIC BENDING STRENGTH(N/mm2) $\mathbf{f_{m,k}}$	22,23	15,11	49,93
20 samples(20x20x300mm)			

Table 4. Parallel compression test results

PARALLEL COMPRESSION	**SAMPLES (TYPE 1)**	**SAMPLES (TYPE 2)**	**SAMPLES (TYPE 3)**
COMPRESSION STRENGTH TEST (N/mm2)	41,57	25,16	37,1
AVERAGE VALUE OF COMPRESSION STRENGTH TEST (N/mm2)	45,93	25,01	36,76
STANDARD DEVIATION (N/mm^2)	1,37	1,6	2,01
DEFORMATION (mm)	2,18	4,46	3,3
CHARACTERISTIC COMPRESSION STRENGTH (N/mm2) $\mathbf{f_{c,0,k}}$	43,22	20,02	23,86
20 samples (20x20x60mm) tested parallel to the fibres			

Table 5. Ultrasonic waves and sclerometer tests results

OTHERS TESTS	SAMPLES (TYPE 1)	SAMPLES (TYPE 2)	SAMPLES (TYPE 3)
Ultrasonic Waves test (m/s)	4107	3517	2819
Sclerometer test (average value, obtained by tacking 10 measurements, tangencial to the fibres) [Penetration direction value (mm)]	11	12	12,5

Conclusions

Juniperus thurifera timber, when used as a raw material in vernacular Mediterranean architecture, has made the conservation of noteworthy examples of traditional buildings, as well as humble constructions, possible. The great variety of case studies that have been built using juniper timber "subproducts", like roots, branches and leaves, is also very interesting. Other types of Mediterranean timber, such as pine, black poplar or oak, used in the same conditions, would probably have been attacked by different biotic or abiotic agents.

Thanks to the results obtained from the destructive and non destructive tests, it is possible to highlight the influence of the weather and humidity conditions on mechanical behavior. But, in this framework, it's interesting to observe that, in spite of exposure to threatening agents, the performance of the samples (in particular from groups 2 and 3) is quite good (the reduction of bending/parallel compression tests in group 3 is less than 50%).Finally the resistograph tests show how the samples respond in more or less the same way to mechanical drilling along the radius of the wood, evaluating the timbers resistance to perforation (on average between 15 and 20%). In all the tests the graphs are practically continuous, with the exception of a few variations and no significant deviations are evident, an aspect which implies that all the wood in the analysed section is in a healthy condition, despite the differences in use, humidity conditions and possible attack from insects in the area cut.

The density and resistance results (determined by the ultrasonic wave or sclerometer tests) emphasize even further the relationship with environmental exposure and moisture content. These factors would result in a loss in the transmission of ultrasonic speed (around 50% reduction) and the penetration direction value would also increase from 11mm (type 1) to 12.5 mm (type 3). But it's interesting to highlight that, even considering these factors, the performance of the 3 groups of samples is noteworthy, with excellent characteristic compression or bending strength results.

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