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THE PRODUCTION OF HARDWOOD X-LAM PANELS TO VALORISE THE FOREST-WOOD CHAIN IN PIEMONTE (ITALY)

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ABSTRACT: The work fits in the framework of the increasing interest on the structural use of wood-based materials by Italian companies and research groups; it describes the preliminary steps of a project about the production and testing of new hardwood panels of the X-Lam type made with local timber, equipment and skills available at regional level.

KEYWORDS: forest-wood chain valorisation, Piedmont, Bois-Lab, X-Lam, chestnut, poplar

1 INTRODUCTION [11122]

With the technical and financial support of the Provincia di Torino and some private companies, a research group of Politecnico and Università di Torino was involved in a preliminary project designed to contribute to the valorisation of the timber coming from a short supply chain and to innovation of the local woodworking sector. After the recent issue, on February 2009, of Piedmont's new forest law, which recognizes the collective, multifunctional value and the economic importance of the regional forest resources, this project, with other remarkable initiatives, intended to verify the possibility of realizing cross-laminated panels (X-Lam) made with chestnut and poplar wood within the present industrial framework. The aim was to increase the structural use of wood produced by local forests and plantations.
The cross-laminated solid timber panel or plywood consists of sawn boards of the same thickness, in some cases joined in a lengthwise direction and arranged in cross-grain layers.
Although they have appeared only recently on the market, X-Lam panels (also dubbed X-Lam or Cross-lam, composite plywood, cross-laminated timber; BBS - Binder BrettSperrholz or MM-BSP (Mayr-Melnhof-Brett Sperrholz Platten), have aroused considerable interest in the sector of technological innovation and eco-sustainable construction materials.

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Originally, cross-laminated timber was intended to permit use of the processing rejects of the large Central European conifer sawmills, while the most innovative aspect consists in having developed large-size prefabricated wood panels of reduced thickness and with high level mechanical strength, used both as walls and ceilings. Openings can be made in the surface by eliminating the part forming the aperture. X-Lam panels are mainly used as "hidden" bearing elements which seldom require material selected according to its aesthetic features. The most frequent types of consolidation include gluing with polyurethane or melamine mixes and also the use of metal staples or nails or wood plugs. The first method is used more frequently in an industrial context, while the other two methods are adopted more in the craft-based and bio-construction sector.
The particular composition of the panels endow these with excellent dimensional stability and the same level of performance in the two directions of the floor, whereby they can perform the structural function of plate and sheet. As they are able to absorb and unload stress in several directions, adopting suitable connection systems, they can be used to construct light, ductile structures with high dissipation capacity, ideal in the case of seismic risk.
As they are dry laid and feature a high degree of prefabrication, use of these panels as bearing structures of walls, ceilings or roofs promotes reduced construction times of the structures and the possibility of immediate fruition of the building. The structure obtained can be lined on both surfaces with a set of insulating layers (usually consisting of other wood panels or of different materials) and finish layers.
In view of their insulating, breathability and thermal comfort properties, the above package is particularly suited for constructing high performance building envelopes and buildings characterised by low energy

consumption and environmental comfort; with suitable stratifications, it also guarantees a significant level of acoustic insulation.
The most frequent uses include the construction of multi-storey residential buildings, public buildings, schools, also simplifying the use of wood for more architecturally demanding buildings and constructions [3].
For this purpose, a small sample of experimental X-lam panels were manufactured in industrial site in order to verify their technical feasibility and some physical-mechanical properties, thereby laying the bases for further testing intended to define their characteristic performance profiles.

2 AVAILABLE WOOD RESOURCES AND VALORAZATION ACTIVITY

Starting from the Second World War, the use of Piedmont forests deeply changed. Over the years, in fact, timber production frequently left its place to other functions like erosion control, natural purposes, conservation of wildlife habitat, recreational use etc. Presently, most of the natural forest resources are mainly managed for maintenance and environmental purposes.
In this context, today a very small quantity of timber transformed by local manufacturers is supplied by the regional stands, while the largest part is imported from neighbouring and foreign countries.
However, during the last years new forest policies were developed in order to satisfy, at least partially, the domestic demand of round wood. This approach consisted in the diffusion of fast-growing tree plantations (made with new poplar clones, special stands for biomass production), high value hardwood plantations with medium-long rotation and other actions connected to the exploitation and promotion of the local timber resources.
The Regione Piemonte covers an area of about 2,600,000 ha. Forests represent 36% of the regional surface and reach about 923,000 ha, of which 875,000 ha are forests and 48,000 ha are hardwood plantations in arboriculture stands [1]. The characteristics of regional forests widely change depending on the different parameters of the territory (Figure 1).

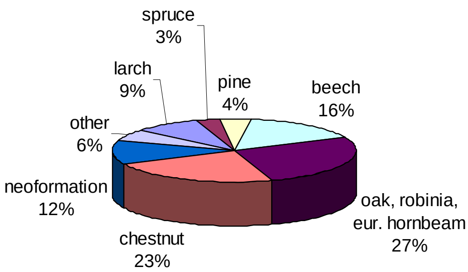

Figure 1: *Main forest types in Piedmont, Italy.*

In the mountains, 54% of the surface is covered by forests, 36% of which are covered by simple coppice, 26% high forest and 17% by coppice with standards. The most common types are chestnut (27%), beech (21%) and larch (12%) forests.
Forests cover 41% of the surface of the hills; about 2/3 of such area is populated by simple coppice followed by coppice with standards and high forest. Robinia (36%), oak (19%) and chestnut (18%) forests are the most common types of forests of this area.
On the plain, forests cover just 13% of the surface. Coppice represents 42%, coppice with standards 28% and high forest 18%. With respect to the forest types, robinia (44%) and oak with hornbeam (20%) forests prevail.
As for property, communal property in the mountains represents 1/3 of the forest surface, public forest in the hills represents 4% of the total, while on the plain it reaches 11%. Nevertheless, up to now, the unfavourable morphology of the forested surfaces and the fragmentation of their property hold back the increase of exploitation.
With respect to the industrial wood sector, poplar and chestnut are the relevant species available in Piedmont.
Poplar (*Popolus x euroamericana*, different clones but mainly the 'I-214') is characterized by a short supply chain which links together farmers, harvesting companies and panel's industry. This chain is highly specialized and particularly devoted to the production of plywood for furniture. The regional production of poplar plantations is around 450,000 m^3/ha per year.
Chestnut (*Castanea sativa* Mill.) covers more than 204,000 ha (Figure 2), of which about 11,000 ha are destined to fruit-growing production. Their mean production is 220 m^3/ha per year and the average increment amounts to 8.3 m^3/ha per year. 91% of the property is private, while the remaining 9% is owned by the government.

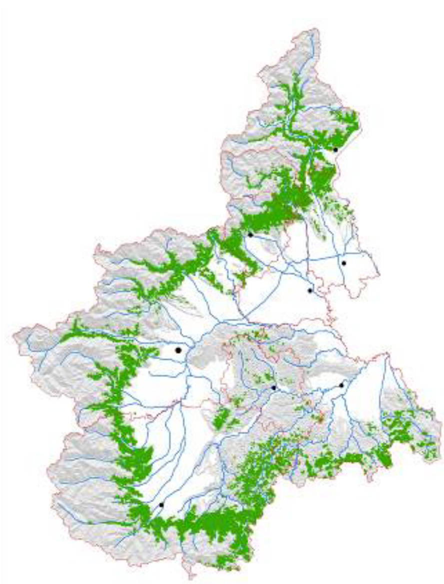

Figure 2: *Localization of chestnut forests (in green) at regional level.*

Up to now the chestnut supply chain was mainly focused on tannin production in a plant located in the southern

part of the region. Its production of 116,000 m^3 of chestnut logs involves more than 60 other small enterprises specialized in chestnut coppice harvesting.
A minor part of local chestnut coming is destined to more valuable uses such as carpentry and sawntimber. In particular, recent studies [3] show that the quantity of higher value timber in chestnut coppices ranges from 4 to 15%.
Finally, the supply chain of other hardwood species is basically related to the production of firewood. About 150 enterprises work in this sector, gathering more than 140,000 m^3 of firewood per year.
Local resources of softwoods are quite limited, especially spruce, which is widely requested by the woodworking sector.

The present work is linked to the implementation of a more active management of the regional forests and to the increment of wood production. Both have been developed by recent projects and studies on forest planning, estimation of the wood resources and the analysis of companies involved in the wood sector and in the promotion and use of local timber through the manufacturing of new products destined to non traditional applications [10]. In particular, the research activity took place within the BOIS-LAB project, a EU-funded programme in the framework of INTERREG/ALCOTRA 2007-2013 that helps Europe's regions to form partnerships to cooperate on common interests. By sharing knowledge and experience, such cooperation enables the regions involved to develop new solutions to economic, social and environmental challenges.
In order to offer improved development opportunities for mountain areas, the Provincia di Torino and the Department of Savoy (France) work together in this project to apply scale strategies able to sustain the offer and demand for industrial timber and wood for energy of local origin, through awareness-raising, training and communication actions.
The project is based on sharing of aims and active participation of all the categories involved in developing the forest-wood chain, giving priority to professional update and training of professionists, craft-based construction and timber firms in the use of local wood.
These actions can be classified in three main categories: forest policies, short wood-chain development and construction timber supply.
Regarding forest policies, two actions of the BOIS-LAB project have been identified to enhance management of local forest assets and sale of logs productions. Through action 1 territorial agreements and procurement plans will be defined while, in action 2 innovative methods for the sale of forest stands and timber will be adopted, including modern systems for qualification of local productions by means of marks and traceability.
Short wood-chain development comprises targeted actions for the improvement of local supply chains. Through action 3, a suite of awareness-raising, animation and involvement actions addressing private forest owners will be drafted with the aim of concentrating the offer, thereby overcoming the negative effects of fragmentation. Action 4 envisages exchange of experiences regarding the valorisation of fuel wood while in action 5 the technical-design documentation for setting the infrastructures required by the wood-energy supply chain will be drafted.
Action 6 about construction timber supply will envisage the validation of automatic ultrasonic sawn timber grading systems according to current European standardization. In action 7, a broad divulgation and documentation plan will be drafted concerning the use of local wood as construction timber, followed by actions 8-9-10 intended to configure a context of updated information regarding best practices, promotion of the use of local wood in public building and coordination/monitoring of project workshops.
The research experienced, intended to verify potential uses of wood of regional origin for the production of construction components, is thereby linked to several actions of the project mentioned above.

3 MATERIALS AND METHODS

Analysing the models of wood supply in a short chain, with specific focus on the differentiation of the local productive sectors, which are well consolidated in various European countries like Austria, Switzerland and Germany, the production of cross-laminated timber (X-LAM) seemed to be particularly interesting for attaining the intended goals. This wood-based material presents different configurations that the identification and establishment of new supply chains and markets made possible through the systematic application of competencies and experience of the *holz cluster* environment.
The research activity focused on certain districts of the Province where the possibility of producing structural panels of the X-Lam type made on chestnut sawn timber and poplar veneers was verified, through discussion with various stakeholders involved in the wood chain and considering the potential of the wood species locally available.
A sector analysis highlighted two industrial partners with adequate technological know-how, equipment and production capacity in this field who have shown interest to participate to the research: a sawmill that operates in the first transformation of chestnut wood and a plywood company specialised in the production of panels for different applications.
With the scientific coordination of Politecnico and Università di Torino, a technical cooperation leading to the production and experimental testing of various cross-laminated construction components was made possible.

3.1 PANELS PRODUCTION

Avoiding to compete with the biggest European timber companies, specialized in structural panels composed with spruce and other softwoods, the panels produced in this project are intended as an initial step towards the valorisation of the construction timber supply chain in Piedmont, with the aim of exploiting the current level of scientific and technological know-how for defining construction industry components.

The chestnut sawn wood used, coming from aged coppice, was selected according to the national standard UNI 11035-1/2 that made it possible to rate the wood material on the basis of surface appearance (according to the dimensions and distribution of major defects) and to reject elements not endowed with the necessary structural features.
The sawn wood was obtained from chestnut logs of small diameter and length ranging from 2 and 2.5 m; this made the construction of panels without butt joints of the pieces possible. The material selected was trimmed and planed with a view to facilitating gluing and guaranteeing a correct composition of the elements.
The final panels size (2x2 m) and thickness (75 mm) were chosen also for avoiding problems connected to an excessive weight during their processing and handling with standard plywood production line.
A total number of 3 panels were produced in this first industrial test, two made of chestnut and one of poplar.
The chestnut panels were obtained by composing three cross layers of 25 mm thick sawn wood) (Figure 4). The side join between the sawn elements forming each single layer of the panel was made using metal staples.

Figure 4. *Chestnut panel during gluing and pressing.*

The poplar panel was produced with the above lay-up but using 5 layers of 15 mm thick plywood alternated with 4 veneers of 2 mm in order to reach the same thickness for the panel (Figure 5).

Figure 5. *Poplar panel during assembling.*

The plywood used was of II/II grade according to EN 635-2 and glued with the same adhesive used for the production of the X-Lam panels type.
The central layers were glued on a two-roller adhesive coating machine using a MUF gluing mix suitable for bearing components, able to guarantee class 2 gluing (for use in humid conditions) and class "E1" of formaldehyde emission. The quantity of adhesive used was 250 g/m^2 per single glue line. The panels were then pressed, inserted in a hydraulic machine, where they remained for about ten hours at a pressure of 10 kg/cm^2 and at an initial temperature of 100 °C that reduced slowly with time. This solution was adopted because with the thermo-setting adhesive system used the height panels thickness needed long polymerization time.

3.2 MECHANICAL TESTING

The reference standardization for the definition of structural performances of X-Lam panels type is in evolution. This panel should be considered as a multilayer SWP for which the main technical documents are EN 13353 (product standard), EN 13986 (Harmonised standard for EC marking of wood-based panels for use in construction) and the standards referred by these (as EN789 for mechanical properties and EN 12369-3 for characteristics values). Other standards can be applied on the basis of specific requirements for the intended use. In order to obtain EC marking some manufacturers decide to homologate their production through the ETA (European Technical Approval) procedure without the guidelines established by EOTA.
After having defined a cutting plane in order to obtain the highest number of specimens these were prepared at the plant side (Figure 6).

Figure 6. *Chestnut and poplar specimens of the X-Lam type produced with local wood.*

Tests were carried out by MASTRLAB – materials and structures laboratory – at Politecnico of Torino.
For this purpose an electronically-controlled hydraulic machine with a maximum load of 500 kN and precision class 1 was used.
Tests were carried out according to EN 789 for bending and compression.
The 4-point bending tests were carried out in a similar manner on 9 specimen measuring 100x75x2000 mm (6 of chestnut and 3 of poplar) for the crosswise bending tests, and measuring 300x75x1500 mm, (again 6 of chestnut and 3 of poplar) for the lengthwise bending (Figure 7).

Figure 7. *4-points bending test equipment.*

The compression tests were carried out on 200x75x 375 mm specimens.
In total 8 chestnut specimens were tested, 4 of which with the grain of the outer surfaces in a lengthwise direction and 3 in a crosswise direction. The same was done by 6 specimens of poplar (3 lengthwise and 3 crosswise) (Figures 8 and 9).

Figure 8. *Compression test equipment (poplar.)*

Figure 9. *Particular of strain gage used for compression test (chestnut).*

4 RESULTS AND DISCUSSION

The project confirmed the technical feasibility of constructing X-lam type panels with the equipment available in the plywood sector, at least as far as reduced-size formats are concerned (compatible with the dimensional and capacity limits of the standard composition lines and, in any case, up to 6 m^2 of surface for each panel).
Of the problems encountered, it is worth mentioning that the presence of shakes was not very evident in the boards used and was, in any case, within the legal tolerance limits while, subsequently, these tended to develop in an excessive manner in some of the panels constructed after the conditioning phase.
Another aspect worth investigating concerns the glue mix used in the assembly process.
With regard to the X-lam type chestnut wood panels in particular, use of different systems from those adopted traditionally in the sector (e.g. polyurethane mixes) should be assessed.
The preliminary results on the mechanical properties of the chestnut and poplar X-lam type panels represent a first step towards their complete physical and mechanical characterisation. Although still partial, the results obtained by the first test campaign have confirmed the good characteristics of the experimental panels developed and the possibility of using these for structural purposes in the building industry. This is indeed a result that will guide future actions of on-going research into the valorisation of regional wood resources.

5 CONCLUSIONS

The research carried out and described in this contribution reflects the will to promote the valorisation of locally available wood species through their use in construction. In accordance with this ambitious goal, a first phase of experimentation was initiated as a practical attempt to verify the production feasibility of cross-laminated panels types made with hardwoods.
This represents an attempt to encourage the exploitation of local resources through setting up the supply chain at regional level.
The production of innovative wood structural panels cannot be configured as an attempt to gain a competitive footing on today’s construction component market but as the possibility of defining niche markets, linked to local supply chains, able to reduce the environmental costs of the product and to valorise autochthonous wood resources, thereby increasing use and management thereof.

The results that will be obtained concerning the mechanical characteristics of the developed panels represent a preliminary indication which can be useful for further actions. In fact, the Construction Products Directive (CPD - 89/106/EEC) requires the EC marking procedure for all products permanently incorporated in buildings. The EC marking on a certain product indicates, in particular, that it complies with various essential requirements and that it was subjected to a conformity assessment procedure.

In continuing the work, attention must drawn to investigating issues tied to verifying the cost-effectiveness of chestnut and poplar based products, also taking into account the range of products already available on the market.
With regard to this aspect, although the territory of Piedmont offers good possibilities (with considerable interest on the part of the Public Administration) for valorising chestnut and poplar wood, as this can be obtained from the stands with the largest extension at Regional level, their use to construct X-lam type panels appears to be not very compatible from a global market viewpoint.
In the case of chestnut, as the average price of second and third grade sawnwood is already higher than the market price of the spruce X-lam panel, its use seems to be unsustainable. For poplar, characterised by a well-structured supply chain at Regional level and able to provide an abundant cheap wood resource, the critical aspect could be its modest mechanical properties.
Apart from the economic and performance considerations that may emerge from this work, it will be necessary to optimise the particular characteristics of the timber used – which, for chestnut, are its good natural durability and, for Italian poplar, its well-known lightness, light colour and surface appearance.
This could involve identification also of non-structural uses or for a niche market immune to the competition of the large foreign manufacturers in the construction compartment for whom these characteristics are a major requirement.

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