Urban Forestry & Urban Greening 38 (2019) 177–182

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Street trees' management perspectives: Reuse of *Tilia* sp.'s pruning waste for insulation purposes

D. Grohmann[a,*], R. Petrucci[b], L. Torre[b], M. Micheli[a], M.E. Menconi[a]

[a] Department of Agricultural, Food, and Environmental Sciences, University of Perugia, via Borgo XX Giugno, 74, 06121, Perugia, Italy
[b] Department of Civil and Environmental Engineering, University of Perugia, Strada Pentima, 4, 05100, Terni, Italy

ARTICLE INFO

Keywords:
By-product smart use
Circular economy
Linden wool
Management of green urban system
Organic insulating material
Urban forestry

ABSTRACT

The management and care of urban greenery is essential to ensure the effective delivery of the ecosystem services it is capable of supplying.

A sufficient and adequate care for urban greenery and in particular for urban forestry is an on-going challenge due to economic hardship of public administrations, to a lack of qualified personnel, and to a lack of a culture of valorization of public goods.

To identify an opportunity to reuse any by-products resulting from pruning operations could signify economic benefits that could be invested in a better maintenance of urban arboreal patrimony, following a circular economy approach.

This paper is the first step of a wider research that has the goal to delineate a strategy for the utilization of the pruning waste of the urban trees as thermal insulation materials.

Particularly, in this paper is studied one of the most common tree species in urban greening and forestry: *Tilia sp*.

Three tiles with different densities obtained mixing wood wool and PVA glue are realized and tested. The resulting thermal conductivity and specific heat varying respectively from 8.30 ± 0.54 to 8.60 ± 1.40 10-2 W/m*K, and from 2.26 ± 0.51 to 2.80 ± 0.65105 J/m^3*K. Using these values, the paper developed a thermal simulation model, regarding the insulation of the roof of a residential building. The model aimed at comparing the thermal performance of the studied tiles, with two commercial materials produced with wood residues from the timber industry, and with the fibers of two vegetable crops, widely used as insulating materials. The linden tiles entailed an energy saving of 55% respect to the model without insulation, the other materials between 51 to 62%.

The results show as the *Tilia* sp.'s pruning waste could be a good source material to create panels for thermal insulation.

1. Introduction

1.1. Taking care of the urban forestry

According to Butler and Spencer (2010), this is the Century of the City, and "The explosion in urban population looks set to continue through the twenty-first century, presenting challenges and opportunities for scientists." (Butler and Spencer, 2010, 901).

The World Health Organization (WHO) seems to support these considerations with its demographic scenarios. At the same time, WHO states that: "many cities lack sufficient trees and other types of vegetation that provide shade from the sun's rays and dissipate heat with evaporated water." (WHO, 2016, 149). In other words, if this is the century of the city, it must also be the century of *nature* in the city (Benedict and McMahon, 2006). Urban greening is a fundamental element in guaranteeing life quality in urban contexts (Gill et al., 2007; Newell et al., 2013; Demuzere et al., 2014; Norton et al., 2015). In this regard, urban forestry plays a central role (Rowntree and Nowak, 1991; Dwyer et al., 1992; Nowak et al., 1996; Coder, 1996; Day and Dickinson, 2008; Gillner et al., 2015), since trees can have a wide effect on water cycling, thermal balances, carbon sequestration and many other ecosystem services (Lafortezza et al., 2009; Pataki et al., 2011; Zheng et al., 2016; Gage and Cooper, 2017). A research carried out by the City of Portland found out that "each tree will remove

* Corresponding author.
E-mail addresses: david.grohmann@unipg.it (D. Grohmann), roberto.petrucci@unipg.it (R. Petrucci), luigi.torre@unipg.it (L. Torre), maurizio.micheli@unipg.it (M. Micheli), mariaelena.menconi@unipg.it (M.E. Menconi).

https://doi.org/10.1016/j.ufug.2018.12.009
Received 6 February 2018; Received in revised form 18 October 2018; Accepted 21 December 2018
Available online 23 December 2018
1618-8667/

approximately 92 g (0.2 pounds) of PM10 per year" (City of Portland, 2010).

Nevertheless, the above-mentioned "effects are only possible if the urban tree stock is vital and unaffected by pests and diseases" (Sjöman et al., 2012, p. 31). A lot of the damage to the urban trees is inflicted during pruning. Trees that grow in urban settings require periodic pruning to address a wide array of problems, for example to guarantee the visibility, the public safety, the clearance of power lines (Dujesiefken et al., 2005; Smiley and Kane, 2006; Fini et al., 2015). All of which, is important to remember, are an expression of human needs, rather than plants' ones, and the pruning cause damage to the trees at different degrees depending on pruning typology, on pruning intensity and on the qualification of the personnel performing it. Alex Shigo pointed out that "[pruning can either be] the best thing an arborist can do for a tree but at the same time, one of the worse things an arborist can do to a tree; much depends on how pruning is carried out" (Shigo, 1989,188). Recent researches on the matter supported this statement (Fini et al., 2015).

Nevertheless, in the agenda of various municipalities, the pruning prescriptions are guided more by short-term economic considerations than the actual best practices (Maurin and Desrochers, 2013; Fini et al., 2015). Urban forestry maintenance is constrained by the limited economic means of public administrations and by the lack of knowledge of correct/acceptable pruning procedures on behalf of agencies and contractors (Campanella et al., 2009). To develop a culture of trees' respect in public Administrations and to attract interest in the correct sustainable management of the urban green system is a long way. Researchers must have this important objective but, at the same time, it is important to find simple ways to have an economic benefit in the short term.

The aim of this paper is to find a way to transform the pruning costs in gains for the public administrations, evaluating the suitability of the use of the urban pruning waste as thermal insulation material.

1.2. Organic insulation materials

Insulation materials are extensively used as a cost effective solution to reduce the heat losses (or gains) from thermal systems in buildings (Al-Ragom, 2003; Menconi and Grohmann, 2014; Menconi et al., 2017; Sevindir et al., 2017).

Organic insulation materials are those obtained from vegetation or other renewable resources, such as sheep's wool, wood chips, seaweed, hemp fibers, reed, and wood wool.

For various reasons related to vast world of sustainable development (efficient use of natural resources, lowering the carbon footprint of product and processes, energy efficiency, disposal, etc.), organic insulation materials are attracting a growing interest (Asdrubali et al., 2015; Kumar et al., 2016) since they are renewable, recyclable, nontoxic, environmentally friendly (Aditya et al., 2017). They also generally show a strong resistance to disrupting processes and factors such fire and moisture. Even though the energy that is required to manufacture organic insulation materials is generally lesser than that of the traditional insulation materials (Asdrubali et al., 2015; Menconi et al., 2017; Liu et al., 2017), their inorganic counterpart are often more efficient from a thermal insulation standpoint (Menconi and Grohmann, 2014; Rocchi et al., 2018).

In the fast growing array of usable organic material, wood continues to be a staple one, with a long history of usage in various forms, usually in sandwich panels (Kawasaki and Kawai, 2006), or in mixture with binding material (Taoukil et al., 2012). The binders added are usually polyvinyl acetate (PVA) glue, Portland cement (mineralized wood panels) or polyurethane resins, to augment the structural resistance of the panels or to enhance their performances regarding fire or moisture.

Generally, forest residues, such as cork, wood fibers/shavings/chips are used for bio-insulation (Asdrubali et al., 2015; Liu et al., 2017).

The scientific community as investigated thoughtfully the valorization of general organic waste (Six et al., 2016; Jimenez et al., 2017; Du et al., 2018), but not so much regarding pruning waste. There area some studies about the utilization of pruning waste produced by plants of agronomic interest such as vineyards and olive groves (Vecino et al., 2017; Jesus et al., 2017; Pérez et al., 2018) as insulating materials, but there are not evaluations about the potentialities of the of urban pruning waste.

The species in Urban Forestry are usually less diverse than many could expect (Blasi et al., 2005; Conti et al., 2005). Recent studies showed as *Acer sp.* and *Tilia sp.* are among the most frequently occurring genera in urban contexts (Fini et al., 2009; Terho, 2009; Sjöman et al., 2012; Moser et al., 2015; Yang et al., 2015).

This paper shows the results of tests and simulations performed on linden trees pruning waste, with the aim to evaluate its suitability as insulation material, from the thermal performance point of view. The general aim of the paper is to offer a reflection about the importance of the valorization of pruning waste in urban contexts, that could translate in more funding for training the personnel regarding the urban green system management, to update the used equipment and in general to carry on the pruning work in a more sustainable and adequate way.

2. Materials and methods

For this study, we produced three types of tiles based on the residues of pruning of linden trees (*Tilia sp.*) in a city of central Italy (Perugia). The first sample is obtained by shredding linden's suckers, cut at the end of August, in order to have a more lignified material. The other two samples were obtained shredding branches of the linden trees with a diameter smaller than 2 cm. The cut was carried out after the fall of all the leaves in early October, to have cleaner samples (Fig.1).

The method consists in two steps. The first step regards a process for generating tiles of linden wool and for the evaluation of their thermal characteristics (conductivity, density, volumetric heat capacity and specific heat). Using these values, the second step develops a dynamic simulation model, regarding the insulation of the roof of a residential building, to compare the thermal performance of the linden tiles with some commercial insulating vegetable fibers.

Fig. 2 is a block diagram representation of the first step.

To generate the tiles of the three types from the samples collected, their biomass was naturally dried for three weeks in a greenhouse at ambient temperature. The shredding was carried out using a bioshredder with 18 blades, 70 cm max diameter, 2–4 mc/h (Fig. 3), Green Technik BC100 allowing to obtain a wood wool (Fig.4). Regarding the shape of the swarfs, we tried as much as possible to incorporate in the sample only the filiform ones, removing the bulkier pieces of wood. The measurement of the swarfs has provided the following values: a length of between 5 cm and 7 cm, a width of around 1 mm, and a thickness of around 0.20 mm.

The humidity, (6.09 ± 0.15)%, of the swarfs was calculated by drying it in a natural ventilation oven for 24 h at a temperature of 60 °C.

The production of the samples presented considerable difficulties, as the swarfs do not have a fully fibrous configuration. For this reason, in this study we used a binder, which must be inserted in such quantity that it does not affect the extent of the wood wool properties. The materials were manually mixed with a mixture of water and PVA glue. The weight of water was the same as the wooden swarfs, the glue represented about 7.5% by weight of the water. It is impossible to

Fig. 1. Pruning residues.

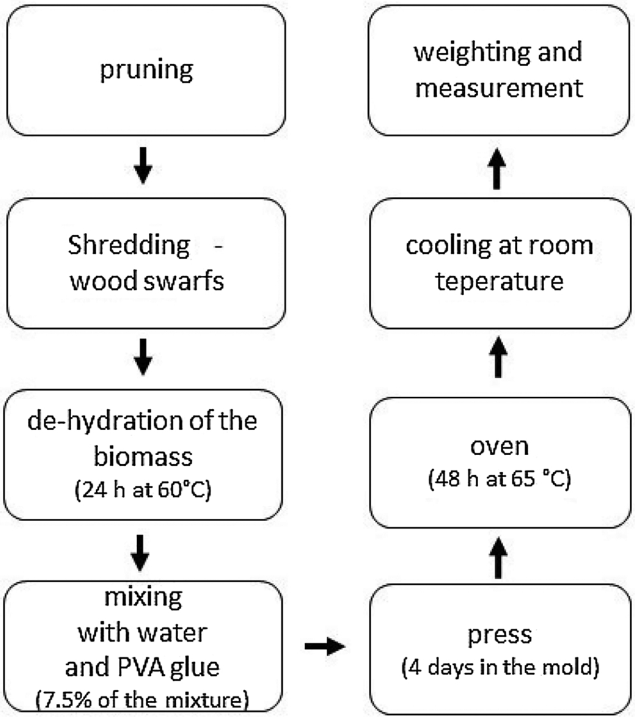

Fig. 2. Block diagram of the process for generating the linden wool tiles.

Fig. 3. Bioshredder Green Technik BC100.

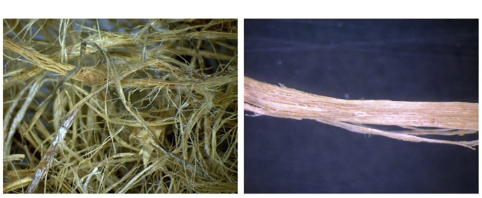

Fig. 4. Samples of Linden wool (7X and 15X magnification).

determine the amount of glue left in the final tiles, since a small part of the liquid solution was squeezed out during tightening. It is also difficult to imagine that the glue was uniformly distributed over the entire mass of wood. However, we can say that the quantity was sufficient to guarantee a good morphological stability and geometry to the obtained samples. The material characteristics are summarized in Table 1.The

Table 1
Characteristics of the material obtained from linden pruning.

Fibers dimensions	Length: 5-7 cm Width: 1mm Thickness: 0.2 mm
Humidity	(6.09 ± 015)%
Compacting ratio	7 N*m
Quantity of glue in the mixture	7.5% of the water's weight
Diameter of the tiles	160 mm
Thickness of the tiles	30 mm

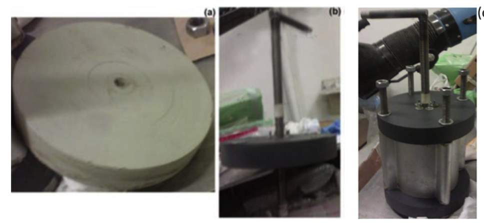

Fig. 5. (a) Cylindrical punch; (b) Tightening screw and (c) fully assembled press.

biomass was then dried in the laboratory for about 24 h at a temperature of 60 °C.

The materials were pressed with a special press, the main components of which are shown in Fig. 5, together with the fully assembled component. The press is composed of a PVC base on which holes have been drilled, through which 15 mm diameter rods have been passed through. Nuts placed under the base prevent the sliding down of the bars in question. An aluminum profile with the central circular section serves to shape the produced tiles and to confine the material. In this regard, the material, once produced, is inserted within the space described by the profile after it has been brought into contact with the base. The material is then surmounted by the cylindrical dart of Fig. 5a, which is pushed by the threaded bar (clamp bar) of Fig. 5b. This is after the PVC cover is tightened on the aluminum profile by means of the nuts. The pressure on the dart and then on the material is produced by rotating the threaded bar. All three samples were realized in order to have a thickness of 30 mm and a density close to 300 kg/m^3.

The pressure exerted was very low, in order to avoid wringing the material too much thus losing the fraction of glue together with the water. The torque exerted by the dynamometric wrench was equal to 7 N * m (circa 4.3 bar).

Each tile was held for four days in the mold (Fig. 5), after performing the clamping and the evacuation of all the excess water, and then transferred in the oven with the whole mold for 48 h at a temperature of 65 °C.

Once out of the oven, the material was allowed to cool off to ambient temperature, within a transparent plastic bag, which has been perfectly sealed. This practice allows checking the presence of residual moisture, as it would show condensation formation, deposited on the walls of the bag.

The resulting samples were weighed and measured to calculate their density for each type of product. The diameter of each sample was approximately 160 mm.

The measurement of thermal conductivity and specific heat were performed on all three materials by means of a membrane probe, which was directly placed on the surface of each specimen. This was carried out by means of a heat transfer analyzer by ISOMET, model 2104.

Measuring principle and accuracy are the following:

- Measuring principle: The device, through the probe, set up a temperature ramp, in order to produce a given ΔT. On the base of the energy actually spent to reach the mentioned ΔT, the instrument calculates the thermal conductivity of the material (k).

- Accuracy: $\pm$ 0.001 $W\ m^{-1}K^{-1}$, in terms of conductivity, and $1 \times 10^3\ Jm^{-3}K^{-1}$ in terms of volumetric heat capacity).

Each sample was subjected to the test several times each flat surface.

The second step starts with the design of a reference thermal simulation model of a residential house. EnergyPlus is the energy performance simulation program used. This software was selected because it is freely downloadable and is one of the most complete tools available for dynamic simulation of thermal performances (Crawley et al., 2001). EnergyPlus was developed by the Department of Energy of the United States of America. The simulation period examined in our study is one year because we want to analyse the behaviour of the building for an entire seasonal cycle. Using an ideal HVAC system, during autumn and winter the house is heated when the internal temperature fall below 22 °C and during spring and summer, the house is cooled when the internal temperature rises above the 27 °C. The paper uses an ideal HVAC with simple operation rules, because the aim is not the optimization of the energy saving for the building but the comparison between insulating materials. Indeed, this step aims at comparing the thermal performance of the studied tiles with two commercial materials produced with wood residues from the timber industry, and with the fibers of two vegetable crops, widely used for insulation purposes. The materials chosen for the comparison and their thermal characteristic are reported on Table 2.

Starting form the reference model, one by one, the method adds an insulation material to the roof and performs the annual dynamic simulation of the energy consumption for the heating and the air-conditioning of the building. The thickness of all the insulating layers is fixed at 15 cm and the panels are placed on the internal surface of the roof. The method place the insulating material on the roof, because it is the most influential component of the envelope of residential building for thermal performance (Menconi et al., 2017).

3. Results and discussion

Performing the first methodological step described on the previous paragraph, it was possible to obtain different tiles out of linden wool (Fig. 6). The process schematized on Fig. 2 generated homogeneous tiles starting from non-bonded elements. This first result is important because, by using probes dedicated to the measure of the thermal conductivity, in the case of a cluster of non-bonded elements and without a well-defined geometry, it would give a measure strongly influenced by the homogeneity of the sample chosen rather than by its actual properties (Domínguez-Muñoz et al., 2009). It is to be said that the measure of the intrinsic conductivity of the material is almost impossible, because it always be influenced by the density of the sample, hence the amount of air present, which tends to lower its value.

The resulting values of the thermic characteristics of the samples are shown in Table 3.

Schiavoni et al. (2016), performing an interesting literately review on insulating materials, identify as insulation materials' characteristics a range of thermal conductivity from 0.038 to 0.050 W/m K, of density from 50 to 270 kg/m^3 and of specific heat from 1.9 to 2.1 kJ/kg K. Table 3 shows as the values of thermal conductivity and specific heat of the three samples are lower than the literature values, but from Table 2 it is possible to observe as even some commercial insulating materials report values outside the Schiavoni et al.ös range (2016).

Generally, the thermal performance of a building's insulation layer is due to many factors, from its physical and morphological structure, that determines its thermal attributes, to the characteristics of the building and the climate qualities of the geographical location. For adapting to these varied situations, the insulating materials have strong differences with each other.

For this reason, as described in the second step of the method, to obtain a readably comparison between the tiles of linden wool and the other benchmark materials, for every insulating material, was performed an annual dynamic simulations of the energy consumption for the heating and the air conditioning of a same building model. These results was compared with the result regarding the energy consumption of the model without insulation. Table 4 and the Fig. 7 show the results of the simulations. These results show as the linden wool tiles, used as an internal coating layer added to the model building's roof, allow to get an annual energy saving of 55% for the heating and the air-conditioning of the building, compared to the building model without any insulation. The optimal values of energy saving are obtained by hard fiberboard and kenaf fibers, that reach a percentage of energy saving of 62%. At this regards, it is important to outline that the thermal characteristics of the different materials used in the simulation are on one hand the optimized values of commercial materials, and on the other, the linden tiles, are the results of the first tests done on this kind of material. Furthermore, the aim of the study is not the research of the best insulating material, but to evaluate if linden wool could be a good source material for insulation purposes. In such context, the halve of the energy consumption seem to be a good result. In addition to these results, considering that the studied tiles are a smart use of a waste material, their usability could also profit from sustainability considerations (Menconi and Grohmann, 2014; Rocchi et al., 2018). A future development will evaluate their sustainability, according to the method proposed by Rocchi et al. (2018) that integrates the dynamic simulation with a Life Cycle Assessment and a Life Cycle Costing.

For obtaining tiles adapt for commercial use, the realization step needs some adjustments, finalized to generate tiles of linden wool with optimal thermal performance. For example, varying the pressure on the press to reduce the density of the tiles, and refining the dehydration protocol (the sample b of Fig. 6 presented a water content, which was too high, lowering the thermal performances and causing the insurgence of mold).

An important reflection on the potentiality of commercial use of this material is that the linden pruning necessities, except for the removal the unlignified suckers that cannot be used at this purpose, are not yearly. Starting from the definition of circular economy as "an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. [...] Circular economy limits the through put flow to a level that nature tolerates and utilizes ecosystem cycles in economic cycles by respecting their natural reproduction rates."(Korhonen et al., 2018a, 39), and considering that "the logic of turning from linear and wasteful to cyclical, restorative, reproductive and smart physical flow structures is appealing and positively provocative crossing sectoral, organizational, administrative and national boundaries and borders in its message" (Korhonen et al., 2018b,551), it is important to give to Public Administrators sustainable ways for

Table 2
Thermal characteristics of the insulating materials for the comparison with the tiles of linden wool.

	thermal conductivity (W/m*K)	density (kg/ m^3)	specific heat (J/kgK)	volumetric heat capacity (10^5 J/ m^{3}K)	thickness (cm)
hard fiberboard	0.04	130	2100	2.730	15
plywood	0.12	540	1210	6.534	15
kenaf fiber	0.037	50	2050	1.025	15
hemp fiber	0.044	50	1700	8.500	15

Fig. 6. Sample a) is obtained by shredding linden's suckers, cut at the end of August. Samples b) and c) were obtained shredding branches of the linden trees in early October and by pressing, in the press showed on Fig. 5, with different intensity to vary their densities: b) 202 kg/m^3; c) 260 kg/m^3.

Table 3
Thermal characteristics of the tiles of linden wool. The description of the different samples is on the caption of Fig. 6.

	thermal conductivity (W/m*K)	density (kg/ m^3)	specific heat (J/kgK)	volumetric heat capacity (10^5 J/ m^{3}K)	thickness (cm)
linden wool tile a)	0.0837 ± 0.0076	333	721	2.40 ± 0,44	15
linden wool tile b)	0.0830 ± 0.0054	202	1119	2.26 ± 0,51	15
linden wool tile c)	0.0860 ± 0.0140	260	1077	2.80 ± 0,65	15

Table 4
Energy consumptions for the annual heating and air-conditioning of the building model, varying the internal coating layer added to the building's roof (The building has a volume of 640 m^3). The characteristic of the envelope are those of the traditional residential buildings of Central Italy "Exterior walls have a structure typical of traditional stonewalls of considerable thickness, the whole structure is held together by mortar of lime and sand. The load bearing walls have a thickness of 40 cm. The interior non-load bearing walls are instead made by solid bricks of 15 cm length. The floor of the ground floor consists of a layer of concrete topped with ceramic tiles. The roof is made of a layer of tiles, which rests atop a wooden truss, topped by roof tiles. External and internal doors are made of wood and have a thickness respectively of 5 and 2 cm. The windows are single glazing not colored." (Menconi et al., 2017, 132). This paper used the Perugia weather file available on the U.S. Department of Energy website for the simulations (https://energyplus.net/weather). Its characteristic are descripted in a previous work (Menconi and Grohmann, 2014). Even if, the resulting gigajoules of consumption depend on the building and the location, the comparison, between the percentages of energy saving linked to the different insulating materials, offers indication transferable to other models of building and other geographical contexts, to optimize the choices about insulation).

	heating (GJ)	air-conditioning (GJ)	energy consumption (GJ)		
building model (without insulation layer)	100.68	18.06	118.74	energy saving (GJ)	energy saving (%)
INSULATING LAYER					
hard fiberboard	39.05	6.27	45.32	73.42	62
plywood	50.73	7.75	58.48	60.26	51
kenaf fiber	38.54	6.28	44.82	73.92	62
hemp fiber	39.84	6.48	46.32	72.42	61
linden wool tile a	46.18	7.26	53.44	65.3	55
linden wool tile b	46.05	7.25	53.3	65.44	55
linden wool tile c	46.45	7.27	53.72	65.02	55

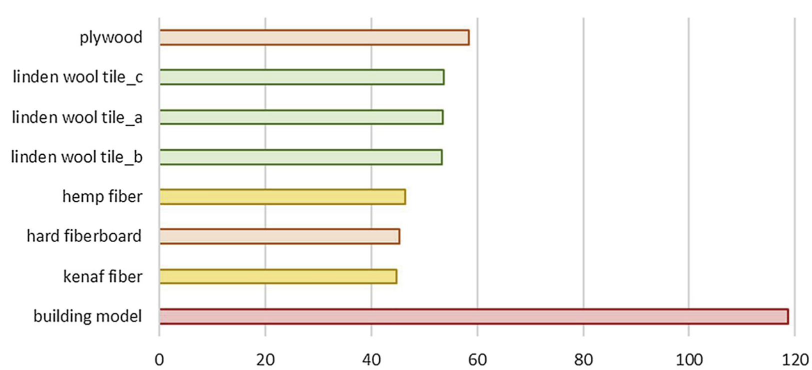

Fig. 7. Bar chart of the values of energy consumptions reported on Table 4.

building the policy and industry consensus. In the case of the smart use of the by-products of urban linden pruning, it could be feasible to mix them with the shredding results of the pruning of different urban tree species for obtaining a constant annual production of these materials that justifies the creation of a dedicated municipal factory to realize a commercial product.

4. Conclusion

This paper is a first contribution to test the suitability of the material obtainable by the management of the urban trees as thermal insulation of buildings. The developed method evaluates the material from the thermal performance point of view. The tests are effectuated on suckers and on pruning waste of linden trees. The results show as this material could halve the annual energy consumption for the conditioning of a residential building. Comparing this result with the thermal performance of commercial insulating materials, it is still lower (55% of annual energy saving respect to the 62%). At the same time, in an overall sustainability evaluation it seems to be very promising because it is an enhancement of a waste material, while most of the commercial products use dedicated crops. Generally, the resulting characterization of the linden wool is close enough to the benchmark values to allow foreseeing a possible use in the insulation materials' market for these products.

The originality of the paper regards mainly the source material for the production of insulation materials that would open interesting, and crucial, scenarios for urban greening's care and maintenance. Indeed the paper suggests smart-utilization of the byproducts of the urban green system management, following a circular economy approach

Sustainable management of urban forestry should be a fundamental goal to achieve for every public administration, as the Trees for Seattle (City of Seattle, 2018) experience seems to demonstrate. There are many obstacles to overcome to reach this goal, in some nations more than other, but one of the steepest slopes for all to climb is of economic nature. To find a suitable use for the maintenance processes outcomes can be the key to unlock those monetary resources indispensable for an adequate care taking approach to the urban arboreal patrimony, to invest on in personnel, techniques and equipment.

Acknowledgements

This work could have never been carried out without the invaluable help of Mr. Massimo Pilli and Mr. Francesco Prosperi, members of the DSA3 technical staff and founding members of the San Pietro Green Team.

References

Aditya, L., Mahlia, T.M.I., Rismanchi, B., Ng, H.M., Aditiya, H.B., 2017. A review on insulation materials for energy conservation in buildings. Renew. Sustain. Energy Rev. 73, 1352–1365.

Al-Ragom, F., 2003. Retrofitting residential buildings in hot and arid climates. Energy Convers. Manage. 44, 2309–2319.

Asdrubali, F., D'Alessandro, F., Schiavoni, S., 2015. A review of unconventional sustainable building insulation materials. Sustain. Mater. Technol. 4, 1–17.

Benedict, M., McMahon, E., 2006. Green Infrastructure: Linking Landscapes and Communities. Island Press, Washington, DC.

Blasi, C., Boitani, L., La Posta, L., Manes, F., Marchetti, M., 2005. Stato Della Biodiversità in Italia (State of the Biodiversity in Italy). Ministero dell'Ambiente della Tutela del Territorio, Rome (In Italian).

Butler, D., Spencer, N., 2010. The century of the city. Nature 467, 900–901.

Campanella, B., Toussaint, A., Paul, R., 2009. Mid-term economical consequences of roadside tree topping. Urban For. Urban Green. 8, 49–53.

City Of Portland, 2010. Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits. Retrieved October 4nd, 2018 from. https://www.portlandoregon.gov/bes/article/298042.

City of Seattle, 2018. Trees for Seattle. Retrieved October 4nd, 2018 from. https://www.seattle.gov/trees/.

Coder, R.D., 1996. Identified Benefits of Community Trees and Forests. Retrieved October 4nd, 2018 from. University of Georgia. https://nfs.unl.edu/documents/communityforestry/coderbenefitsofcommtrees.pdf.

Conti, F., Abbate, G., Allessandrini, A., Blasi, C. (Eds.), 2005. An Annotated Checklist of the Italian Vascular Flora. Palombi, Rome.

Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J., Glazer, J., 2001. EnergyPlus: creating a new-generation building energy simulation program. Energy Build. 33 (4), 319–331.

Day, S.D., Dickinson, S.B., 2008. Managing Stormwater for Urban Sustainability Using Trees and Structural Soils. Virginia Polytechnic Institute and State University, Blacksburg.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A.G., Mittal, N., Feliu, E., Faehnle, M., 2014. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manage. 146, 107–115.

Domínguez-Muñoz, F., Anderson, B., Cejudo-López, J.M., Carrillo-Andrés, A., 2009. Uncertainty in the thermal conductivity of insulation materials. Proceedings of the Eleventh International IBPSA Conference Glasgow.

Du, C., Abdullah, J.J., Greetham, D., Fu, D., Yu, M., Ren, L., Li, S., Lu, D., 2018. Valorization of food waste into biofertiliser and its field application. J. Clean. Prod. 187, 273–284.

Dujesiefken, D., Liese, W., Shortle, W., Minocha, R., 2005. Response of beech and oaks to wounds made at different times of the year. Eur. J. For. Res. 124, 113–117.

Dwyer, J.F., McPherson, E.G., Schroeder, H.W., Rowntree, R.A., 1992. Assessing the benefits and costs of the urban forest. J. Arboric. 18, 227–234.

Fini, A., Ferrini, F., Frangi, P., Amoroso, G., Piatti, R., 2009. Withholding Irrigation During the Establishment Phase. Affected Growth and Physiology of Norway Maple (*Acer platanoides*) and Linden (*Tilia spp.*). Arboric. Urban For. 35, 241–251.

Fini, A., Frangi, P., Faoro, M., Piatti, R., Amoroso, G., Ferrini, F., 2015. Effects of different pruning methods on an urban tree species: a four-year-experiment scaling down from the whole tree to the chloroplasts. Urban For. Urban Green. 14, 664–674.

Gage, E.A., Cooper, D.J., 2017. Urban forest structure and land cover composition effects on land surface temperature in a semi-arid suburban area. Urban For. Urban Green. 28, 28–35.

Gill, S., Handley, J., Ennos, A., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environ. 33, 115–133.

Gillner, S., Vogt, J., Tharangc, A., Dettmanna, S., Roloff, A., 2015. Role of street trees in mitigating effects of heat and drought at highly sealed urban sites. Landsc. Urban Plan. 143, 33–42.

Jesus, M.S., Romaní, A., Genisheva, Z., Teixeira, J.A., Domingues, L., 2017. Integral valorization of vine pruning residue by sequential autohydrolysis stages. J. Clean. Prod. 168, 74–86.

Jimenez, J., Lei, H., Steyer, J.P., Houot, S., Patureau, D., 2017. Methane production and fertilizing value of organic waste: organic matter characterization for a better prediction of valorization pathways. Bioresour. Technol. 241, 1012–1021.

Kawasaki, T., Kawai, S., 2006. Thermal insulation properties of wood-based sandwich panel for use as structural insulated walls and floors. J. Wood Sci. 52, 75–83.

Korhonen, J., Honkasalo, A., Deppala, J., 2018a. Circular economy: the concept and its limitations. Ecol. Econ. 143, 37–46.

Korhonen, J., Nuur, C., Feldmann, A., Birkie, S.E., 2018b. Circular economy as an essentially contested concept. J. Clean. Prod. 175, 544–552.

Kumar, A., Staněk, K., Ryparová, P., Hajek, P., Tywoniak, J., 2016. Hydrophobic treatment of wood fibrous thermal insulator by octadecyltrichlorosilane and its influence on hygric properties and resistance against moulds. Compos. Part B Eng. 106, 285–293.

Lafortezza, R., Carrus, G., Sanesi, G., Davies, C., 2009. Benefits and well-being perceived by people visiting Green spaces in periods of heat stress. Urban For. Urban Green. 8, 97–108.

Liu, L.F., Li, H.Q., Lazzaretto, A., Manente, G., Li, N.P., 2017. The development history and prospects of biomass-based insulation materials for buildings. Renew. Sustain. Energy Rev. 69, 912–932.

Maurin, V., Desrochers, A., 2013. Physiological and growth responses to pruning season and intensity of hybrid poplar. For. Ecol. Manage. 304, 399–406.

Menconi, M.E., Grohmann, D., 2014. Model integrated of life-cycle costing and dynamic thermal simulation (MILD) to evaluate roof insulation materials for existing livestock buildings. Energy Build. 81, 48–58.

Menconi, M.E., Chiappini, M., Hensen, J.L.M., Grohmann, D., 2017. Thermal comfort optimisation of vernacular rural buildings: Passive solutions to retrofit a typical farmhouse in central Italy. J. Agric. Eng. 48 (3), 127–136.

Moser, A., Rötzer, T., Pauleit, S., Pretzsch, H., 2015. Structure and ecosystem services of small-leaved lime (*Tilia cordata* Mill.) and black locust (*Robinia pseudoacacia* L.) in urban environments. Urban For. Urban Green. 14, 1110–1121.

Newell, J.P., Seymour, M., Yee, T., Renteria, J., Longcore, T., Wolch, J.R., Shishkovsky, A., 2013. Green Alley Programs: Planning for a sustainable urban infrastructure? Cities 31, 144–155.

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M., Williams, N.S.G., 2015. Planning for cooler cities: a framework to priorities green infrastructure to mitigate high temperature in urban landscapes. Landsc. Urban Plan. 134, 127–138.

Nowak, D.J., Rowntree, R.A., McPherson, E.G., Sisinni, S.M., Kerkmann, E.R., Stevens, J.C., 1996. Measuring and analyzing urban tree cover. Landsc. Urban Plan. 36, 49–57.

Pataki, D., McCarthy, H., Litvak, E., Pincetl, S., 2011. Transpiration of urban forests in the Los Angeles metropolitan area. Ecol. Appl. 21, 661–677.

Pérez, A., Martín-Lara, M.A., Gálvez-Pérez, A., Calero, M., Ronda, A., 2018. Kinetic analysis of pyrolysis and combustion of the olive tree pruning by chemical fractionation. Bioresour. Technol. 249, 557–566.

Rocchi, L., Kadzinski, M., Menconi, M.E., Grohmann, D., Miebs, G., Paolotti, L., Boggia, A., 2018. Sustainability evaluation of retrofitting solutions for rural buildings through life cycle approach and multi-criteria analysis. Energy Build. 173, 281–290.

Rowntree, R.A., Nowak, D.J., 1991. Quantifying the role of urban forests in removing atmospheric carbon dioxide. J. Arboric. 17, 269–275.

Schiavoni, S., D'Alessandro, F., Bianchi, F., Asdrubali, F., 2016. Insulation materials for the building sector: a review and comparative analysis. Renew. Sustain. Energy Rev. 62, 988–1011.

Sevindir, M.K., Demir, H., Ağra, Ö., Atayılmaz, Ş.Ö., Teke, İ., 2017. Modelling the optimum distribution of insulation material. Renew. Energy 113, 74–84.

Shigo, A.L., 1989. Tree Pruning: A Worldwide Photo Guide. Shigo and Trees Associates, Durham.

Six, L., Velghe, F., Verstichel, S., De Meester, S., 2016. Sustainability considerations on the valorization of organic waste. Chapter 11 In: Poltronieri, P., D'Urso, O.F. (Eds.), Biotransformation of Agricultural Waste and By-Products. The Food, Feed, Fibre, Fuel (4F) Economy. Elsevier, pp. 287–307.

Sjöman, H., Östberg, J., Bühler, O., 2012. Diversity and distribution of the urban tree population in ten major Nordic cities. Urban For. Urban Green. 11, 31–39.

Smiley, E., Kane, B., 2006. The effects of pruning type on wind loading of Acer rubrum. Arboric. Urban For. 32, 33–40.

Taoukil, D., El Bouardi, A., Ajzoul, T., Ezbakhe, H., 2012. Effect of the incorporation of wood wool on thermo physical proprieties of sand mortars. J. Civ. Eng. 16, 1003–1010.

Terho, M., 2009. An assessment of decay among urban Tilia, Betula, and Acer trees felled as hazardous. Urban For. Urban Green. 8, 77–85.

Vecino, X., Rodríguez-López, L., Gudiña, E.J., Cruz, J.M., Moldes, A.B., Rodrigues, L.R., 2017. Vineyard pruning waste as an alternative carbon source to produce novel biosurfactants by Lactobacillus paracasei. J. Ind. Eng. Chem. 55, 40–49.

World Health Organization, 2016. Global Report on Urban Health: Equitable, Healthier Cities for Sustainable Development. Retrieved October 4th, 2018 from. . http://www.who.int/kobe_centre/measuring/urban-global-report/en/.

Yang, J., Chang, Y., Yan, P., 2015. Ranking the suitability of common urban tree species for controlling PM2.5 pollution. Atmos. Pollut. Res. 6, 267–277.

Zheng, S., Zhao, L., Li, Q., 2016. Numerical simulation of the impact of different vegetation species on the outdoor thermal environment. Urban For. Urban Green. 18, 138–150.