Natural fibers insulation panels: an adaptive production

RSD7 2018

RELATING SYSTEMS THINKING AND DESIGN 7th SYMPOSIUM

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Proceedings of Relating Systems Thinking and Design (RSD7) 2018 Symposium
Published by the Systemic Design Association in March 2019
Editor: Silvia Barbero
ISSN 2371-8404

Please, cite as:
Author (2018). Article title. In *Proceedings of Relating Systems Thinking and Design (RSD7) 2018 Symposium* (pp. xx-xx). Turin, Italy, October 24-26, 2018.

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Natural Fibers Insulation Panels: An adaptive production

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Abstract The research team recently developed an innovative system with low environmental impact for the production of semi-rigid panels for thermal and acoustic insulation, obtained from recycled sheep's wool from Piemonte region. Starting from the previous work, a new semi-rigid panel has been produced, combining sheep wool with hemp technical fibers. Both sheep wool and hemp comes from agri-food systems and are considered as a wastes from existing production chains. Panels show low environmental impact and stiffness as main innovative features, if compared with other similar products on the market. A further experimentation phase allowed to improve the production process adaptability degree to the availability of natural by-products from local agri-food systems, with the aim to develop an “open recipe” able to answer to the building market different requests. The contribution presents the methodology adopted for the research in progress, the "open" technology assessment adopted for panels production and results of preliminary thermal tests.

Keywords: Sheep wool, Insulation panels, Agri-food by-products, Corn bracts, Almond shells, Dry bean pods.

1. Introduction

In Italy the building market is currently characterized by a drastic decrease in new constructions and a increasing importance of existing building stock refurbishment, thanks also to specific public incentives. In public procurement it has been mandatory from 2016 to apply the Minimum Environmental Criteria – CAMs (Decreto Legislativo 19 aprile 2017, n. 56). CAMs are aimed at identifying design solution, product or services, offering the better possible environmental performances along the whole life cycle, taking into account market availability. In the future, their application will probably lead to deep changes in the demand-supply system of the building market, expecting an increasing availability of low environmental impact products, designed within a circular economy perspective. Research in eco-building field is more and more focusing on circular economy issues: starting from a systemic analysis of existing production chains, waste products, currently not recycled, are often analysed in order to find new uses or applications. Circular economy topic were also one of the main pillar of *Cartonlana* research project, born from the opportunity to face the so called sheep wool issue. In Italy, and in Piedmont region, sheep farming is a traditional activity now aimed only at meat and milk production. Sheep wool has become an economic weakness in the production supply-chain due to a double cost: the final disposal and the shearing costs (Bosia et al. 2011). Because of its low quality, Italian sheep wool hardly find use in the textile industry. On the other hand, due to its excellent thermal insulating features, and low environmental impact, sheep wool have been finding increasing use as a raw material for building components production, with an evident paradox: local wool is usually wasted, buried or landfilled, while imported wool, particularly from New Zeland, is used for insulation panels production (Figure 1). In *Cartonlana* (Bosia 2011) research project wasted sheared wool from Piedmont region was collected and used for insulation panels production, defining not only a production process, but also a "systemic" concept for building products design, which follows the main principles of CAMs. After *Cartonlana*, *FITNESs* project have been developed, mixing sheep wool and wasted hemp fibres and testing how the panel performance were influenced changing the original 100% wool composition. In this paper the research team try to further enlarge the research field, working on other wasted material coming from existing agro-industrial productions chains localized preferably in the Piedmont region context or in other Italian regions where sheep wool breeding has an interesting widespread.

As Italian sheep wool, natural waste materials explored for the new research steps, have no use for the farmers and are generally buried, landfilled or disposed otherwise, often generating additional costs, while not finally disposed, using them as a biomass. The aforementioned approach is intended, as in the previous works, to keep new panels with a low environmental impact while, at the same time to recognize economic value to local agri-food by-products, that could help to lower breeders and farmers activities economic management cost.

The research main aim is to develop an "open recipe" based on the previous researches *Cartonlana* and *FITNESs* production process and adapting it to the specific features of the new raw materials, proposed to be used in combination with sheep wool fibers, for new panels production.

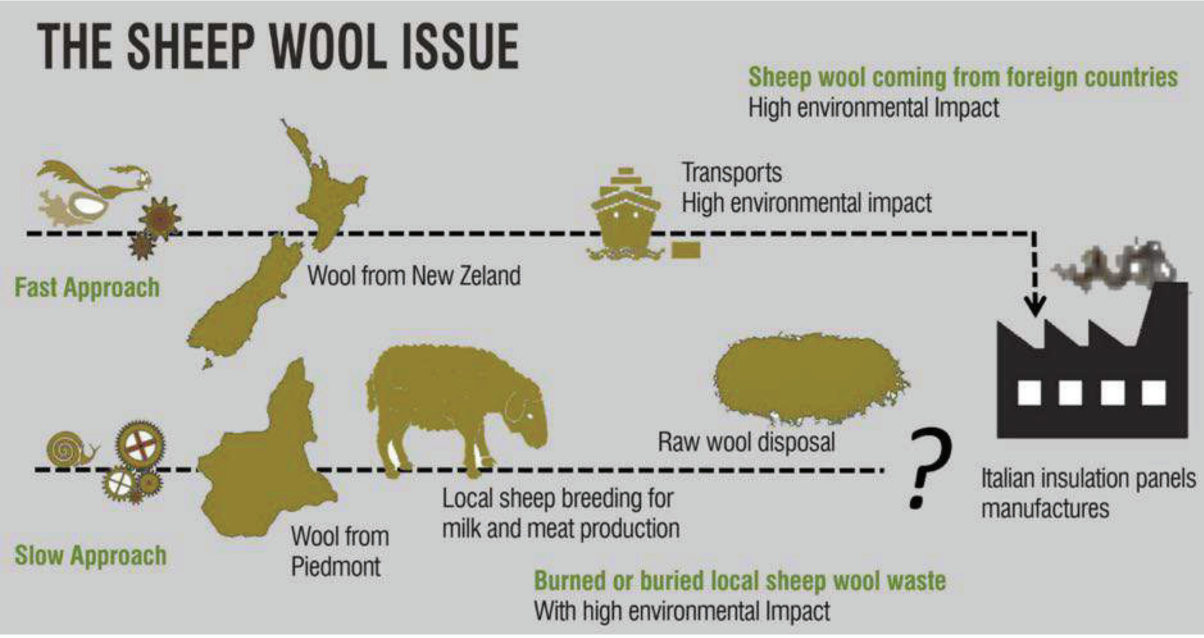

Figure 1. The Sheep wool issue, in Italian market raw wool from sheep breeding is generally disposed as a waste while sheep wool for building insulation products is imported from foreign countries.

2. "Open recipe" – an adaptive production method

2.1. Cartonlana and FITNESs

The multidisciplinary research team, composed by Biella *CNR ISMAC* and *Department of Architecture of Politecnico di Torino* members, in collaboration with the textile company *Davifil* and *Assocanapa*, recently developed an innovative system for the production of low environmental impact semi-rigid panels, *Cartonlana*, for thermal and acoustic insulation, obtained from recycled sheep's wool coming from Piedmont region breeding. Starting from that first work, the production system was implemented, combining in equal measure sheep wool with hemp technical fibers, leading to *FITNESs* panels production.

Both two panels have two main innovative features: unlike the already existing hemp and wool insulation mats, they are semi-rigid products, which allows a wider range of uses in architecture, and they has low environmental impact, as shown by the Life Cycle Assessment (Pennacchio et al. 2017). Panels stiffness was obtained through a production process peculiar feature; the keratin contained in the wool fibers works as a binding matrix and, when drying, constitutes a rigid structure, conferring stiffness to the product. The panels have been tested, both in laboratory and in real use conditions, in order to measure their thermal conductivity and transmittance and their acoustic absorption, demonstrating excellent performance, in line with similar natural products currently on the market. Laboratory measurements showed a thermal conductivity of 0,041 W/mK for *Cartonlana* and 0,040 W/mK for *FITNESs*. As for sound absorption performance, particularly *FITNESs* panels, shown a really competitive sound absorption coefficient value, measured in α_w=0,75 MH, slightly improved if compared to *Cartonlana*'s α_w=0,55 MH (Pennacchio et al. 2017).

Figure 2. *Cartonlana* and *FITNESs* panels composition

2.2. The "charge", an adaptive selection method based on low environmental impact requirements

Starting from *Cartonlana* and *FITNESs* experiences, a further research phase regarding the feasibility to use other natural waste materials or by products, coming from local agri-food systems, to be aggregated to sheep wool fibers in the panels production process is being implemented. The research main aim is to define an "open recipe" for insulation panels production, able to adapt to the real availability of local resources, keeping unaltered the panel main innovative features.

New panels, as those already developed by the research group, consist of two main components:

- a "matrix" based on sheep's wool chemically treated, according to a process patented by the research group able of constituting the rigid keratin structure of the insulating panel;
- a "charge", made up of waste from agri-food chains; natural fibers with no use on the market.

In the "open recipe" the binding matrix is mixed with a "charge" in different proportions fixing the appropriate rules and variables to keep panels thermal and acoustic performances suitable for the building sector.

The research group defined a Technology Assessment to be adopted for the selection of products to be eventually used as a charge. Some principles were fixed, in order to keep as low as possible the environmental impact of the insulation panel. The selection process was oriented to:

- waste materials, without any specific use, from production chains already existing and sufficiently widespread in sheep breeding areas, where sheep wool is available, but currently discarded as a waste too;
- natural waste materials, in order to facilitate the end-of-life disposal, assuming, ultimately, a thermo-valorization as biomass scenario;
- preferably fibrous materials, or however easily to be combined with wool fibers, in order to produce panels with an homogeneous composition.

Considering these requirements, the research group selected the following materials as possible alternatives: wood sawdust, chestnut bark, corn bracts, dry bean plant residual - referring to the Piedmont region territory - and almonds shells - referring to Puglia and eventually Sicily region. After a preliminary analysis of products availability, a local production-chain study (Figure 3) have been developed for corn bracts, dry bean plant residuals and almond shells, while panels specimens have been also produced in laboratory.

2.3. Selected by-products: Corn bracts, Almond shells, Dry bean pods.

Corn bracts are considered a by-product of corn cultivation harvesting; the bracts are single sheath leaves, protecting the corn female inflorescence, an ear that grows sideways to the stem, at the height of the 6-7th node below the male inflorescence, a panicle at the top of the stem (Agraria - Istruzione agraria online 01/10/2018, Dipartimento di Agraria – Università di Sassari (12/09/2018). Corn plants generally present a single ear 10 – 20 long, but occasionally can reach 42 cm length, and 3 – 5 cm large (Assomais, Baldoni 2018), carrying about 1000 dry one-seeded fruit, the caryopsis, each. The female inflorescence is supported by a peduncle generating the bracts, generally in number of 5-6 each flower and representing about 7% by weight of a mature whole corn plant (CRAB 2004). Corn is highly widespread in North Italy, while Piedmont is one of the four regions with the highest corn production in Italy, with a production area of about 140000 ha and about 1.350.000 tons harvested production (ISTAT 2019), despite suffering a sensible decrease of cultivation area of about 33%, after 2014. In Italy, corn harvesting is usually planned in September-October, and it is generally made using a combine harvester machine (Bertolino 2005). A square meter corn plantation area is likely to make about 6-8 corn ears, about 30 – 48 bracts, 40 – 65 t/ha of chopped plant, in north Italy. As a corn plantation by-product, bracts have quite no use, excepting, as biomass and boilers fuel, together with other corn residuals, they are also used in craftsmanship to weave baskets or bags. Otherwise corn harvesting residuals are generally shredded and used as litters in stables or sold on the market as a by-product. Moreover, the large widespread on the regional area, its fibrous nature and low protein content, make it a potentially interesting product to be tested as a “charge” for the panels open-recipe.

Almond shells are considered a by-product of the almond fruits harvesting; the shells are the non-edible parts of the fruits of the almond trees. The almond (*Prunus dulcis*) is a deciduous tree, belonging to *rosaceae* family, genus *prunus*, species *amygdalus*. It is characterized by medium height (from 5 to 7 metres in its adulthood) and slow rate of growth but very long-lived. It generally goes into production around the age of 5 and achieves maximum productivity no earlier than 20 years of age. It well tolerates drought and high temperatures in summer and adapts to dry and poor soils. Its fruit is an ovoid and elongated drupe, with a fleshy, light green coloured and hairy (sometimes also glabrous) exocarp (hull), which detaches when ripe. The endocarp (shell) is woody, whose consistency can be hard or brittle. Inside the shell are contained seeds (almonds). The harvesting period goes from the end of August to the end of September, depending on pedoclimatic conditions and cultivar, when the hull is completely open and almost detached from the shell. The edible parts are separated and collected for commercial uses. Almonds are mainly used by the confectionery industry and, partly, consumed as dried fruits. Currently, more than 93% of national production comes from two regions: Sicily (60%) and Puglia (33%). The total amount of the national production of shell fruits is about 79,600 tons (ISTAT 06/02/2019). Given a yield of 25-30%, remain about 55,000-60,000 tons of non-edible parts (shells) that are merely used in cosmetic industry or become fuel that could be employed, instead, as "charge" for making panels. Moreover, as in Sicily and in Puglia both sheep breeding and almonds cultivation are largely widespread (ISTAT 09/02/2019), there could be the opportunity to build a local sustainable production chain for almonds shells and sheep wool fibers panels.

The opportunity of using the dry bean plant residuals as a "charge" for the insulation panels comes from:

- great material availability in Piedmont region, where 23% of the whole Italian beans cultivation area is concentrated (ISTAT 06/02/2019);

- the expected of thermal conductivity performance, due to the dried plant physical similitude to other kind of straws, already used in building components for thermal insulation for their physical features.

The province of Cuneo could be considered as the most suitable scenario for setting up a panels production because of both sheep breeding and beans cultivation widespread and because of the local beans production identification by the IGP (Protected Geographical Identification) denomination as "Fagiolo di Cuneo". Moreover, another research group from Department of Architecture and Design has recently developed a local beans production-chain and valorization scenario, referred to the IGP denomination, as part of to the EN.FA.SI.2 project (Barbero et al. 2012), funded by Piedmont Region.

The beans are harvested by hand or through threshing in different phases during the autumn season. In the threshing-harvest, the thresher collects the beans, leaving the rest of the plant (stem, leaves pods) in the field, where it completes its drying process. The plant is rarely harvested, more often it is turned in the field, with the risk of soil contamination by parasites. In few cases is used as cattle litter (with lower yield than straw) or burned as biomass to produce energy. On the base of the EN.FA.SI.2 research outcomes, the research group propose to use the entire dry plant for the production of the panels as aggregate "charge" to combine with the sheep's wool "matrix".

Figure 3. Selected by-products features

3. Sample production and thermal conductivity tests

3.1. Sample production

As already mentioned, the production of Fitness panels consists in mixing the fibrous materials (sheep's wool and hemp) and treating them with a chemical bath, which partially turn wool into a keratin glue. The glue sticks the fibres and gives stiffness to the panel. After the chemical treatment the panels are dried, getting enough rigidity to be considered self-supporting, but flexible enough to be easily assembled into building components such as walls or roofs. Compared to Fitness, the introduction of new "charges", needed production process to be adapted to new materials features. In fact, while the in field-macerated hemp presents long and well separated fibres, ready to be easy aggregated with sheep wool (with long fibres, very separated each other) the new charges requested to be processed in advance, before mixing.

In order to define the production process, adapting the Fitness one, different specimens were produced, using the selected products:

- 3 specimens with corn bracts and sheep wool, changing some variables like the two material percentage and the chemical bath composition;
- 1 specimen mixing corn bracts, bean dry plant, wood sawdust and sheep wool;
- 1 specimen with bean dry plant residual and sheep wool;
- 1 specimen composed with almond shells and sheep wool.

During the chemical bath, keratin “glue” produced by sheep wool fibers needs to spread and distribute as homogeneously as possible, in order to provide stiffness equally to the whole panel volume. Both corn bracts and beans dry plant combines less homogeneously than hemp with wool fibers; moreover, since they have not undergone maceration processes, they must be divided into smaller parts, separating the fibres so as to properly mix them with wool.

Corn bracts and beans dry plant samples were produced separating fibres manually, which took quite a time; an hypothetical production scale-up, would require the use of a specific tool or machinery in order to keep the whole process within a reasonable duration.

Despite. Almond-shells haven't a fibrous structure, can were considered an interesting possible "charge" for the insulation panel because of their "quarry" section, which in nature has exactly the purpose of insulating and protecting the almond seed inside. However, during the sample production their aggregation abilities with the wool before entering the chemical bath proved to be limited. So, in order to achieve a proper cohesion between the matrix and the charge, the chemical treatment was prolonged, with a greater production of keratin glue. The result is a sample showing limited thickness high density and low flexibility. Compared to the other samples, the almond shells one proved to be more fragile and less workable then the others, so was not considered suitable for thermal insulation purposes, while other kind of uses in building components could be considered anyway.

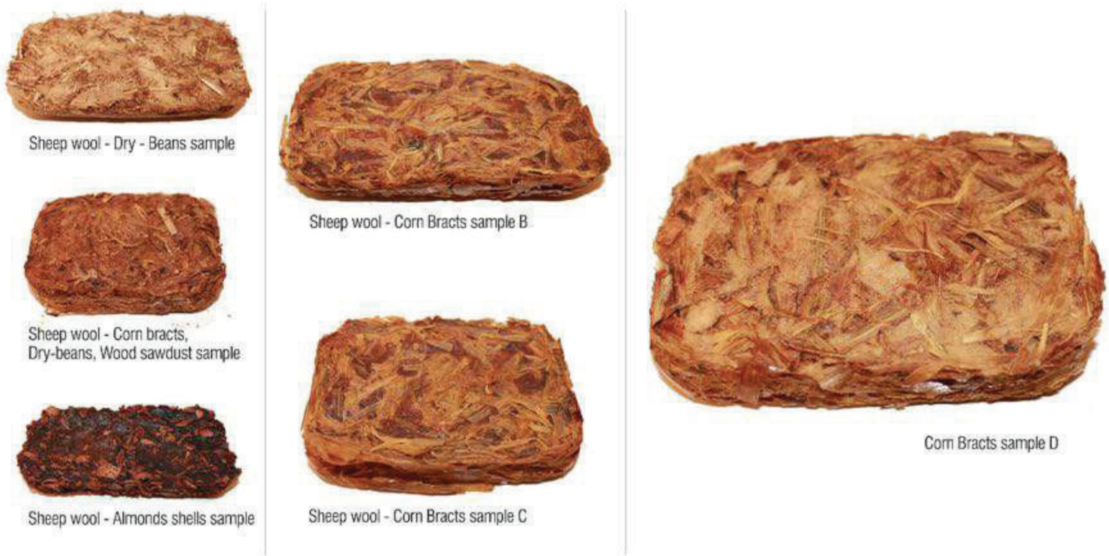

Figure 4. Samples produced in laboratory, combining sheep wool with different selected agri-food by products.

3.2. Thermal conductivity measurements

Thermal Tests took place in the laboratory of the *Department of Energy (DENERG)* of *Politecnico di Torino*, on the 300 x 300 mm and 32 mm thick, sheep wool and dry bean pods specimen. In order to be able to better compare resulting performances, measurements were carried out applying the same methodology followed for the previous works *Cartonlana* and *FITNESs*. The thermal tests were conducted according with the heat flow meter method and the EN ISO 12667 (EN 2011) regulation for the evaluation of the thermal conductivity of building products with high and medium thermal resistance, by means of a *Lasercomp FOX600* Guarded Heat Flux Meter apparatus.

The apparatus is provided with two plates generating a temperature difference of 20°C, inducing a heat flow through the thickness of the specimen, placed in the middle. Steady state thermal measurements were carried out at two different average temperature setpoints, respectively of 25°C and 40°C, while the sample was previously dried in oven during 2 days, at a constant 60.5 °C temperature.

Test were held over 24h allowing to define the specimen thermal conductivity λ; according to measurements result, the sample shown an average thermal conductivity of 0.05 W/mK, which is a little higher than Cartonlana and FITNESs’, but can be considered quite an interesting result to be improved.

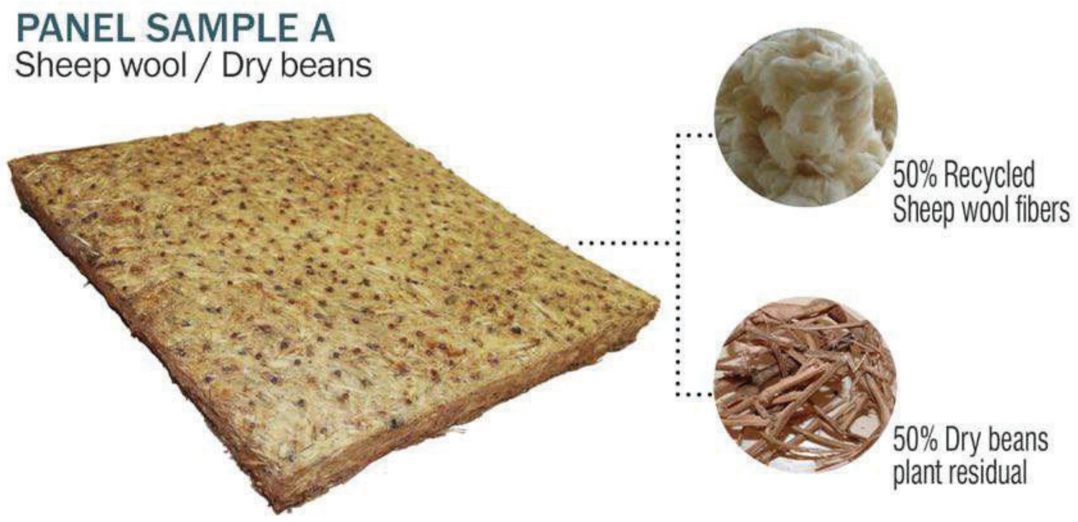

Figure 5. Sheep wool/Dry beans plant residual sample produced in laboratory composition.

4. Discussion

Almond shell have been considered as a possible “charge” for panels production due to its porous section, interesting in terms of thermal insulation features and its large cultivation in Italian regions where also sheep breeding is particularly widespread. Nevertheless because of its non-fibrous shape, chemical treatment during sample production needed to be extended, resulting in a high density, low flexibility and fragile sample. The production of the sheep wool and dried bean plant panel specimen gave a positive result, with qualitative features similar to the already tested *Cartonlana* and *FITNESs* panels, highlighting, however, some difficulties in separating the dried plant fibers in order to improve the workability pf the mixture and the homogeneous distribution of the two different fibrous materials.

Corn Bracts and beans dry plants showed a low homogeneity degree and needed additional work to separate fibers manually and chop them in smaller parts, in order to obtain a proper mix with wool fibers. In a future production scale-up a suitable specific tool would be required. Nevertheless both of them have been considered suitable for thermal insulation panels. Particularly corn bracts, due to their entirely fibrous nature, showed quite a high compatibility with wool fibers and the panels production process oriented at keratin dissolution. However, corn bracts yield cannot be considered particularly interesting with respect to the corresponding corn plants growing surfaces, so dry beans plants residual was chosen for a further implementation of the panel to be thermally tested.

Thermal measurements showed how dry-beans plant residual could be potentially considered as a suitable material to combine with sheep wool fibers for insulation panel production (Savio 2018). Matrix and charge mixing proportions, as chemical bath duration, need further research anyway, in order to improve panel sample thermal conductivity, to bring its thermal performance as closer as possible to *Cartonlana* and *FITNESs*, as to similar products still existing on the market.

5. Conclusion

Sample production tests realized during the research allowed to assess the feasibility of combining sheep wool fibers with other Piedmont region agro-industrial chains by-products or wastes, as a charge for insulation panels production, in accordance to the production method assessed during previous researches.

The encouraging thermal performances shown by sheep wool fibers and dry-beans plant residual sample, also open the research field to not entirely fibrous agro-industrial by-products, to be used in combination with sheep wool fibers for insulating panel production. As a result, also full corn plant field cut residual, containing already tested corn bracts, acquire further additional interest as a possible charge to be used in panels production, due to its high production yield and to large corn production areas in Piedmont.

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