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OPTISOUNDWOOD project: enhancing poplar plywood with sound absorption properties

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ABSTRACT

The paper presents the results of a project funded by the Piedmont Region – Northern Italy – aimed at developing, testing and manufacturing innovative wood-based products for acoustic improvement and mainly realized with poplar plywood. This species was chosen both for its remarkable lightness and because it is the only local wood, with long arboricultural tradition, for which the offer of timber can meet the industrial needs. After an introduction on the state of the art and trends of poplar cultivation in Italy, the paper describes the artifacts (sound absorbing perforated panels, frames and bass traps) developed within the project. The research envisaged a preliminary investigation through physical models that guided the realization of perforated small-scale specimens. Tests were carried out with the impedance tube method and the more interesting drilling patterns were realized on products in end-use dimensions. These were installed and tested in a dining hall and their sound absorption properties were also determined using the reverberation room method. Since developed products are also proposed as furniture elements their appearance represents a fundamental issue. For this reason different kinds of surface finishing were experimented: painting, milling of decorative figures, image printing and tissue coverings. Technical aspects related to assembly and installation of end products were also considered. The final products showed interesting sound absorption properties in the low frequency range and poplar plywood turned out adequate for satisfying the requirements foreseen by the proposed uses.

INTRODUCTION

Acoustic quality is a fundamental parameter of large environments intended for speech such as dining rooms, open space offices or restaurants (Everest and Pohlmann 2009). These spaces are often subjected, when crowed, to high noise levels, mainly determined by people's voice. Poor acoustics have negative rebounds on the usability of these environments and on their occupants who can perceive high levels of stress (Yost 2014, Kuttruff 2009). Therefore, products for improving the acoustics of closed spaces are often in good demand, also due to the high amount of buildings affected by low acoustic quality (Negro *et al.* 2010).

The OPTISOUNDWOOD project was carried out by a Temporary Association of Scope constituted by a plywood manufacturer (the project leader), two academic partners (Dept. Agroselviter – University of Torino and DiPRADI – Politecnico di Torino), an acoustic consultant and the Province of Torino. The main goal was to develop, test and realize innovative wood-based panels and composites (Figure 1 and 2); these were mainly made of poplar plywood, produced using timber of local provenance and intended for acoustic purposes (Negro *et al.* 2016).

Figure 1: Examples of developed sound absorbing panels (left) and frames (right)

Figure 2: Examples of developed cubic (left) and cylindrical (right) bass traps

In particular the project envisaged the production of some prototypes intended for optimizing the acoustics of their end-use environment through the Helmholtz resonance and the membrane effects (Everest and Pohlmann 2009); these physics principles enable to confer sound acoustic properties to wood-based products (Bucur 2006).

Helmholtz resonance is based on a mass-spring system made of two communicating volumes named *neck* and *cavity*. When the acoustic waves hit the air in the neck (the mass), they push it inside the cavity; the air already laying there is thus compressed and reacts (like a spring) expanding itself and rebounding the incoming air. This originates an oscillatory movement that dissipates high quantities of sound energy, particularly in correspondence of a specific frequency named "of resonance". In the developed products, the holes drilled on their surface represent the necks, while the empty spaces placed inside or at their back are the cavities. Holes and cavities were dimensioned

according to physical models (Kuttruff 2009) in order to place the resonance within the low frequency range, i.e. where human voice is mainly emitted.
Further, two new types of bass traps were also realized: the first is cylindrical and made of bendable poplar plywood; the other has a cubic shape with a movable partition. Both interact with sound through their membrane resonance effect: the acoustic waves hit the front panel inducing a vibration that (like a membrane) absorbs the incident sound.
All of the above products were realized using poplar wood, that was chosen for several technological reasons (see also Box): its remarkable lightness enables to produce light and easy to install elements; its low density can also be exploited for realizing the vibrating elements of membrane resonators; its anatomical features and workability make it suitable for producing bendable plywood that constitutes the main component of one of the developed products; its light color is suitable for several finishing types, among which surface printing; finally, poplar is the only local species able to meet the national industrial needs in terms of adequate and continuous supply of wooden raw material for plywood manufacturing (Castro and Zanuttini 2008).
After testing the Helmholtz resonators on small-scale specimens by means of the impedance tube method, the sound absorption properties of a prototype for each final product were assessed in end-use applications and in reverberation room; in particular their acoustic behavior within the low frequency range was investigated.
The project also considered some environmental and eco-sustainability targets. The use of natural adhesives, without formaldehyde and alternative to the traditional thermo-hardening resins, was investigated for the production of panels and artifacts; further, the use of new poplar clones, selected by CRA – Research Unit for Wooden Products Outside Forest, has been assessed. A relevant part of the study regarded the installation methods and the finishing or aesthetic solutions (for instance printing on wood and surface milling using a CNC machine).
This contribution aims to give an overview of the project, presenting the experimental design and some properties of the developed products that, as a further result of the research, are currently ready for commercialization.

BOX - Trends in poplar cultivation in Italy

Problems of environmental sustainability, particularly regarding conservation of tropical rainforests, have brought a growing diffusion of certified wood products on the market (Castro and Zanuttini 2008). Even poplar had to deal with the necessity to obtain such recognition.
The first step towards the certification of poplar plantations was the tuning, within the frame of a preliminary project (ECOPIOPPO), of appropriate guidelines for cultivation with special attention to the environmentally sensitive areas; agreed upon by the interested parties, these indications foresee limitations in the use of chemical products and a reduction of farming operations. Their integration at national level into the PEFC and FSC standards for a sustainable management of poplar stands favoured their adoption as technical reference, facilitating monitoring and inspections from the certification bodies.
Features shared by such standards are the necessity to reduce the environmental impact of the plantation management, to adopt an accurate planning, an adequate care to staff training and workplace safety. The FSC standard is however more demanding as for the obligation to reserve part of the surface for the native vegetation growth, a stricter threshold in terms of clone differentiation, the

prohibition to use dithiocarbamates and a size of plantations accepted to be homogenous for age and clone composition which cannot be larger than 10 hectares. The PEFC standard, which is better suited to the critical issues of the Italian poplar cultivation, shows greater attention to traditional practices, which is probably the reason for its greater success among poplar growers (AA.VV. 2008).

Both standards have however generated positive feedback. Firstly, the possibility of choosing and obtaining group certification has brought to new form of association aimed at reaching economies of scale. On the other hand, they have become a keystone for facilitating the introduction of new poplar clones, which although not yet widely accepted by the plywood industry, show advantages from the productivity and the environmental point of view (requiring fewer cultural practices) as well as in terms of technical features that make them interesting for new, unconventional, uses.

At the moment in Italy there is only a very little amount of FSC-certified hectares, all privately owned and generally destined to meet the demand for plywood production destined to foreigner markets, while the PEFC-certified hectares are much more diffuse. As far as the processing industries that use poplar wood are concerned, given that there is no mutual recognition between the two schemes, many have resorted to the double implementation of their Chain of Custody (CoC). Among them certification is frequent and concerns dozens of companies having implemented both schemes.

The market of certified poplar, however, is quite young and a well-structured planned demand still does not exist. The processing industries, moreover, despite the higher costs incurred by poplar growers, are not willing to accept a premium price for certified wood. Growers decide then to obtain certification mainly to maintain their market quota and to be visible in wider contexts, improving in the meantime their relationship with local stakeholders.

Recently, new poplar clones have been selected (and legally registered for commercialization) which need fewer treatments thanks to their good resistance to a wide range of biotic stresses. Some of them, following results from experimental trials, have been recognized as "MSA clones" (from the Italian acronym for "clones having with more environmental sustainability"). In the framework of the new financial resources aimed to sustain the rural development some Regions have therefore decided to provide funding only for plantations including a high percentage of these clones.

Finally, some innovative models of polycyclic plantations have been tried where poplar is mixed with valuable hardwoods (for example walnut and cherry) and, in some cases, with secondary shrub species, added to have growth synergies, better conformation of the trunk, multifunctional objectives and the reduction of the risks of single-species cultivation. In these new types of plantation poplar provides an income at an early stage of the overall rotation. The first results seem encouraging, although it is too early for a general judgement (Buresti Lattes *et al*. 2008, Castro *et al*. 2013, Buresti Lattes *et al*. 2015).

Often the poplar material obtained from the above “non-conventional” plantations is quite different to that from traditional ones: timber is slightly heavier and the derived material is generally less homogeneous, since various clones are used. It is therefore important to find differential uses in which poplar wood can better satisfy *ad hoc* requirements like lightness (typical for the ‘I-214’) or higher mechanical performances (with many other clones).

EXPERIMENTAL

The prototypes realized within the project are listed below; types 1 and 2 exploit the Helmholtz resonance, while types 3 and 4 the membrane resonance effect:

1. *Panels*: made of drilled poplar plywood installed on a plywood frame with a sound absorbing mat inside (Figure 1, left);
2. *Frames*: sandwich panels made of plywood skins (one of which thicker and designed to remain in view) bonded to an inner core constituted by a honeycomb structure of veneered cells (Figure 1, right);
3. *Cubic bass traps*: cubic structures made of plywood with a face of limited thickness (the membrane element); this partition can be moved in order to vary the frequency of resonance and can be covered with sound absorbing materials (Figure 2, left).
4. *Cylindrical bass traps*: made of a cylindrical body of bendable poplar plywood covered with a sound absorbing mat and placed between two circular plywood plates (Figure 2, right).

A preliminary investigation of the sound absorption properties of drilled panels was performed using the impedance tube method according to EN 10534-2. The most suitable drilling schemes were realized on prototypes in end-use dimensions: panels of 2120x1250x9 mm, frames of 600(and multiples)x600(and multiples)x38 mm, cubic bass traps of 616x616x336 mm, cylindrical bass traps of 600x500 mm.

The sound absorbing properties of all prototypes were validated in a dining room of a Small Medium Enterprise in order to simulate a real application. The selected environment is highly reverberant and characterized by poor acoustic quality. This situation is typical of large enclosures with plane and rigid walls, ceilings and floors (Kang 2002). In detail, its volume of 243.81 m^3 and its surface of 231.55 m^2 meet the dimensional requirements envisaged by EN ISO 354. During testing the room was arranged with plastic tables and chairs. Measurements intended to assess the reverberation time and the maximal noise level when the room is occupied by 10/25 users (depending on working shift) were also made.

The room was arranged with the following prototypes installed on its walls and distributed uniformly in place:

- 8 sound absorbing panels, for a total surface of 21.2 m^2;
- 26 acoustic frames, for a total surface of 14.4 m^2.

Investigation methodology was set according to EN ISO 3382, that prescribes the measurement criteria and parameters on the basis of the impulse response; the testing and the assessment of the results were performed according to EN ISO 354. Two acoustic measurements (for a total of 10 repetitions) of reverberation were realized using the technique of pink interrupted noise; this enabled to obtain the noise levels during the lunch and dinner breaks.

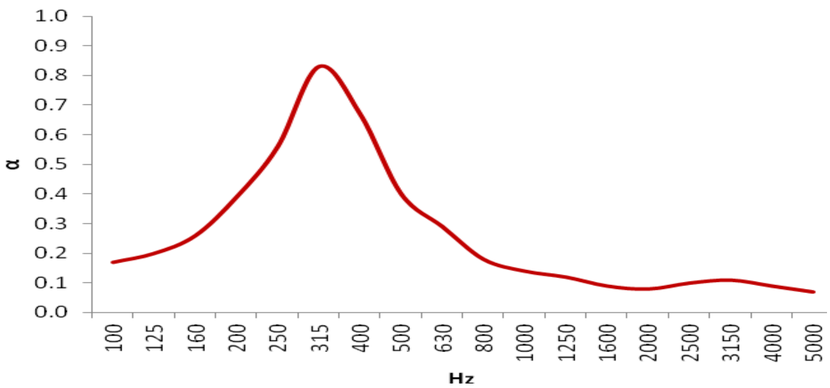
The acoustic properties of end-size samples were also determined in a reverberation room according to EN ISO 354 (Figure 3). This enabled to better compare the performances of the developed products with those of other materials already available on the market.

Figure 3: Main phases of the acoustic testing: on small specimens through impedance tube (left), on end-size samples in a dining room (center) and in reverberation room (right)

Finally, during a lunch break a questionnaire was submitted to 14 workers in order to assess their perception of the effect of the acoustic products installed within the room.

RESULTS AND DISCUSSION

The acoustic properties determined by means of the impedance tube were confirmed by testing on samples in end-use dimensions in the dining and in the reverberation room. The absorption values of the developed panels, frames and bass traps achieved absorption peaks of about $\alpha = 0.90$ (which means that the 90% of the incident sound is absorbed) at frequencies of 100, 300, 400 and 800 Hz (Figure 4 top and bottom). These fall within the low frequency range (that includes frequencies up to 1600 Hz), where the main sound emitted by human voice is perceived.



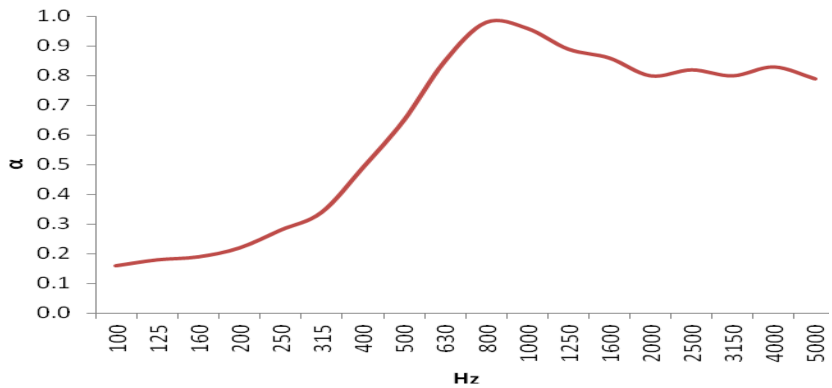


Figure 4: Examples of the sound absorption properties achieved by the acoustic panels (top) and by the bass traps (bottom)

The absorption curves of some prototypes show rapid slopes (meaning that the absorption behavior is selective around the frequency of resonance). These can be enlarged by adding sound absorbing mats (behind, inside or ahead depending on the product), even if this solution determines a lowering of the peak values (Everest and Pohlmann 2009).
The results of the survey concerned to the acoustics of the dining room indicated that the presence of the realized products was clearly perceived by the workers. On the whole the users stated that the overall background noise was lowered, that they heard the conversation better and that the acoustic quality of the room significantly improved. Further it is also important to note that a more complete acoustic recovery of the environment would require to add a higher amount of sound absorbing products, that would result in an even better comfort.
A relevant part of the project included the study of the best solutions for installing the acoustic panels and assembling the bass traps (Figure 5). These facets were carefully investigated since the developed products are intended for end-users.
As for the acoustic panels, aluminum profiles that guarantee a rapid and solid fastening to the walls were individuated through a market research; their compatibility with the acoustic panel was assessed on prototypes in standard dimensions. As for the bass traps, the best assembling methods were chosen among various realized on a series of prototypes.

Figure 5: Detail of an installation system made of aluminium profiles

Different types of surface finishing were also experimented and evaluated, among which the covering with tissues, the milling with a CNC machine and the printing with specific tools (Figure 6). This latter is particularly interesting since the picture can be provided directly by the final user, who can thus customize his purchase. Surface printing can also be designed to conceal the holes on the surface: for some applications this represents an innovative aesthetic solution.

Figure 6: Examples of decorative milling (left) and surface printing (right) of drilled panels

CONCLUSIONS

The OPTISOUNDWOOD project enabled to develop, test and realize at industrial level a series of new panels and composites made of poplar veneers coming from local plantations. Products were designed to provide sound absorption within the low frequency range; their finishing was also considered.
The project constituted an opportunity of collaboration among different subjects operating in the poplar chain. Their competencies contributed to find technical solutions suited to reach products with higher value added. These enable to differentiate the production of the manufacturer towards new market niches and non-traditional applications.
The results obtained confirmed the interesting performance of the prototypes and allow to propose veneered products specifically intended for the acoustic improvement of confined environments. In particular, they can be used in closed spaces subjected to be highly crowded, such as dining rooms, theatres, commercial centers, open offices, restaurants etc. They are also suitable for use in environments in which a fine tuning of the acoustics is required, such as recording rooms, television studios or workshop areas in fairs.
Poplar plywood turned out to be adequate for realizing the designed products. From the acoustic point of view, while in Helmholtz resonators the key parameter is the geometry of holes and cavities, in membrane resonators the lightness of poplar wood enabled to activate the sound absorbing vibrations. In the cylindrical bass trap poplar veneers resulted suitable for producing the easily bendable panel that constitutes the main element of this artifact. Finally, the availability of poplar timber of local provenance was relevant to meet the demand of raw material from the plywood industries and to place on the market some new value-added wood-based products with a better and more sustainable environmental profile.

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