BUILDING WITH BIO-BASED MATERIALS: BEST PRACTICE AND PERFORMANCE SPECIFICATION

Final COST Action FP1303 International Scientific Conference
Zagreb, Croatia – 6th and 7th September 2017

Proceedings

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Building With Bio-Based Materials: Best Practice And Performance Specification

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PREFACE

It hardly seems that it was some 5 years ago I came up with the idea to submit a COST proposal to help fill the gap left after the many successes of previous Actions from previous years, including:
E2: Wood durability (1994 – 1999)
E5: Timber frame building systems (1996 – 2000)
E8: Mechanical performance of wood and wood products (1996 – 2000)
E13: Wood adhesion and glued products (1998 – 2002)
E22: Environmental optimisation of wood protection (1999 – 2004)
E29: Innovative Timber & Composite Elements/Components for Buildings (2002 – 2007)
E34: Bonding of Timber (2004 – 2008)
E37: Sustainability Through New Technologies for Enhanced Wood Durability (2004 – 2008)
E49: Processes and Performance of Wood-based Panels (2005 – 2009)
E55: Modelling of the performance of timber structures (2006 – 2011)
FP0904: Thermo-Hydro-Mechanical Wood Behaviour and Processing (2010 – 2014)

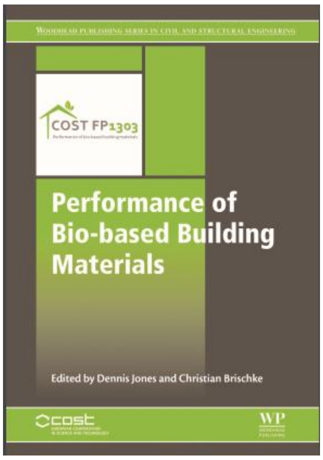
Many of the Early Career Investigators in this Action may be unaware of these previous Actions, but some of those here (myself included) have been active in several of these (indeed I recall being involved in a joint meeting between E2 and E8!). Many of you were present in the kick off meeting of our Action on 22 October 2013 in Brussels:

However, we are now reaching the point where our Action will soon be joining this growing list of successfully completed Actions.

Through our Action, we have had meetings and training schools in France (Paris), Germany (Hannover), Portugal (Lisbon), Slovenia (Kranjska Gora), Estonia (Tallinn), United Kingdom (Llandudno), Finland (Helsinki), Switzerland (Zurich), Spain (Madrid), Italy (San Michele All’Adige), Poland (Poznan), United Kingdom (Bangor), Bulgaria (Sofia), and now we find ourselves meeting together for one last time in Zagreb, Croatia. We have also managed to organise successful round-robin assessment trials.

Our Action has been fortunate to have strong links with COST FP1407 (Understanding wood modification through an integrated scientific and environmental impact approach (ModWoodLife)) and COST FP1404 (Fire safe use of bio-based building products), as well as the European Conference on Wood Modification (ECWM), The International Panel Products Symposium (IPPS) and the International Research Group on Wood Protection (IRG).

This meeting will focus on many of the key deliverables outlined within the original Memorandum of Understanding – specifically Moisture and Materials, Best Practice Specification, Indoor Environment, Outdoor Performance, Innovative Materials and New Methods, Assessment Tools and Education and Knowledge Transfer. As with all our previous meetings, a lot to go through in two days - testimony to the continued hard work of all Action members and their keenness to present their latest work and establish new collaborative links.



The degree of collaboration by members has been shown by a key outcome from the Action, with the publication of a book "The Performance of Bio-based Building Materials". Published by Woodhead Publishing, this book comprises some 650 pages of state of the art reports across all areas of the Action, and more impressively, written by 66 authors! Whilst myself and Christian Brischke are the named editors on the front cover, without the combined effort of all authors this would never have been possible – our most sincere thanks for helping make this happen.

Whilst this Action started off as my rambling ideas more than 5 years ago, it would never have happened without the activity of many people within our network. However once started, I must offer my sincerest thanks to the following:

Vice-Chair: Christian Brischke
WG1 Leaders: Stig Bardage and Lina Nunes
WG2 Leaders: Miha Humar and Sabrina Palanti
WG3 Leaders: Andreja Kutnar and Ed Suttie
STSM Manager: Carmen-Mihaeala Popescu

Then we have the COST Office. This Action has seen three Scientific Officers: Melae Langbein, Fatima Bouchama and Karina Marcus. However, the person in Brussels who has had to put up with the majority of my constant questions over the past 4 years is our Finance Officer, Cassia Azevedo. Many thanks to all at the COST Office.

Thanks must also go to all venue hosts during the four years. Also, my sincerest thanks to our hosts for this final meeting, University of Zagreb Faculty of Forestry and specifically Vjekoslav Živković for all his help in making this happen.

And finally, to ALL Action participants (more than 260) over the 4 years, for making this a friendly group. It has been an immense pleasure for me to meet and work with you all. Let's keep this success going with new collaborations and projects (and hopefully new COST Actions). Hope you all enjoy this final meeting.

Dennis Jones
Chair FP1303

FOREWORD

Revival of timber building in many European countries commits and inspires not only architects and planners but also wood scientists and other enthusiasts to plan and build long lasting high-quality timber products. Durability of timber products outdoors can be achieved by proper material selection, technical design (physical protection, adequate detailing), chemical and surface protection and regular maintenance.

This final conference is therefore organised with the aim to assess developments over the four years of the COST Action, and what has been achieved in that time in terms of best practice for bio-based materials in construction, how research and development has helped increase awareness, and commercial opportunities that now exist.

This conference has been organised within the frames of COST action FP 1303 *Performance of bio-based building materials* and hosted by the Faculty of Forestry, University of Zagreb. As local organisers, we wish to thank authors, scientific committee members, moderators, and all other that made this conference possible. We hope that you will find this conference useful and take good memories from Zagreb and Croatia.

Vjekoslav Živković, local organiser
Vladimir Jambreković, dean of the Faculty of Forestry

PUBLICATIONS ACCEPTED IN WOOD MATERIAL SCIENCE AND ENGINEERING

The following papers presented at this conference were slected for publication in Wood Materal Science and Engineering (published by Taylor and Francis):

Intelligent recycling of bio-based construction materials
Mark Irle, François Privat, Laetitia Couret, Christophe Belloncle, Gérard Déroubaix, Estelle Bonnin, Bernard Cathala

Fungal and bacterial colonies growing on weathered wood surfaces
Julia Buchner, Mark Irle, Christophe Belloncle, Franck Michaud, Nicola Macchioni

Improvement of dimensional stability of wood by silica-nanoparticles
Miklós Bak, Ferenc Molnár, Róbert Németh

Wood modification with DMDHEU – State of the art, recent research activities and future perspectives
Lukas Emmerich, Holger Militz

Performance of wooden windows and facade elements made of thermally modified and non-modified Norway spruce in different natural environments
Aleš Ugovšek, Barbara Šubic, Jernej Starman, Gregor Rep, Miha Humar, Boštjan Lesar, Nejc Thaler, Christian Brischke, Linda Meyer-Veltrup, Dennis Jones, Urban Häggström, Jose Ignacio Lozano

Performance of wood in the WWII Franja partisan hospital
Miha Humar, Davor Kržišnik, Christian Brischke, Boštjan Lesar, Nejc Thaler

The interactions between wood, wood components and water at a micro level

Callum Hill

NIBIO, Ås, Norway

InnoRenew, Koper, Slovenia

Keywords: water, hydroxyl groups, mechano-sorption, Kelvin-Voigt, viscoelasticity

ABSTRACT

One of the advantages of using natural materials in buildings is their 'breathability', which is a function of their relationship with atmospheric moisture. The sorption behaviour of lignocellulosic materials has been studied for over one hundred years, but we are still far from reaching a consensus to explain why these materials show sigmoidal sorption isotherms and why we observe sorption hysteresis. This paper will present some of the work in this field that has been undertaken by the author over the past decade and discuss how the water vapour sorption properties of plant-based materials can be linked to behaviour at the molecular level.

INTRODUCTION

One of the questions to be asked, is how important are hydroxyl groups to the sorption behaviour of wood? Nearly every talk about the subject is based on the assumption that it is the OH groups that are responsible for determining the behaviour and this is the accepted wisdom on the subject. But there is very little evidence to support this assumption and some recent work on the sorption behaviour of modified wood combined with direct measurements of the accessible OH content using deuterium exchange has shown that there is no correlation between the two properties. Charcoal shows high levels of sorption of water vapour, but does not contain any measureable OH content.

It is possible to create models of sorption behaviour that do not rely on OH groups at all. An important part of such a model is the fact that water sorption in a lignocellulosic material, results in swelling of the material during adsorption and shrinking during desorption. The swelling of the material represents stored strain energy, which is supplied by the thermal motion of the sorbed water molecules. At the point of equilibrium moisture content, the water molecules in the cell wall are in a state of dynamic equilibrium with the water molecules in the atmosphere. This state of equilibrium is reached when the rate of the diffusion of water molecules into the cell wall is exactly balanced by the rate at which the water molecules are leaving the cell wall. Under conditions of adsorption, there are more water molecules entering the cell wall than leaving and under conditions of desorption, there are more departing than entering. This is a very well-known phenomenon in chemistry and is related to the Gibbs free energy change of the system. For any process to take place spontaneously, the change in Gibbs free energy is negative and when the system is in equilibrium, the change in Gibbs free energy is zero.

The model, which is presented here is derived from kinetics work that has been ongoing using dynamic vapour sorption apparatus for over a decade. It has been found that the sorption kinetics can be accurately modelled using the empirical parallel exponential kinetics (PEK) model, which is:

$$MC = MC_0 + MC_1.[1\text{-exp}(-t/t_1)] + MC_2.[1\text{-exp}(-t/t_2)] \quad (1)$$

Where, MC is moisture content at time t, MC_0 is the moisture content at time t=0, MC_1 is the moisture content at infinite time of the fast process, MC_2 is the moisture content at infinite time of the slow process and t_1 and t_2 are time constants for the fast and slow processes, respectively.

The fast and slow components of the PEK equation have a mathematical form that is identical with that describing the dynamic response of a Kelvin-Voigt element when subjected to an instantaneous stress increase (σ_0):

$$\varepsilon = (\sigma_0 /E)[1 - \exp(-t/\varphi)] \quad (2)$$

Where ε is the strain at time t, E is the elastic modulus and φ is a time constant which is defined as the ratio η/E, where η is the viscosity. In the case of a plant fibre subjected to a change in relative humidity (RH), there is a change in the swelling pressure (Π – equivalent to σ_0) exerted within the cell wall when the atmospheric water vapour pressure is raised from an initial value p_i to a final value p_f given by Equation 3:

$$\Pi = - (\rho/M)RT.\ln(p_i/p_f) \quad (3)$$

Where ρ is the density and M is the molecular weight of water, R is the gas constant and T is the isotherm temperature in kelvin. In the model described herein, the strain of the system is assumed to be equivalent to the volume change of the cell wall as a result of water vapour adsorption or desorption. This volume change is further assumed to be linearly related to the change in the mass fraction of the water present in the cell wall. The appropriate mechanical analogue comprises two Kelvin-Voigt elements arranged in series (Fig. 1) with E_1, E_2 being the moduli associated with the fast and slow processes respectively and η_1 and η_2 being the equivalent matrix viscosities.

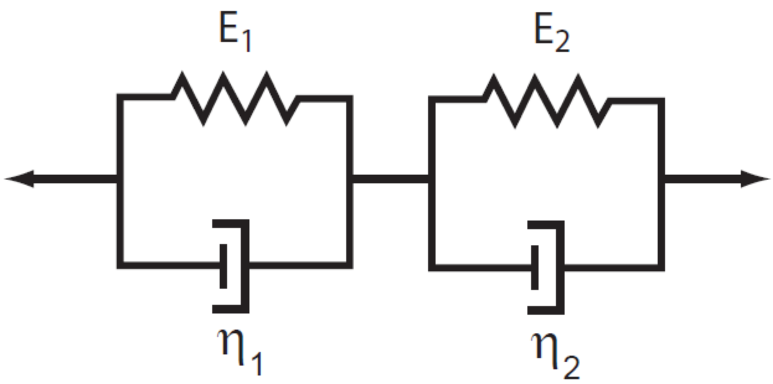


Figure 1: Two Kelvin-Voigt elements in series

The EMC in such a model is purely a function of the modulus of the spring elements and the rate of sorption is controlled by the viscosity of the elements. This model does not require consideration of OH groups. The EMC is therefore a function of the stiffness of the cell wall. The reduction of the EMC of thermally-modified wood can then be explained as being due to an increase in modulus of the cell wall caused by degradation of the hemicelluloses and increased cross-linking of the lignin and not being due to a reduction in the number of accessible OH groups. The lack of any strong correlation between accessible OH groups and EMC has been noted in an experiment where deuterium exchange was used to determine the OH content of thermally-modified wood Rautkari et al. (2013).

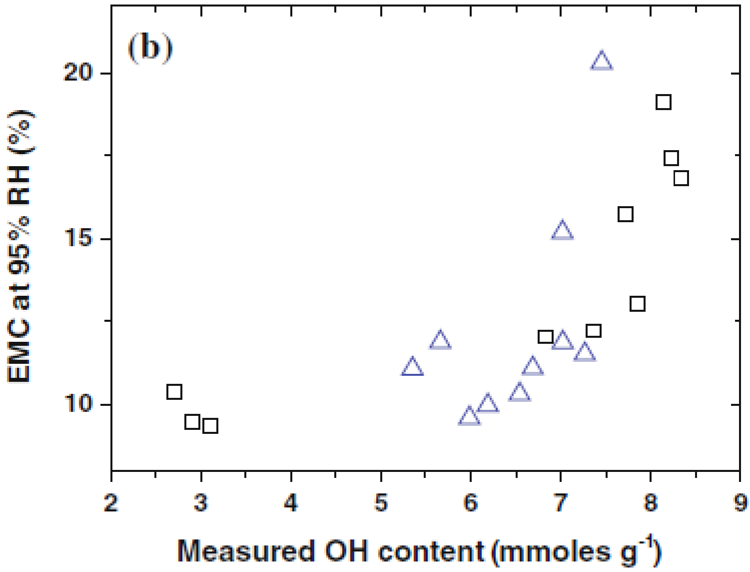


Figure 2: Plot showing the relationship between EMC at 95% RH and the accessible OH content determined by deuterium exchange

This does not mean that the cell wall OH groups have no role to play in the sorption behaviour of wood, but that there are additional factors that must be taken into account.

When examining the sorption behaviour of lignocellulosic materials, it is important to note that the results obtained between the first and subsequent sorption cycles may be different. This is particularly noticeable for the sorption behaviour of thermally-modified wood.

The change in sorption behaviour between the first and second sorption cycles has been known for thermally modified wood for quite some time (Mitchell et al. 1953, Obataya et al. 2000, Obataya and Tomita 2002, Hill et al. 2012). Hill et al. (2012) compared unmodified, densified, thermally modified, and a densified plus thermally modified samples of Scots pine. The samples were subjected to three sorption cycles in the DVS apparatus, with the results shown in Figure 3. The intention of this experiment was to see if the properties of the densified wood could be 'fixed' by using a subsequent thermal modification reaction. Densification was performed in an open-press system and involved heating at 150°C with the application of pressure for 1 hour, which is a form of low temperature thermal modification. The first adsorption cycle exhibited lower EMCs compared with subsequent cycles, but the desorption loop followed essentially the same path for all three cycles. Consequently, the sorption hysteresis was larger for the first cycle for the modified wood samples.

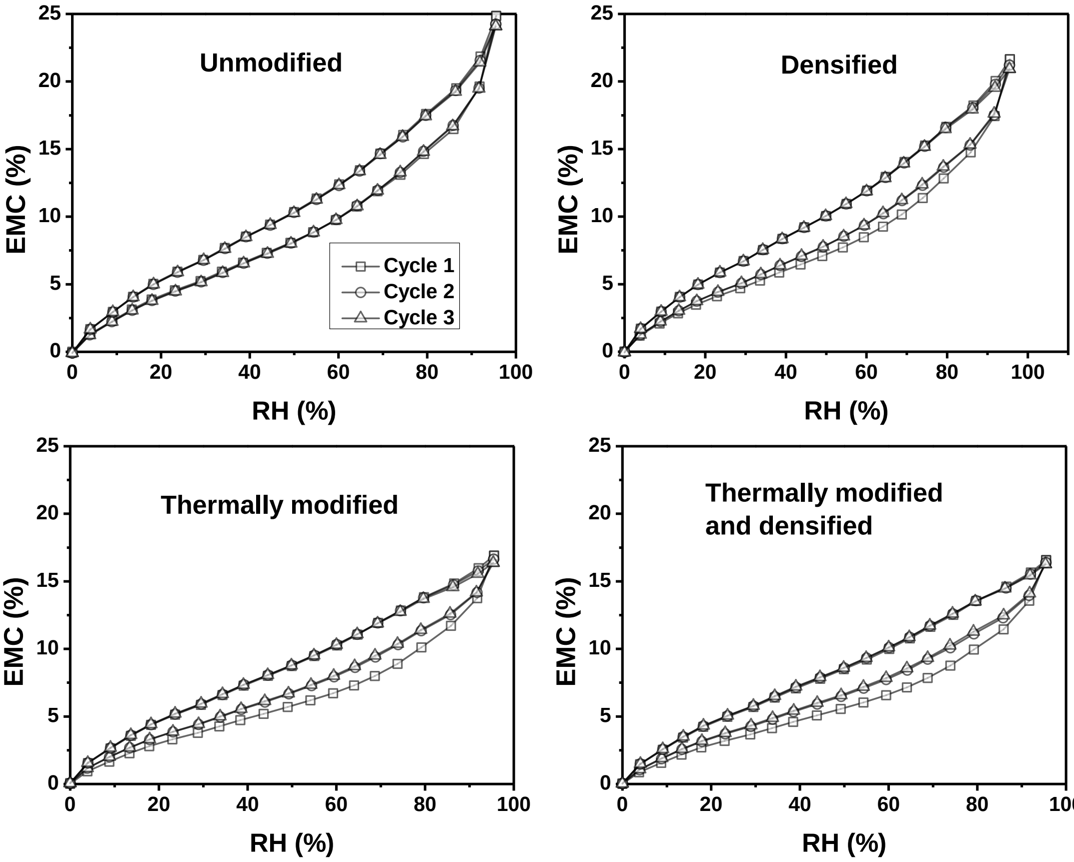


Figure 3: Comparison of sorption isotherms over three cycles for unmodified, densified, thermally modified, thermally modified and densified Scots pine.

This observation, that thermally modified wood exhibits an increased sorption hysteresis is consistent with a model where sorption occurs with a material that is in a glassy state (Lu and Pignatello 2002, Lu and Pignatello 2004, Vrentas and Vrentas 1996). This model predicts that hysteresis will be observed when the sorption isotherm is performed at a temperature lower than the glass transition temperature (Tg) of the material and that as the sorption isotherm temperature is raised the hysteresis will decrease, finally collapsing at the Tg. This will be examined later in this paper. The thermal modification and the densification procedures will both be expected to raise the Tg of the material, due to partial degradation of the hemicelluloses and increased crosslinking within the cell wall. This will result in an increased hysteresis between the adsorption and desorption branches of the isotherm. However, the reduction in hysteresis after the first sorption cycle is not easily explained. Clearly there is an annealing process taking place, but what does this mean exactly? Figure 4 shows the change in absolute hysteresis (obtained by subtracting the adsorption EMC from the desorption EMC) with each cycle, for the four wood specimens. It can be seen that much of the decrease in hysteresis occurs between the first and second sorption cycle, but there is a small change between the second and third cycles. There is also a slight change in hysteresis observed with the unmodified sample. Finally, the magnitude of the absolute hysteresis is identical in all samples in the third cycle, even though the sorption isotherms are different; this is unexplained.

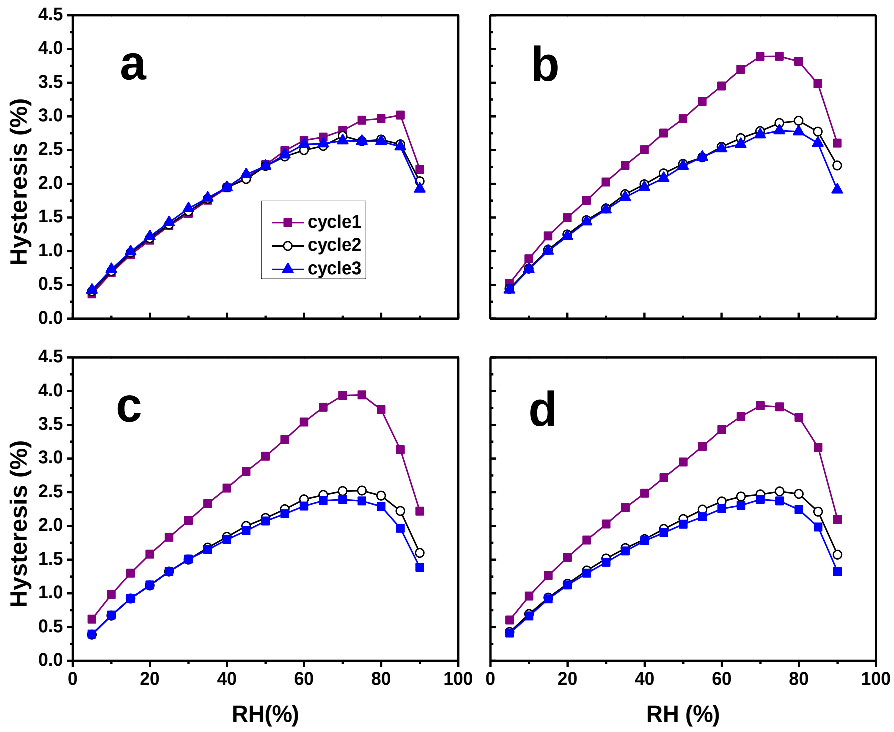


Figure 4: Change in absolute hysteresis with each sorption cycle for unmodified (a), densified (b), thermally modified (c), densified and thermally modified Scots pine.

The change in hysteresis in the unmodified sample indicates that there is an annealing process taking place in the first sorption cycle. The magnitude of the hysteresis between the adsorption and desorption isotherm is also related to the temperature of the isotherm. As the isotherm temperature increases, the magnitude of the hysteresis decreases, as is seen in the example of sorption isotherms of Sitka spruce (Fig. 5) (Hill *et al*. 2010).

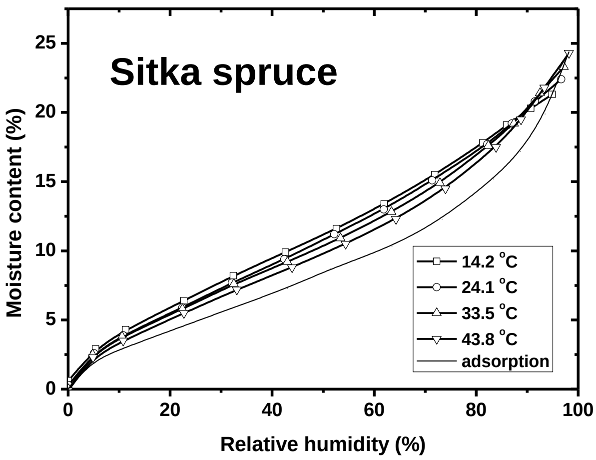


Figure 5: Decrease in sorption hysteresis with increasing isotherm temperature as observed for Sitka spruce.

Further support for this explanation of hysteresis is found in the sorption isotherm of galactomannan (guar) (Keating et al. 2013). Figure 6 shows the sorption isotherm of a guar film compared with a composite of cellulose whiskers embedded in guar. The guar film shows collapse of hysteresis at 70-80% RH.

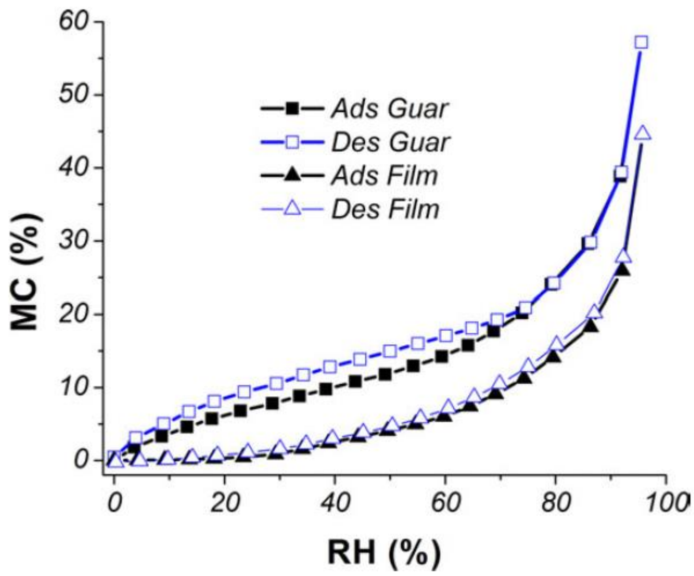


Figure 6: Comparison of the sorption isotherm of guar compared with a cellulose reinforced guar matrix composite (labelled film).

The change in absolute hysteresis with RH is compared with the storage modulus measurements obtained by performing a dynamic mechanical analysis at the same temperature and varying the relative humidity. The dramatic reduction in storage modulus corresponds to the onset of the glass transition temperature of the film. It can be seen that the collapse of hysteresis and the reduction in storage modulus coincide.

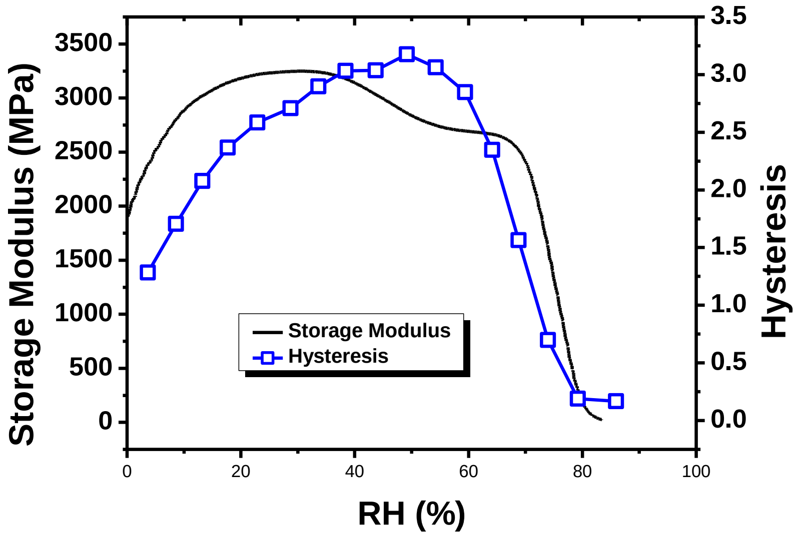


Figure 7: Comparison of the behaviour of absolute hysteresis with the storage modulus obtained byDMA of a guar film.

The situation with wood is not as simple because it does not display a single T_g (Hill and Beck 2017), but the theory is still applicable. Plasticisation of the cell wall matrix polymers occurs at high moisture contents and with higher temperatures, having the effect of a net reduction in the glass transition temperature. The glassy behaviour of the cell wall components is linked to the mobility of the macromolecules. Below the T_g, there is not enough void volume surrounding the molecules to allow for relaxation to occur. As the cell wall absorbs moisture, this leads to swelling of the material, which creates void volume. However, at room temperature, even at the highest levels of EMC, the T_g is still not reached.

CONCLUSIONS

Current models of the water sorption of lignocellulosic materials which just rely on the concept of sorption sites (OH groups) need to be modified to take into account the stiffness of the cell wall, which is a very important factor determining the EMC. The glassy nature of the wood cell wall is responsible for the sorption hysteresis phenomenon, an explanation that is well understood in the polymer science literature.

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Moisture requirements of wood decay fungi – Review on methods, thresholds and experimental limitations

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Keywords: Basidiomycetes, brown rot, durability, white rot, wood moisture content

ABSTRACT

Lignocellulose degrading fungi have the potential to cause severe damage on buildings and built infrastructure such as timber houses, bridges and a wide range of further wood products used in the outdoor environment or under humid conditions indoors. To protect organic and thus biodegradable building materials from decay, it is of immanent importance to avoid high moisture loads, particularly in terms of liquid water. Modelling fungal decay and thus the expected service life of wooden structures requires accurate information about the physiological needs of wood-destroying basidiomycetes. Within this review, we focussed on different studies to determine the minimum moisture thresholds for fungal decay in laboratory tests referring to different exposure scenarios in real life. Several authors, starting in the 1930s, reported on experiments where wood specimens were exposed to different climates and infected with white and brown rot causing basidiomycetes. The experimental set-ups differed in external moisture supply and the way of infecting the test specimens, and consequently in the minimum thresholds determined for different combinations of wood and fungal species. Generally, it became obvious that wood-destroying basidiomycetes were able to degrade wood at high relative humidity (*RH*) with and without an external source for liquid water. Although the method of moistening the wood samples had an effect on the lower moisture thresholds obtained, it was concordantly evident that different basidiomycetes were able to cause significant decay of wood at moisture contents (*MCs*) considerably below fibre saturation, but thresholds seem to be species and substrate specific.

INTRODUCTION

Moisture has been recognized as key parameter for infestation and decay of wood by wood destroying fungi. Besides supply of oxygen, favourable temperatures, and accessible nutrients it is the most essential factor to characterise the risk for fungal decay of wooden commodities and structures. For many decades it was therefore of utmost concern to define critical thresholds of wood moisture content allowing transport and activity of fungal enzymes into the wood cell walls leading to degradation and severe rot of wooden elements. Today, wood moisture content is the most important input variable for many service life and performance prediction models, both in engineering and natural sciences (Brischke and Thelandersson 2014).

Minimum moisture thresholds and other physiological requirements of decay fungi were sought in field tests (Scheffer 1971; Van den Bulcke *et al.* 2009; Meyer-Veltrup *et al.* 2017) as well as in experiments under laboratory conditions (Viitanen 1997; Viitanen *et al.* 2010). It is consensus that free water available in the cell walls is critical, but not that in the cell lumens (Schmidt 2006; Stienen *et al.* 2014). Nevertheless, there are reports on fungal decay in cases, when the *MC* was significantly below the fiber saturation point (*FSP*) (Bavendamm and Reichelt 1938; Theden 1941; Griffin 1977; Viitanen and Paajanen 1988; Carll and Highley 1999; Stienen *et al.* 2014; Höpken 2015; Meyer and Brischke 2015; Meyer *et al.* 2015; Zelinka *et al.* 2015, Brischke *et al.* 2017). The data about the minimum moisture requirements in the literature are deviating – not at least due to the different experimental designs for their determination. In the following, we reviewed experimental laboratory studies aiming on the physiological needs of wood decay fungi with respect to minimum moisture thresholds, differences in boundary conditions and limitations due to the respective experimental set up.

CHRONOLOGY OF LABORATORY EXPERIMENTS TO DETERMINE MINIMUM MOISTURE THRESHOLDS

Bavendamm and Reichelt (1938) conducted growth tests on malt agar with wood sawdust and small wood blocks using seven different basidiomycetes. To regulate the *MC* of the substrate sodium chloride solutions of different concentration were used to generate *RH* between 81.5 and 99 % in small glass vessels (Figure 1). Wood blocks were infested using pre-inoculated saw dust, which was mixed with fungal mycelium and incubated for 10 days. After four months of exposure more than 2 % mass loss ($ML_{\%}$) was detected on blocks stored at only 85.6 % *RH*. The *MC* after incubation was not determined and consequently no minimum moisture threshold for fungal decay provided.

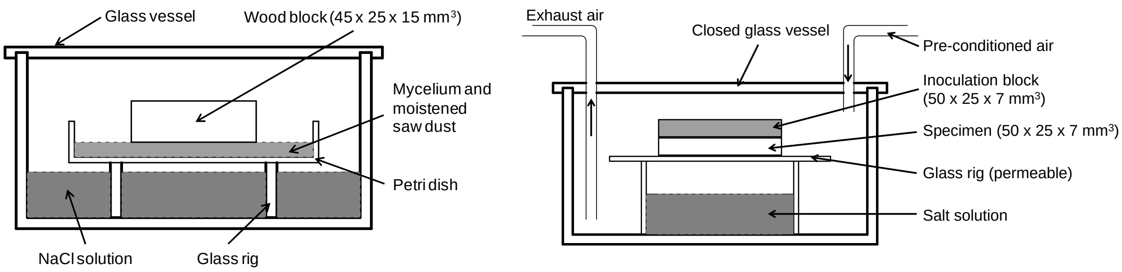

Figure 1: Experimental set up for decay tests. Left: Set up according to Bavendamm and Reichelt (1938). Right: Set up according to Theden (1941).

Theden (1941) examined the *MC* requirements of various rot fungi and conducted different experiments to determine the minimum *MC* for new infection through mycelium, progress of decay in already incubated samples, and reactivation of decay in infected, dried, and remoistened samples. Again, sodium chloride solutions of different concentration were used to obtain defined climates (20 °C; 83 – 100 % *RH*), but using pre-conditioned air for a permanent exchange of air in the small test vessels (Figure 1). Pre-inoculated wood blocks were used for inoculation of test specimens, which were afterwards incubated for four months. According to Theden (1941) the minimum *MC* for onset of fungal decay was achieved at 98.2 % *RH* for different basidiomycetes. However, wood decay at *MC* below *FSP* was not detected, since the *MC* of the specimens after four months of incubation superseded the theoretical equilibrium moisture content (*EMC*) of wood by far. The higher the $ML_{\%}$ by fungal decay, the higher was the *MC* after incubation, which Theden (1941) explained by the production of water during biochemical degradation of wood or cellulose respectively according to the following equation:

$$(C_6H_{10}O_5)_n + 6 \cdot n \cdot O_2 = 6 \cdot n \cdot CO_2 + 5 \cdot n \cdot H_2O \qquad (1)$$

In summary, Theden (1941) did not determine minimum moisture thresholds below *FSP*, even though decay started at *RH* below 100 %.

Ammer (1963) used pre-inoculated specimens and stored them in screw-top jars above different saturated salt solutions referring to 22 – 100 % *RH*. Similar to Theden (1941), drastic differences occurred between the target wood *EMC* and the actual *MC* after incubation of specimens that showed significant $ML_{\%}$. Saturated salt solutions have higher potential to release and take up moisture from the wood samples in the vessel compared to sodium chloride solutions with varying concentration without any effect on the *RH* in the test. Ammer (1963) examined Norway spruce (*Picea abies*) sapwood and seven different decay fungi at 15 °C and 25 °C. The specimens were exposed hanging above the salt solution as shown in Figure 2. Specimens were infected through exposure on mycelium grown on malt agar in Kolle flasks. Ammer (1963) determined a minimum *MC* threshold of 19 % for fungal decay at 85 % *RH*, which was approximately 7 %-points below the *FSP* of Norway spruce.
A slightly deviating experimental set up was used by Saito *et al.* (2012) to determine *MC* thresholds for fungal decay at different temperatures. They exposed specimens made from Japanese red pine (*Pinus densiflora*) in small vessels with even smaller containers filled with different saturated salt solutions representing 93, 97, and 100 % *RH* (Figure 2). Specimens were inoculated through direct contact with mycelium of *Fomitopsis palustris* and afterwards incubated for up to twelve months. No decay was observed at *MC* below fiber saturation and below 100 % *RH*.

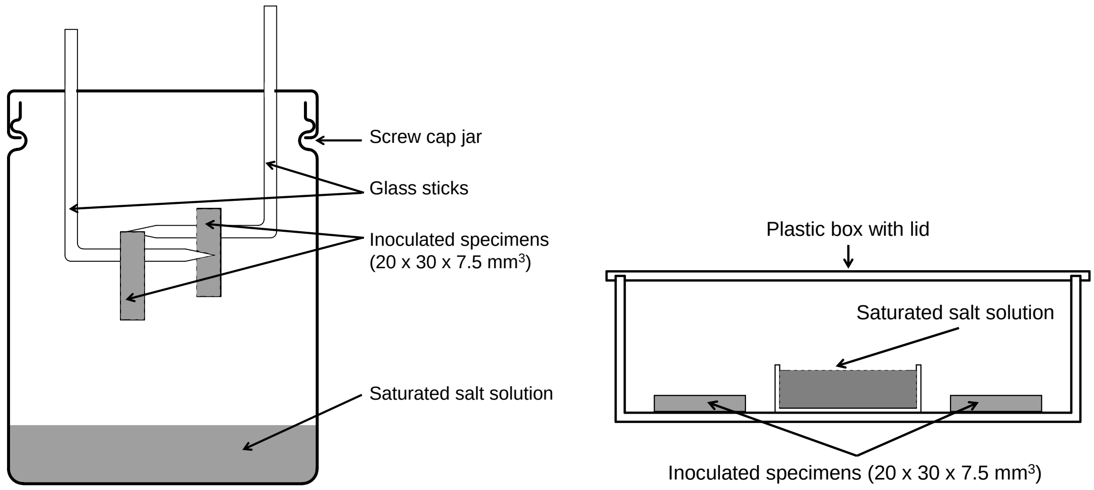

Figure 2: Experimental set up for decay tests. Left: Set up according to Ammer (1963). Right: Set up according to Saito et al. (2012).

Schmidt *et al.* (1996), Huckfeldt *et al.* (2005), Huckfeldt and Schmidt (2006), and Stienen *et al.* (2014) performed experiments with small piled wood samples in Erlenmeyer flasks. The bottom of the piles was exposed to malt agar inoculated with fungal mycelium serving as nutrition and water source at the same time (Figure 3). This set up provided a moisture gradient pile upwards and limit values for fungal growth and decay. A slightly modified set up was used by Meyer and Brischke (2015) and Meyer *et al.* (2015) to determine *MC* thresholds of fungal decay for different basidiomycetes and different

Europe-grown wood species as well as thermally and chemically modified wood. In contrast to previous tests, the axial direction of the small specimens (5 x 40 x 40 mm³) was now identical with the pile direction allowing easy water transport and mycelium growth through the wood specimens. Within all the above-mentioned studies using the piling method the minimum moisture thresholds were below *FSP*, partly remarkably far below *FSP*. For instance, Meyer *et al.* (2015) found a lower moisture limit for decay ($ML_{\%}$ = 2.2 %) of beech wood by *Trametes versicolor* of only 15.4 % *MC*. However, as critically discussed by the authors themselves, the piling method using malt agar at the pile bottom provides an external moisture and nutrition source for the fungus. The fungus is able to transport water and likely nutrition from the agar pile upwards through mycelium and strains. It was therefore frequently questioned to what extent the threshold values obtained from the piling method can reflect the real-life situation for decay fungi outdoors where a permanent water source is usually not available.

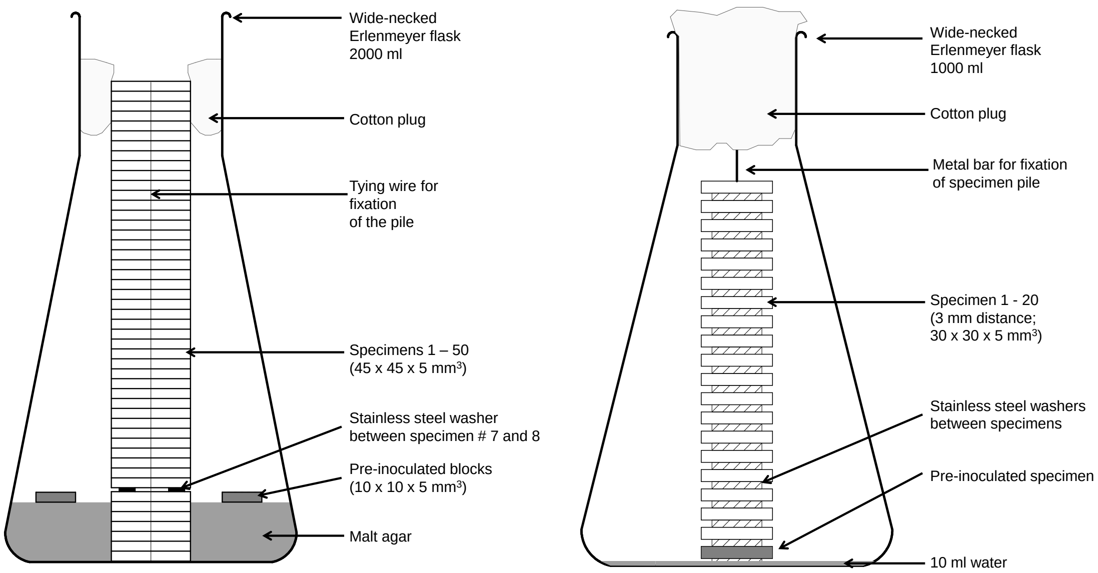

Figure 3: Experimental set up for decay tests. Left: Set up according to Stienen et al. (2014). Right: Set up according to Höpken (2015).

Höpken (2015) modified the pile test method to examine the ability of decay fungi to transport water. The specimens were provided with drilling holes in their center and put on a stainless steel bar. To interrupt capillary water transport stainless steel washers were placed between the specimens causing a distance of 3 and 8 mm respectively (Figure 3). Pile tests were run in comparison with and without malt agar at the pile bottom for in total 61 days of incubation. In tests where the piles were placed in water instead of malt agar fungal growth was slower and the maximum $ML_{\%}$ was less compared to those tests with malt agar. Höpken (2015) could clearly show that different fungi are able to actively transport water within the piles.

Brischke *et al.* (2017) aimed on further evaluating the effect of an external moisture source on the physiological needs of wood-destroying basidiomycetes. Therefore, different experimental set ups, which did not provide an external moisture source, were used to determine moisture thresholds. The experimental set up referred to the tests conducted by Ammer (1963) using different saturated salt solutions and to the pile tests conducted by Meyer and Brischke (2015), but omitting malt agar as nutrition and moisture source (Figure 4).

Trametes versicolor caused significant $ML_{\%}$ on beech wood at 96 % *RH*, *i.e.* at 25.3 % *MC,* when pre-inoculated specimens were stored above saturated salt solutions as well as on specimens in contact with mycelium stored over deionized water. Piled Norway spruce specimens showed significant $ML_{\%}$ already at 16.3 % *MC* caused by *T. versicolor* without external supply of liquid water.

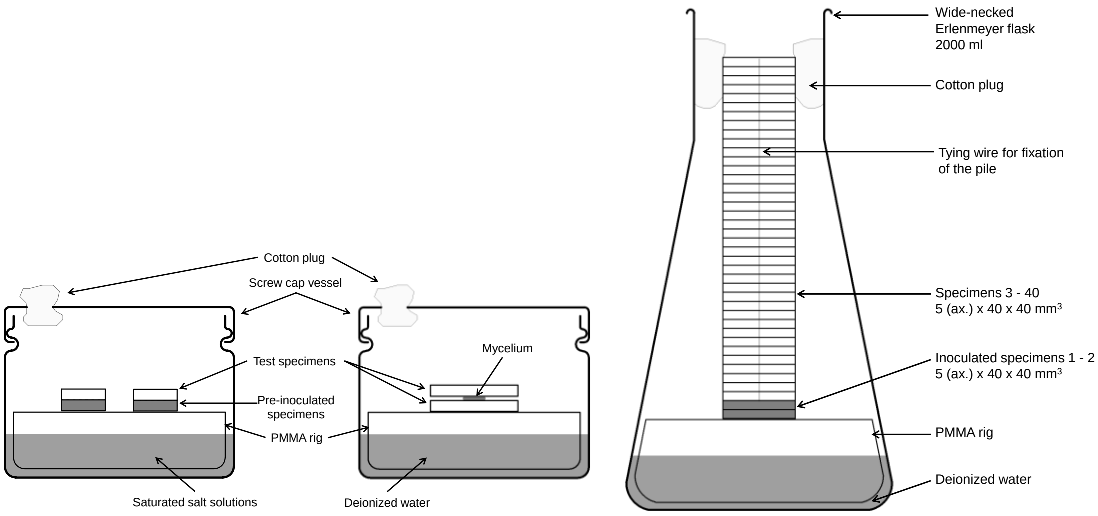

Figure 4: Experimental set up for decay tests in different climates according to Brischke et al. (2017). Left: Exposure of wood specimens in screw cap vessels filled with different saturated salt solutions (Infection of test specimens through pre-infected wood samples) and exposure of wood specimens in screw cap vessels filled with deionised water (Infection of specimens through mycelium). Right: Pile test set up: 40 specimens (5 (ax.) x 40 x 40 mm^3) piled up and placed on a PMMA rig above deionized water. Axial direction of the wood was identical with pile direction.

CONCLUSIONS

Generally, it became obvious that wood-destroying basidiomycetes were able to degrade wood at high *RH* without an external source for liquid water. Although the method of moistening the wood samples had an effect on the minimum moisture thresholds obtained, it was concordantly evident that different basidiomycetes were able to cause significant decay of wood at *MCs* considerably below fiber saturation. Conditioning single or pairs of wood specimens above saturated salt solutions allowed the fungus to take up adsorbed moisture in equilibrium with the humidity of the air and to some extent from pre-infected specimens. In real life this refers to situations where decay is already established, but further ingress of moisture is limited or completely restricted. In experiments using the piling method fungal decay establishes at the bottom of the pile. Subsequently, the fungus produces extra water through biodegradation of carbohydrates and can transport it to dryer parts of the pile upwards. With decreasing *MC* in the pile $ML_{\%}$ is decreasing, and decay as well as mycelium growth stop. This scenario refers to situations where after damage (e.g. leakage) fungi infested the material and decay expands from an area with extremely high humidity (*i.e.* approx. 100 % *RH*) to drier areas. Finally, the difference between pile tests with and without water and agar refers to the question if water supply, e.g. through leakage is only temporarily or a continuous problem. A third scenario to be expected from exposed wooden building components is the absence of developed fungal mycelium, but the presence of spores. Future experiments should therefore show to what extent the moisture requirements from spore germination deviate from those for fungal decay starting from mycelium.

The moisture threshold values determined in pile tests in combination with previously reported data about the physiological requirements of decay fungi can be used for modelling decay processes and thus service life of wood products and timber constructions. However, further parameters such as the effect of time on moisture limits in particular for more durable wood species and preservative treated material need to be quantified and will be considered in future research.
Furthermore, reducing the size of specimen fragments for determining the $ML_{\%}$ and *MC* might further increase the accuracy of determining moisture thresholds. However, since the specimen size is finite, the accuracy of experimental test methods as such is limited.
Finally, further improvements might be needed to determine *FSP*. More sophisticated methods to determine *FSP* of wood-based materials, such as the Wilhelmy method, are available, but did not allow to incubate the samples at *FSP*. Therefore, the simplified approach of conditioning specimens above deionized water, i.e. at approximately 100 % *RH*, appears as a feasible alternative, even though condensation effects might affect the thresholds obtained.

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Behavior of the wood outside the contact with the ground in Spain. Project BIA 2013-42434R.

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Keywords: Durability, parametric durability, wood climate

ABSTRACT

Within the framework of the Project BIA-42434R titled '*Evaluation of the functional performance of wood in outdoor above ground applications*', seven trials containing seven pieces of sawn wood measuring 750x100x20mm, belonging to seven different wood species (Scots pine, radiata pine, Laricio pine, sweet chestnut, eucalyptus, Thermo-treated radiata pine and spruce), were exposed to unprotected outdoor conditions at seven different locations (Asturias, Palencia, Valencia, Madrid, Cordoba, Huelva and Vitoria). Temperature and moisture content evolution of the wood were monitored every two hours using Scanntronik devices (Thermofox+Gigamodule). Stainless steel screws inserted from the outer face to the centre of the pieces (10 mm) were used as sensors, the first 7mm of which were Teflon covered to avoid measuring the surface moisture.
The initial conclusions that can be drawn from the data obtained during 20-24 months with regard to the effect of species on the performance of wood outdoors under different climatic conditions are presented in this work.

INTRODUCTION

INIA is currently coordinating a national scale project BIA-42434R entitled "*Evaluation of the functional performance of wood in outdoor above ground applications*". This project involves the characterisation and, if possible, modelling of decay risk for wood in outdoor above ground applications for different geographical locations, the quantification of the impact of material exposure and of the design detailing as well as the characterisation of intrinsic resistance of the main national woods and the influencing variables.
This work presents the first conclusions drawn from the analysis of results obtained from the monitoring of the "*climate of the material*" (temperature and moisture content) under the most representative climatic conditions in Spain and the influence of the wood species in this behaviour.

EXPERIMENTAL

Seven metallic tables containing seven boards of 20x100x750 mm from seven different wood samples (Scots pine, radiata pine, Laricio pine, sweet chestnut, eucalyptus, Thermo-treated radiata pine and spruce) were exposed to outdoor conditions with no protection from the rain in seven test sites (Asturias-Llames, Palencia, Valencia, Madrid, Cordoba, Huelva and Vitoria). These locations were chosen so as to include the effect of the most representative climates in Spain: Continental (Madrid, Palencia, Vitoria and Cordoba), northern-Atlantic coast (Asturias-Llames), southern-Atlantic coast (Huelva) and Mediterranean coast (Valencia). Within the sites with a continental climate (Madrid, Palencia, Vitoria and Cordoba) we consider the effect of proximity of large sources of humidity (Vitoria), the effect of extremely hot summers (Cordoba) or of cold winters (Palencia).

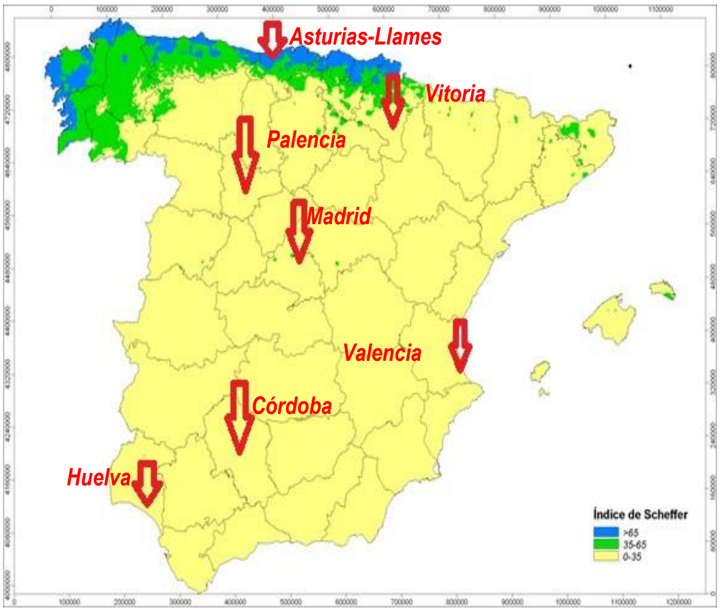

Figure 1. Test sites (in colour Scheffer indexes)

In each of the seven trials, the temperature and moisture content of each of the seven pieces of every test device were recorded every two hours. All the details regarding the measuring methodology can be found in Fernandez-Golfin *et al* (2017). This methodology and equipment was similar to that recommended in this COST Action FP 1303 (Brischke *et al*. 2014).

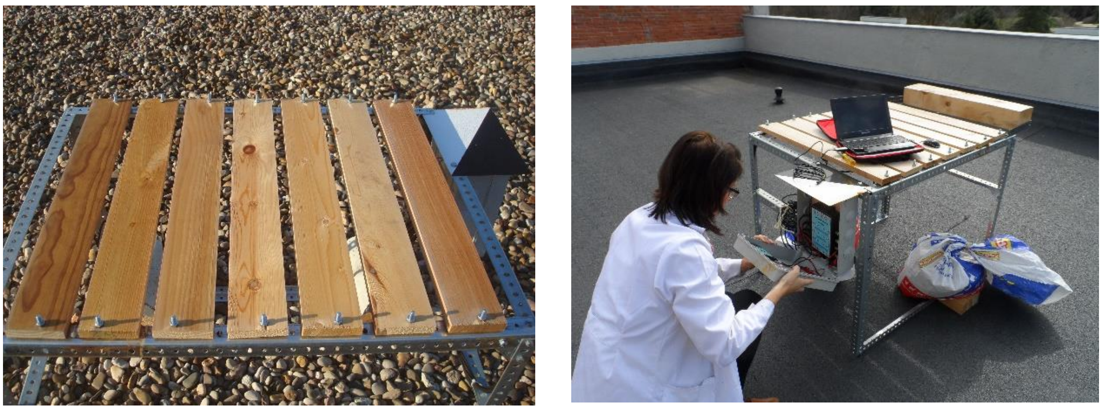

Figure 2. Trial set-up

The seven trials were set-up in the following locations and on the dates specified:

- Madrid (INIA): 27/11/2014
- Palencia (UVA): 28/01/2015
- Vitoria (NEIKER): 12/03/2015
- Valencia (Private individual): 4/03/2015 (removed 16 September 2016)
- Asturias-Llames (Private individual): 19/03/2015
- Córdoba (UCO): 07/04/2015
- Huelva (UHU): 08/04/2015

Three years of data recording and visual decay assessment are foreseen in every exposure site. However, the Valencia trial (Mediterranean coast) was withdrawn from the study in September 2016 due to the absence of precipitation and some other problems related with the measuring equipment.

RESULTS AND DISCUSSION

Table 1 provides a brief summary of results. In the table 1, TOW is the Time Of Wettness, being the number the threshold considered (TOW18 is the time during which the wood remains at a humidity above 18%). The TOW values are expressed in two ways: by means of the total number of hours in the year 2016 and in percentage.

Table 1. Results

	Station	Temp	EU	PL	PC	PS	PR	CS	PRMMT
Max	**Madrid**	45.4	27.5	55.8	55.8	60.4	60.0	55.9	68.3
Min	**Madrid**	-8.4	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Median	**Madrid**	13.6	9.5	12.3	13.0	14.5	12.4	10.2	10.1
Average	**Madrid**	15.0	9.5	12.8	12.7	15.2	12.7	10.9	12.7
TOW18 (2016) h	**Madrid**		0.0	1558	1472	3064	1498	918	2392
TOW18 (2016) %	**Madrid**		0.0	17.8	16.8	35.0	17.1	10.5	27.3
TOW25 (2016) h	**Madrid**		0.0	520	622	828	384	574	566
TOW25 (2016) %	**Madrid**		0.0	5.9	7.1	9.5	4.4	6.6	6.5
Max	**Palencia**	45.9	26.0	46.2	51.4	40.3	26.2	20.5	73.1
Min	**Palencia**	-8.5	7.7	5.5	5.5	5.5	6.1	5.5	5.5
Median	**Palencia**	12.1	12.8	14.9	14.1	15.0	13.9	11.8	15.1
Average	**Palencia**	13.8	13.2	15.4	15.5	15.8	14.2	11.9	15.6
TOW18 (2016) h	**Palencia**		894	3802	3932	3834	2804	724	4496
TOW18 (2016) %	**Palencia**		10.2	43.4	44.9	43.8	32.0	8.3	51.3
TOW25 (2016) h	**Palencia**		0	544	1404	1038	6	0	758
TOW25 (2016) %	**Palencia**		0.0	6.2	16.0	11.8	0.1	0.0	8.7
Max	**Cordoba**	**52.5**	31.3	37.3	35.3	32.6	32.2	22.6	52.4
Min	**Cordoba**	-5.3	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Median	**Cordoba**	19.5	9.4	10.9	10.8	11.1	10.1	9.2	10.1
Average	**Cordoba**	21.1	10.8	11.6	11.4	11.8	10.7	9.4	11.9
TOW18 (2016) h	**Cordoba**		1624	1700	1522	1780	606	0	1926
TOW18 (2016) %	**Cordoba**		18.5	19.4	17.4	20.3	6.9	0.0	22.0
TOW25 (2016) h	**Cordoba**		16	136	102	280	12	0	494
TOW25 (2016) %	**Cordoba**		0.2	1.6	1.2	3.2	0.1	0.0	5.6
Max	**Valencia**	40.3	16.2	22.8	25.8	25.8	23.4	28.5	71.4
Min	**Valencia**	9.1	9.7	8.5	7.4	8.7	8.6	8.5	6.2
Median	**Valencia**	25.6	12.4	12.6	11.8	12.1	12.8	11.5	10.8
Average	**Valencia**	24.9	12.4	13.2	12.2	12.7	13.2	11.9	14.1
TOW18 (2016) h	**Valencia**		14	768	78	318	536	58	1806

	Station	Temp	EU	PL	PC	PS	PR	CS	PRMMT
TOW18 (2016) %	**Valencia**		0.2	8.8	0.9	3.6	6.1	0.7	20.6
TOW25 (2016) h	**Valencia**		0	2	0	2	6	2	550
TOW25 (2016) %	**Valencia**		0.0	0.0	0.0	0.0	0.1	0.0	6.3
Max	**Huelva**	44.4	28.0	32.9	44.6	68.4	41.0	45.2	76.8
Min	**Huelva**	0.5	6.9	6.0	5.6	5.3	5.7	5.0	4.4
Median	**Huelva**	19.4	11.7	12.0	12.0	11.9	11.7	12.0	11.2
Average	**Huelva**	19.7	11.9	12.6	12.5	13.1	12.3	12.6	13.9
TOW18 (2016) h	**Huelva**		362	778	738	1258	840	714	2892
TOW18 (2016) %	**Huelva**		4.1	8.9	8.4	14.4	9.6	8.2	33.0
TOW25 (2016) h	**Huelva**		90	186	234	392	100	66	584
TOW25 (2016) %	**Huelva**		1.0	2.1	2.7	4.5	1.1	0.8	6.7
Max	**Vitoria**	42.6	22.6	55.2	44.4	60.8	63.5	50.6	47.3
Min	**Vitoria**	-11.3	9.4	8.0	5.5	7.5	8.4	5.5	5.5
Median	**Vitoria**	11.4	15.2	21.8	16.2	18.5	29.9	16.2	15.2
Average	**Vitoria**	12.5	15.6	22.5	18.1	19.2	28.8	17.8	16.5
TOW18 (2016) h	**Vitoria**		2604	8598	4512	4182	8424	5046	4112
TOW18 (2016) %	**Vitoria**		29.7	**98.2**	51.5	47.7	**96.2**	57.6	46.9
TOW25 (2016) h	**Vitoria**		0	4314	1830	754	6470	1448	1194
TOW25 (2016) %	**Vitoria**		0.0	49.2	20.9	8.6	**73.9**	16.5	13.6
Max	**Asturias**	34.0	187.0	176.0	57.8	174.0	72.7	37.8	40.8
Min	**Asturias**	-1.0	7.9	4.2	4.3	8.3	6.2	4.0	7.0
Median	**Asturias**	14.7	15.8	20.6	21.3	22.8	38.25	17.1	14.5
Average	**Asturias**	14.8	15.7	20.9	22.1	23.6	36.8	17.5	15.3
TOW18 (2016) h	**Asturias**		1526	8390	8388	8376	8562	5418	2096
TOW18 (2016) %	**Asturias**		17.4	**95.8**	**95.8**	**95.6**	**97.7**	61.8	23.9
TOW25 (2016) h	**Asturias**		0	1724	4208	3772	7394	756	126
TOW25 (2016) %	**Asturias**		0	19.7	48.0	43.1*	**84.4***	8.6	1.4

EU: Eucalypt; PL: Laricio pine; PS: Scot pine; PC; spruce; PR: Radiata pine; CS: Sweet chestnut; PRMMT: Thermotreated radiata pine (210ºC)
(*) Decay rate 1 in July 2017

It is important to say that MC values lower than 7% or upper than 30-40% should be considered with some precaution because they are outside the limits of the measuring technology.

If we look at the TOW25 (in %) values, we can see that only in Asturias (PR) and in Vitoria (PR) there is a real risk of decay and this only in radiata pine samples. But if on contrary we consider the value of TOW18, we can see that this risk is broader (affecting not only radiata pine, but also Laricio and Scots pines and spruce) and more in accordance with observations that we do in the field.

CONCLUSIONS

Although we need a longer exposure time to observe decay in all localities and woods, from the data obtained so far, we can draw some first and provisional conclusions:

1. As regards the "*time of wetness*" and for the same species, there is a notable difference in performance between the boards located in the test sites of Asturias-Llames and Vitoria with those located at the rest of the sites. The Vitoria site is specially affected by a high level of condensation and Asturias by a high number of rain events. In general, the trials located in areas with a continental climate (Palencia, Madrid,

Cordoba) present similar performances, with only slight differences depending on the rainfall regime.
2. The main factor affecting the performance of wood exposed to outdoor conditions is the presence of rainfall rather than relative humidity (compared to the values corresponding of the Huelva site, next to the salt marshes but with a very reduced of rain events, with that of Asturias, very close to the sea and with an intense rainfall regime).
3. Atmospheric humidity alone does not allow a moisture content above 18% at least if condensation is not present. Hence, for us, the main decay risk in outdoor conditions is the presence of liquid water from rainfall or surface condensation.
4. Considering a critical threshold for the beginning of the growth of decay fungi and decay development of 25% in moisture content, the time of wetness (TOW25) in Spain is very reduced in all the sites analysed (Except in Asturias with PR). According to TOW25, wood at the sites analysed in this study would never decay, although this would not be true in the Spanish case. Even more, some presence of decay signs has been recorded in Asturias in PR and PS samples. Hence, it should be noted that the European predictive models based on this threshold are not suitable for the Spanish climate and conditions, perhaps due to the presence of various decay agents (fungi) or to their different activity or synergy. Current research adopts a more conservative approach, considering a critical threshold of 18% to define the time of wetness (TOW18) while analysing its relationship with observed decay.
5. The presence of checking on the surface of the boards completely changes the outdoors wood performance, increasing their permeability and to a certain extent evening out the differences between the species. Hence, from our perspective, the classification of the different species according to the expected relation with water cannot be carried out either by a hygroscopic characterisation or by the analysis of its water permeability by simple immersion of defect-free specimens, but it is necessary to first induce checks and subsequently characterise its permeability by immersion in water and its subsequent drying in controlled climatic conditions.
6. Thermo-treated wood suffers in Spain severe checking in continental stations.

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Durability-based design of timber structures – Guidelines for architects and planners

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Keywords: decay, service life prediction, performance-based design, dose-response model, engineering tool

ABSTRACT

Timber structures for bridges, buildings, claddings and decking are often an economically and sustainably feasible alternative to structures in other building materials. Predicting the performance (e.g. the service life) of building products made from timber and other bio-based building materials has become increasingly important. Performance data are requested by designers, planners, authorities and approval bodies, but rarely available. On the one hand, raw data on performance as well as reliable performance indicators are sparsely documented, on the other hand the number of reliable performance prediction models is limited.

The service life of a timber structure is influenced by degrading mechanisms such as mould fungi, decay fungi, insects, termites etc. Service life of timber structures in outdoor conditions is predominantly affected by the climatic conditions in terms of moisture and temperature over time. During recent years various modelling approaches were reported that can be used to predict performance of bio-based building materials, in particular wood and wood-based products. In the first instance, the effect of climate (i.e. exposure) and the effect of the material resistance have been considered and were both found to be closely connected to the moisture performance of the material. Furthermore, the effect of design, constructive protection measures, microclimate, coatings, and maintenance schedules were set into perspective with the moisture-induced risk for decay.

Within the research projects ‘WoodExter’, ‘WoodBuild’, and ‘Durable Timber Bridges (DuraTB)’ engineering tools were presented to predict fungal decay of wood, both for commodities such as claddings and decking as well as for load-bearing structures such as timber bridges. The approach used in these tools is presented here and shown with an example.

The advantages of the new performance-based prediction models are that they are scientifically based, with all factors being determined either by laboratory or field testing, modelling or expert opinions. As the approach is open, future research results can be easily implemented as well as the user might use own input factors. The tools promote a systematic approach to durability by design, they can function as a check list for the designer and can consider project specific conditions in a more precise manner.

INTRODUCTION

Timber structures for bridges, buildings, claddings and decking are often an economically and sustainably feasible alternative to structures in other building materials. Timber as a naturally renewable material has a beneficial carbon footprint and it is expected that building with timber increases due to the increased focus on life cycle analysis (LCA). However, when designing timber structures and commodities, the focus should not only be on meeting the load-carrying and aesthetic expectations, but also to design for a reasonable service life. For load-bearing timber structures, the demanded service life is described in Eurocode 1990 (2002) and should be e.g. 15 to 30 years for agricultural buildings, 50 years for building structures and 100 years for bridges. To reach the intended service life, the designer can choose between timber protection by design, use of naturally durable timber species or use of preservatives (or a combination of those methods). However, it has not really been possible to prove that a certain design leads to a certain intended service life with the information given in standards or earlier handbooks. Predicting the performance of building products made from timber and other bio-based building materials has become increasingly important. Performance data are requested by designers, planners, authorities and approval bodies, but rarely available (Brischke and Jones 2016). On the one hand, raw data on performance as well as reliable performance indicators are sparsely documented, on the other hand the number of reliable performance prediction models is limited. In the past, at least to some extent performance prediction was run against or at least only parallel to traditional durability testing of wood and wood preservatives, whereby the latter was focused on for decades due to its overwhelming market importance.

The service life of the structure is influenced by degrading mechanisms such as mould fungi (aesthetics), decay fungi, insects, termites etc. Service life of timber structures in outdoor conditions is predominantly affected by the climatic conditions in terms of moisture and temperature over time. On the one hand, the two parameters moisture content and temperature determine the exposure-induced dosage that can lead to fungal infestation and subsequent decay. On the other hand, the material resistance of wood stands in opposition to exposure and is itself affected by the inherent protective properties of wood and its ability to take up and release water in liquid or vapour form (Meyer-Veltrup *et al.* 2017). Other factors such as design details, in-use conditions, and maintenance only indirectly affect the service life of wooden structures and can be accounted for through the aforementioned parameters.

During recent , various modelling approaches were reported (Brischke and Thelandersson 2014) that can be used to predict performance of bio-based building materials, in particular wood and wood-based products. In first instance, the effect of climate (i.e. exposure) and the effect of the material resistance have been considered and were both found to be closely connected to the moisture performance of the material. Furthermore, the effect of design, constructive protection measures, microclimate, coatings, and maintenance schedules were set into perspective with the moisture-induced risk for decay. Within the research projects ‘WoodExter’, ‘WoodBuild’ and ‘Durable Timber Bridges (DuraTB)’ tools are presented to predict fungal decay of wood, both for commodities as claddings and decking as well as for load-bearing structures as timber bridges. The tools have the potential to serve as instrument for design and service life prediction of timber structures. Several logistic decay models were applied and compared with respect to their feasibility to quantify direct and indirect decay influencing factors such as climate on macro, meso and micro level, topography, design details such as shelter through roof overhangs, end grain and side grain contact faces, and diverse metal joints.
To include all those factors, a factorization approach is used based on dose-response relationship between wood material climate and responding fungal decay, where onset of decay is defined as limit state (Brischke *et al.* 2017). The concept does also allow for

quantifying the material resistance of untreated, modified and preservative treated wood using factors based on laboratory and field durability tests and short-term tests for capillary water uptake, adsorption and desorption dynamics.

In the following an engineering approach is presented for service life prediction of timber structures and how this can be implemented in design guidelines and standards. The overall aim is to transport the rather complex and comprehensive knowledge achieved in various long-term research projects to users such as architects, planners, engineers, and finally craftsmen and house owners. The way from a complicate back-end approach based on bio-physical and engineering mathematical models to simple front-end tools with a user-friendly interface will be illustrated.

APPROACH FOR DETERMINATION OF SERVICE LIVES

Performance prediction of wooden structures is generally a three-step approach (Brischke and Thelandersson 2014, Brischke *et al.* 2015, Niklewski *et al.* 2016a). As illustrated in Figure 1, a design solution is considered successful if the exposure over time stays equal or below the resistance of the material in use. In other words, and in analogy to structural engineering, the load should never exceed the capacity. To quantify the dose on "both sides of the balance" at least three separate models are needed: exposure model, decay model and resistance model.

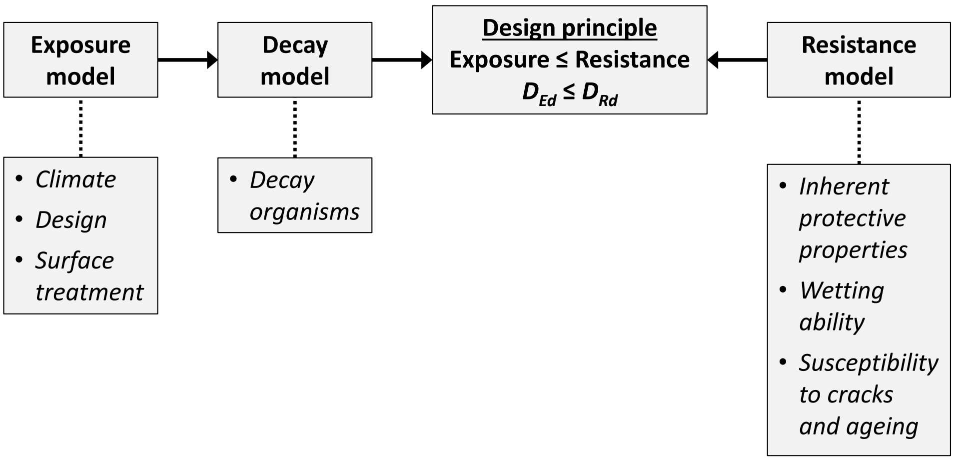


Figure 1: *Performance* modelling with three-step approach.

For components or details exposed to free water, the service life should be evaluated according to the approach presented in Figure 2. If members/details are protected from free water, then a risk analysis of the durability/service life of the protective part should be carried out.

The evaluation of a given component or detail exposed to free water should be made in the following steps as shown in the flowchart in Figure 2. The tool as presented in Figure 2 is the version developed for timber bridges (Pousette *et al.* 2017), however, the same general approach is also valid for cladding and decking. The differences between the bridge tool and the previous cladding/decking tool (according to Isaksson *et al.* 2014 and 2015) are pointed out later in this section.

A design solution (choice of design and material) is accepted if the exposure is less than the resistance (Eqn. 1):

$$D_{Ed} = D_{Ek} \cdot \gamma_d \leq D_{Rd} \quad (1)$$

where D_{Ek} is the characteristic exposure dose, D_{Ed} is the design exposure dose, γ_d is a factor accounting for severity class and D_{Rd} is the design resistance of the chosen material. γ_d is chosen according to the consequences of non-performance and is determined to 0.6, 0.8 and 1.0 for low, medium and high consequences/risk respectively. For load-bearing bridge structures, γ_d=1.0.

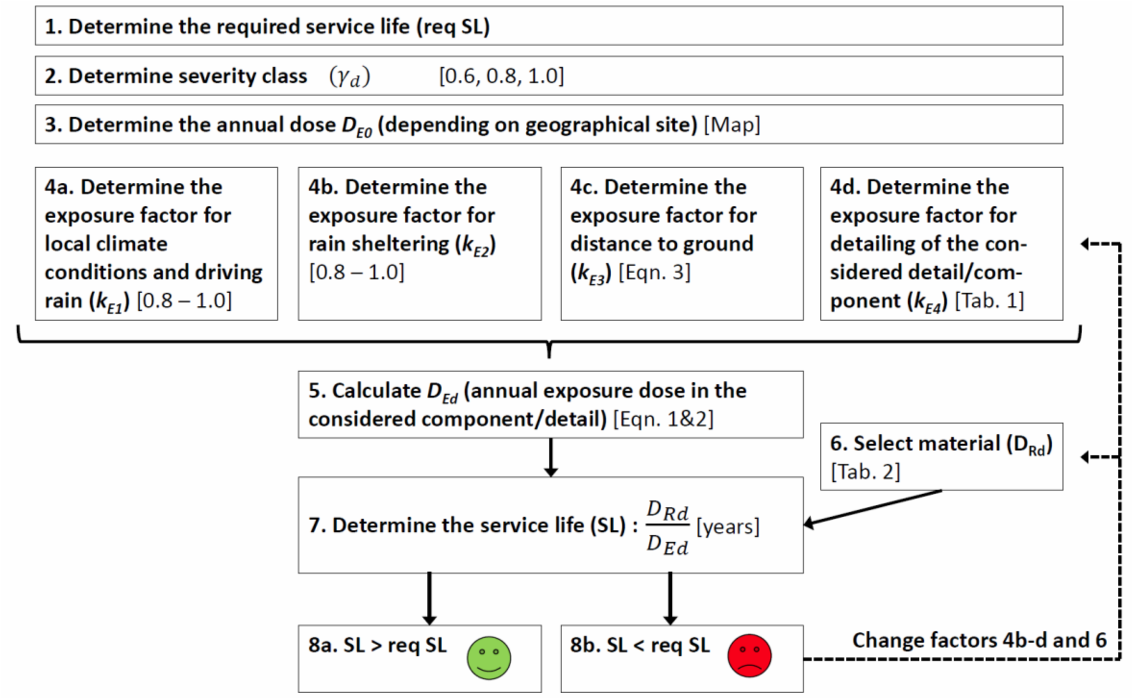


Figure 2: *Evaluation* of service life (SL) for a component or detail, based on Pousette *et al.* 2017.

Determination of exposure

The exposure is calculated as follows (Eqn. 2):

$$D_{Ek} = D_{E0} \cdot k_{E1} \cdot k_{E2} \cdot k_{E3} \cdot k_{E4} \cdot k_{E5} \cdot c_a \quad (2)$$

With the factors accounting for

- Local climate conditions and driving rain, k_{E1}
- Sheltering, k_{E2}
- Distance from ground, k_{E3} (Eq. 3)
- Detailed design (risk of water traps), k_{E4} (Table 1)
- Calibration factor c_a, to be taken as 1.4. The calibration factor was determined from reality checks, safety considerations and expert opinions.

In the tool for cladding and decking (Isaksson *et al.* 2014, 2015), factor k_{E1} is divided into two factors, one for local climate conditions and one for driving rain respectively. Also, the calibration factor is set to 1.0 instead of 1.4.

The *annual exposure dose D_{E0}* is dependent on the geographical location and takes into account the climatic effects. It is determined for a reference specimen on the basis of dose-response modelling and decay test results at different locations in Europe (Isaksson *et al*. 2013). To be able to present input data for D_{E0} for any place, modelled climate data (Software Meteonorm) were used and the annual exposure doses were calculated for a large number of places in Europe and compiled in a map where eleven different zones were created by interpolating between the sites (Pousette *et al.* 2017). In general, the highest values for the exposure dose D_{E0} can be found along the western coast of Europe, and there is a trend of decreasing values from South to North in general. D_{E0} varies between 9 days per year in the lowest zone to 66 days per year in the highest zone. This means that depending on the regional climate, a factor of about 7 in service life can be found across Europe, with all other factors kept constant. A map showing the different climate zones and a table giving the annual dose D_{E0} are presented in Pousette *et al.* 2017. In the cladding and decking tool (Isaksson *et al.* 2014 and 2015), the annual exposure dose D_{E0} is presented for Sweden, with values between 15 and 32 days per year, thus showing a smaller variation than the variation over whole Europe.

Factor k_{E1} takes *local climate conditions and driving rain* into consideration. Local climate conditions can mean protection by adjacent buildings or topography, and just like driving rain (simultaneous rain and wind), it usually cannot be affected by the designer. In Pousette *et al.* (2017), a map showing the free driving rain intensity is presented. The authors propose to include the effect of driving rain for high intensity regions, which in general can be found on the west coast of Europe, whereas driving rain could be neglected for the inner parts of Europe. For vertical surfaces, the factor k_{E1} should then be taken between 1.0 (driving rain, no sheltering) and 0.8 (no driving rain, but sheltering). For horizontal surfaces, $k_{E1}=1$. In cases, where the effect of driving rain or local sheltering by adjacent buildings are difficult to determine, it is recommended to use the conservative value $k_{E1}=1$. For comparison, in the claddings and decking tool (Isaksson *et al.* 2014, 2015), there are separate local climate conditions (sheltering) and driving rain factors, with the sheltering factor varying between 0.8 and 1.0 and the driving rain factor ranging between 0.85 and 1.05 (for Sweden).

The *effect of sheltering* located above the detail/component studied is based on field tests described by Bornemann *et al.* (2012), being included in the design by factor k_{E2}. The higher the overhang e and the smaller the vertical distance d (see Figure 3), the larger is the sheltering effect. Factor k_{E2} attains values between 0.8 ($e/d \geq 1$) and 1.0 ($e/d=0$), with a linear variation (Pousette *et al.* 2017, Isaksson *et al.* 2014, 2015).

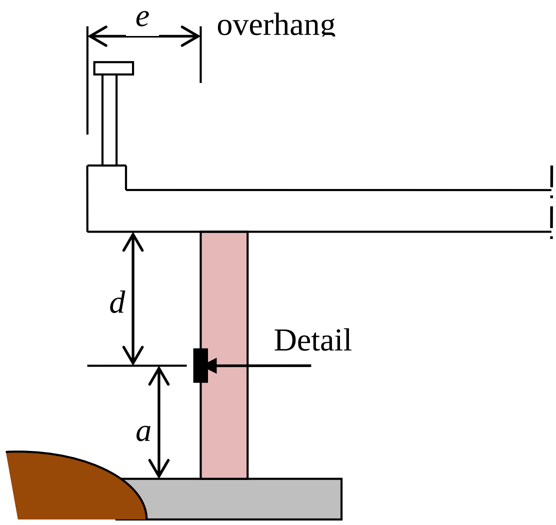


Figure 3: Definition of measures for overhang e and distance to ground a. From Pousette et al. (2017).

The *effect of distance from the ground* is considered by increasing the exposure for details/components located closer than 400 mm to the ground. Distances <100 mm should not be used due to splash effect and possible increased water uptake, resulting in decreased durability. The factor k_{E3} is determined by Eqn. 3 shown below, with distance a as described in Figure 3.

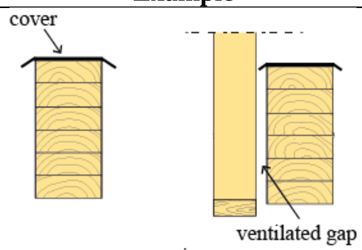
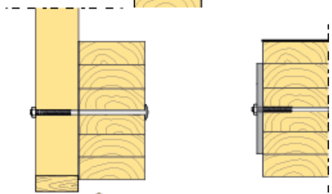
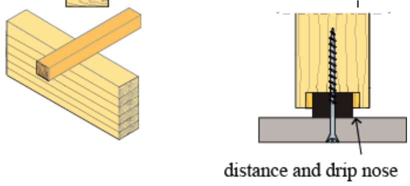
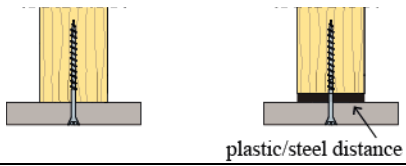
$$k_{E3} = \begin{cases} \dfrac{700 - a}{300} & if\ 100\ mm < a < 400\ mm \\ 1.0 & if\ a > 400\ mm \end{cases} \quad (3)$$

The effect of sheltering above the detail/component in question and effect of distance to the ground are treated equally for both bridges and claddings/decking.

The *effect of detail design* (factor k_{E4}) is based on field test carried out by Niklewski *et al.* (2016b). Several typical timber bridge details were moisture monitored over two years. Post-processing with the simplified-logistic dose model (Isaksson *et al.* 2013) resulted in annual doses for the specimens and could be compared to a reference without moisture trap, resulting in relative annual doses. The details were grouped in five classes, depending on their water trapping behaviour, from excellent (group 1) to poor (group 5), see Table 1 for the factor k_{E4}.

Also, in the cladding and decking tool (Isaksson et al. 2014, 2015), details are grouped into five classes from excellent to poor. However, different descriptions and examples of details assigned to the classes are given for cladding and decking respectively due to the different types of exposure and especially the effect of ventilation. Here, the correction factor varies for claddings between 0.9 (excellent) and 4.0 (poor) and for decking between 0.9 (excellent) and 2.5 (poor).

Table 1: Rating of details with respect to exposure (factor k_{E4}). After Pousette et al. (2017).

Class	k_{E4}	Description	Example
Excellent	0.8	Design characterized by excellent ventilation (air gap >10 mm) and no standing water. Example: a vertical surface without connecting members or with sufficient gap between members[1]	
Good	1.0	Design characterized by excellent ventilation but standing water after rain events. Example: horizontal surface without connecting member	
Medium	1.25	Design characterized by poor ventilation but limited exposure to water. Example: vertical contact areas without sufficient air gap	
Fair	1.5	Design characterized by poor ventilation and high exposure to water *or* end-grain with good ventilation and limited exposure to water[1]. Example: horizontal contact areas and end-grain with sufficient air gap	
Poor	2.0	Design characterized by exposed end-grain with no ventilation and very high exposure to water. Example: end-grain contact area without air-gap	

[1] *It is assumed that the gap is kept completely free from dirt and vegetation.*

Determination of wood material resistance

The resistance of different wood species or treated wood products, when exposed above ground, depends mainly on the material inherent resistance against fungal decay (e.g. toxic substances) and the wetting ability. Thus, the design resistance dose is defined as follows:

$$D_{Rd} = D_{crit} \cdot k_{wa} \cdot k_{inh} \tag{4}$$

where D_{crit} is the critical dose, which corresponds to decay rating 1 (slight attack, according to EN252 (2015)), k_{wa} accounts for wetting ability of the tested material (relative to the reference Norway spruce) and k_{inh} accounts for the inherent protective properties against decay of the material (relative to the reference Norway spruce). D_{crit} was evaluated for Scots pine sapwood and Douglas fir heartwood and was about 325 days and can be seen as constant for different wood species, if the differences between species are accounted for by the factors k_{wa} and k_{inh}. The factors k_{wa} and k_{inh} were estimated from testing and described in detail for a large number of wood species and treatment types by Meyer-Veltrup *et al.* (2017). The relative D_{Rd} in the right column (Table 2) expresses the ratio in service life (time to decay rating 1) between a certain species and Norway spruce, showing that the choice of right material is important. The material resistance dose D_{Rd}

for a large number of wood species and treatments used in both bridge, cladding and decking applications can be found in Table 2. In determination of service life, the material resistance dose D_{Rd} (days) is compared with the design exposure dose according to Eqn. 1 and 2.

Table 2: Material resistance dose D_{Rd} (design value). After Pousette et al. (2017) and Meyer-Veltrup et al. (2017).

Wood species	D_{Rd} [days]	Relative D_{Rd} (reference: Norway spruce)
Norway spruce *(Picea abies)*	325	1.0
Scots pine sapwood *(Pinus sylvestris)*	300	0.9
Scots pine heartwood *(Pinus sylvestris)*	850	2.6
European larch heartwood *(Larix decidua)*	1900	5.8
Douglas fir heartwood *(Pseudotsuga menziesii)*	1700	5.2
Western Red Cedar *(Thuja plicata)*	1050	3.2
Beech *(Fagus sylvatica)*	313	1.0
Oil-heat treated spruce *(Picea abies)*	2400	7.4
Thermally modified pine *(Pinus sylvestris)*	2400	7.4
Preservative-treated wood NTR AB[1]	1700	5.2
Preservative-treated wood NTR A[2]	2600	8.0

[1] accepted for use class 3.2 according to EN 335 (2013)
[2] accepted for use class 4 according to EN 335 (2013)

EXAMPLES

The possible use of the engineering tools described above and presented in detail in Pousette *et al.* (2017) and Isaksson *et al.* (2014, 2015) will be illustrated here with the help of two examples, one for a timber bridge detail and one for a cladding. As not all tables and figures from the tools are presented here in this paper, the reader is referred to the original sources for the additional information needed.

Example 1: Service life of a cladding

Consider a cladding with vertical boards on a single-family home in Stockholm, Sweden, and calculate the service life (SL) for the lower edge of the cladding according to the flowchart in Figure 2 and with help of the cladding and decking tool presented in Isaksson *et al.* (2014, 2015). The different factors and the resulting SL are shown in Table 3.

Table 3: Example of calculation of SL for the lower edge of vertical cladding in Stockholm, Sweden. Reference is made to tables (T), figures (F) and equations (Eq) in Isaksson et al. (2015).

Factor	Value	Source	Comments
Consequence class, γ_d	0.6	T2	Easy to change cladding
Annual exposure dose D_{E0}	28	F6, T4	
Factor for driving rain	0.91	T6	
Factor for sheltering by topography/buildings	0.9	T8	Assumed sheltering by adjacent buildings
Factor for rain sheltering	1.0	T14	Assumed no sheltering as lower edge is considered
Factor for distance to ground	1.7	F17	Distance to ground assumed to 200mm
Factor for detail design	0.9	T13	Assumed full ventilation and sealed end grain
Design exposure D_{Ed}	21 days	Eq 1+4	
Design resistance D_{Rd}	325 days	T20	Assumed Norway spruce
Service life $SL=D_{Rd}/D_{Ed}$	15.5 years		

Comments and conclusions:

- A SL of about 15 years for the lower edge of a cladding of a single family home is satisfactory. However, by changing the wood species, e.g. by using European larch heartwood, the SL could be increased to almost 90 years.
- This SL of about 15 years was obtained for the lower edge, which is close to the ground (200 mm distance). If the distance to ground is 400 mm, the SL increases to about 26 years which might be a cheaper solution than changing the wood material.
- If horizontal cladding is used instead of vertical cladding, the lowest cladding boards can easily be removed and substituted with new ones – for vertical cladding, maintenance of the lower ends of the cladding is much more complicated.

Example 2: Service life of timber bridge detail

Consider a bridge with a stress laminated timber deck of untreated spruce in Stockholm, Sweden and calculate the service life according to flow chart in Figure 2. The worst detail is assumed to be the connection between the pressure plates for pre-stressing rods and the timber deck, which is protected from rain. The different factors and the result are presented in Table 4.

Table 4: Example of calculation of SL for a timber bridge detail in Stockholm, Sweden. Reference is made to tables (T), figures (F) and equations (Eq) in Pousette et al. (2017).

Factor	Value	Source	Comments
Required service life, req SL	100 years	T2.1	
Consequence class, γ_d	1.0	T2.2	Bridge, load bearing
Annual exposure dose D_{E0}	32 days	F2.6	Zone g
Factor for driving rain and sheltering by topography/buildings	0.9	F2.7,T2.4	Low driving rain index → driving rain can be neglected; assumption of no sheltering
Factor for rain sheltering	1.0	F2.9	many bridges are subject to leaks at some point, effectively negating the effect of the cover[1] and it is thus assumed no sheltering
Factor for distance to ground	1.0	F2.10	Assumption: distance to ground >400mm
Factor for detail design	1.25	T2.5	
Design exposure D_{Ed}	50 days		
Design resistance D_{Rd}	325 days	T2.6	Assumed Norway spruce glulam
Service life $SL=D_{Rd}/D_{Ed}$	6.4 years		

[1] *Pousette and Fjellström (2016)*

Comments and conclusions:

- The service life (SL) of the detail in question is much lower than the required SL. This is not surprising, as it is difficult/impossible to reach long service life if untreated wood is exposed to moisture.
- The calculated SL of about 6 years should be used to determine inspection intervals (recommended 6 years) instead of being a real SL.
- By choosing a different material, e.g. preservative-treated wood NTR-AB or NTR-A (Table 2), the SL would increase to about 33 - 51 years. This might be a good strategy, especially if there is a risk for leakage.
- A good alternative would be to protect the load-bearing structure, e.g. by cladding. The cladding according to example 1 has a SL of 15-26 years, which would result in maintenance intervals of about 15 years. However, the inspection interval should still be around 6 years (due to risk of leakage (Pousette and Fjellström (2016)).

- The method can be used to determine inspection intervals so that more resources can be allocated to high-risk bridges. This in contrast to current practice where the condition of any bridge is checked every 6th year, regardless of the associated risks.

CONCLUSIONS

As shown for two examples, the engineering tools are quite easy to use, as the in-data are taken from tables and figures, i.e. the user can choose between several typical cases. The tools can be used both for prediction of service life and for prediction of necessary maintenance or inspection intervals, depending on the type of structure or element considered. The tools can also be used for parameter studies – in order to choose between different possible designs, and as a checklist for designers. The advantages of the new performance-based prediction models are that they are scientifically based, with all factors being determined either by laboratory or field testing, modelling or expert opinions. As the approach is open, future research results can be easily implemented as well as the user might use own input factors. The tools will hopefully result in more durable and better timber structures and help architects, planners, builders, and craftsmen to build them.

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The NTR-NWPC scheme for approval of wood preservatives and quality control and certification of preservative-treated wood

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Keywords: wood preservatives, preservative-treated wood, approval, quality control, certification

ABSTRACT

Official quality requirements for industrially preservative-treated wood have existed in the Nordic countries since 1976, when a common Nordic standard for preservative-treated wood was introduced after an initiative by the Nordic Wood Preservation Council (NTR-NWPC). Today five classes of preservative-treated Scots pine and other permeable woods, NTR M, NTR A, NTR A Pole, NTR AB and NTR B, each suitable for a certain end use, have been defined:

NTR M	marine applications/sea water with a salinity of >0.6% (Use Class 5/EN 335)
NTR A	in ground contact/fresh water (Use Class 4)
NTR A Pole	in ground, utility and telecom poles (Use Class 4)
NTR AB	above ground, in general (Use Class 3)
NTR B	above ground, external joinery (Use Class 3)

For classes NTR M, NTR A, NTR A Pole and NTR AB full sapwood penetration applies, and for class NTR B the requirement is 6 mm lateral penetration of preservative in the sapwood.

In 2011 a classification of preservative-treated spruce was launched by the NWPC. It is limited to commodities such as cladding, barge boards, battens (NTR GRAN) and window components (NTR GW). There is no penetration requirement, but only requirement on retention in the outer 3 mm zone for these classes.

The required retention is specified for each preservative and class by the NWPC in accordance with an approval scheme (NWPC Document No 2), adapted to EN 599-1. Field testing has a long and strong tradition in the Nordic countries and is required for all classes.

To treat according to the NWPC wood protection classes requires affiliation to a quality control and certification scheme which includes third party inspections. At present approximately 90% of the production of preservative-treated pine in Denmark, Finland, Norway and Sweden takes place at treating companies that are affiliated to the NWPC quality control and certification scheme. The quality control consists of two parts:

- Factory Production Control (FPC) (the treater's own quality control). The aim of the FPC is to steer and ensure the quality of the production with respect to those

product requirements defined for each wood protection class in NWPC Document No 3, Parts 1 and 2.

- Third party inspections - The aim of the third party inspections is to ensure that the FPC is carried out and to check that the quality of the treated wood complies with the requirements.

Before a plant can be affiliated to the quality control, the production equipment, equipment and routines for the FPC shall be examined and approved by the quality control body. If the initial inspection is successful, the treater will get a certificate that shows the right to produce and brand treated wood with the NTR-NWPC quality marks.

INTRODUCTION

The Nordic Wood Preservation Council NTR-NWPC, a body for co-operation in the field of wood protection between the Nordic countries (Denmark, Finland, Norway and Sweden) founded in 1969, early recognised the need for an appropriate classification and quality requirements - fit for its purpose - of industrially produced preservative-treated wood. Already in 1976 such a classification was in place, based on three fundamental principles:

- A classification of treated wood with respect to intended end use comprising requirements on wood preservative penetration and retention,
- A scheme for approval of wood preservatives with the purpose of specifying appropriate retentions for different end use situations, and
- A quality control and certification scheme for treaters to secure a high quality of treated wood on the Nordic market.

As Scots pine (*Pinus sylvestris*) has traditionally been used for wood preservation in the Nordic countries the classification initially only was applicable to Scots pine. It has then been extended to include also other permeable softwoods. In 2011 a classification system was introduced for spruce (*Picea* spp) for certain end uses.

Since 1998 the Nordic system for classification of treated wood, approval of wood preservatives and quality control and certification of treated wood is entirely based on European standards.

CLASSIFICATION OF PRESERVATIVE-TREATED WOOD

The classification system has developed over time and today (2017), the classification of Scots pine and other permeable softwoods (NWPC Document No 1, Part 1) comprises five wood protection classes, each suitable for a certain end use:

NTR M	marine applications/sea water with a salinity of >0.6%
NTR A	in ground contact/fresh water
NTR A Pole	in ground contact, utility and telecom poles
NTR AB	above ground, in general
NTR B	above ground, external joinery

Similarly, the classification of spruce (NWPC Document No 1, Part 2) comprises two classes:

NTR GRAN	above ground, restricted to cladding, barge boards and battens
NTR GW	above ground, window components

The wood preservative penetration and retention requirements for each wood protection class are shown in Figure 1 and how the NTR-NWPC wood protection classes are related to EN 351-1 and EN 335 is shown in Figure 2.

Wood protection class	**Treatment requirements**	
	Penetration class according to EN 351-1	**Retention of wood preservative**
NTR M, NTR A, NTR A Pole and NTR AB	NP 5 Full sapwood penetration	According to NWPC approval for the wood preservative
NTR B	NP 3 Minimum 6 mm lateral penetration into the sapwood	
NTR GRAN	NP 1 No penetration requirement	According to NWPC approval for class NTR AB in the 3 mm analytical zone
NTR GW	NP 1 No penetration requirement	According to NWPC approval for class NTR B in the 3 mm analytical zone

Figure 1. Penetration and retention requirements for NTR-NWPC wood protection classes.

Penetration class according to EN 351-1		**Inter relation between Use Classes 1 - 5 in EN 335 and the NTR classes M, A, A Pole, AB, B, GRAN and GW**				
Penetration class	**Penetration requirement\ Use class**	**UC 1**	**UC 2**	**UC 3**	**UC 4**	**UC 5**
NP 1	None			NTR GRAN NTR GW		
NP 2	Minimum 3 mm lateral into the sapwood					
NP 3	Minimum 6 mm lateral into the sapwood			NTR B		
NP 4	Minimum 25 mm lateral (roundwood)					
NP 5	Full sapwood			NTR AB	NTR A NTR A Pole	NTR M
NP 6	Full sapwood and min 6 mm into exposed heartwood					

Figure 2. Inter-relation between the NTR-NWPC wood protection classes and EN 351-1 and EN 335

From a commercial point of view, NTR AB is by far the most important, followed by

NTR A and NTR A Pole. Treatment according to the spruce classes is still marginal.

APPROVAL OF WOOD PRESERVATIVES

Already in 1970 The NWPC established principles (NTR Standard 1.2.1./70) for evaluation and approval of wood preservatives with respect to their efficacy against decay and marine wood destroying organisms. Based on NTR Standard 1.2.1./70 the NWPC Technical Expert Group (TEG) issued recommendations for minimum retentions, expressed as kg wood preservative product/m^3 *Pinus sylvestris* sapwood, for "normal use in and above ground" and "marine use" and applicable in the Nordic countries.

In 1980, the NWPC TEG became responsible for a more official approval scheme for wood preservatives to be used for the wood protection classes M, A and B. In 1989 it comprised the new class AB as well. In 1998 the approval scheme was adapted to EN 599 (NWPC Document No 2) and the requirements for testing specified in this standard. The NWPC approval of wood preservatives is voluntary, but if a wood preservative manufacturer wants to deliver products to be used to treat wood according to the NWPC wood protection classes, approval is mandatory to have. The NTR approval does not comprise health and safety and environmental aspects. Any wood preservative product has to be approved in accordance with EU's Biocidal Products Regulation (BPR) and requirements by national chemical authorities.

A main feature of the NWPC wood preservative approval system is requirements on field testing. Field testing has a long and strong tradition in the Nordic countries and is required in principle for all wood protection classes, see Figure 3. There is no doubt that the field testing requirement, in particular for Use class 4, has been an important tool for NWPC TEG to assign realistic retention levels for all wood protection classes. This in turn will contribute to a safe use of the treated wood and fit for its purpose.

NTR class	End use/Use class	Field test required
M	Marine/UC 5	EN 275, ≥ 5 years
A	In ground/fresh water/UC 4	EN 252, ≥ 5 years
A Pole	Utility poles, piles/UC 4	EN 252, ≥ 5 years
AB	Above ground/UC 3 in general	CEN TS 12037 (lap-joint), until reference samples have reached a median rating 3 (severe decay)
B	Above ground/UC 3 joinery	EN 330 (L-joint), until reference samples have reached a median rating 3 (severe decay)

Figure 3. Field testing requirements for NTR-NWPC wood protection classes.


Figure 4. Simlångsdalen "old" test field and rig for marine testing according to EN 275 at Kristineberg on the Swedish west coast.

QUALITY CONTROL AND CERTIFICATION

To treat according to the NWPC wood protection classes requires affiliation to a quality control and certification scheme which includes third party inspections. At present approximately 90% of the production of preservative-treated pine in the Nordic countries takes place at treating companies that are affiliated to the NWPC quality control and certification scheme. As mentioned earlier, the production of NTR classified spruce is marginal although substantial volumes of spruce are preservative treated in Sweden in particular. Most of the treated spruce is exported outside the Nordic region and treated according to other specifications, however.

Quality control bodies carrying out the third party inspections must be accredited by the NWPC.

The quality control consists of two parts:

- Factory Production Control (the treater's own quality control). The aim of the Factory Production Control is to steer and ensure the quality of the production with respect to those product requirements defined for each wood protection class in NWPC Document No 1, Parts 1 and 2.
- Third party inspections. The aim of the third party inspections is to ensure that the Factory Production Control is carried out and to check that the quality of the treated wood complies with the requirements in NWPC Document No 1, Parts 1 and 2.

Before the plant can be affiliated to the quality control, production equipment, equipment and routines for the Factory Production Control shall be examined and approved by the quality control body. If the initial inspection is successful, the treater will get a certificate that shows the right to produce and brand treated wood with the NWPC quality marks, Figure 5.

Third party inspections are normally carried out twice a year. During the inspection visit the inspector shall:

- audit the Factory Production Control and check that treatment records are carried out continuously according to given instructions

- check the plant's equipment for Factory Production Control, mainly equipment for measuring the concentration of the treating solution (if applicable) and the wood moisture content
- take a sample of the wood preservative/treating solution for chemical and/or physical analysis; the latter mainly applies to creosote
- take random samples from the treated wood for analysis of the preservative penetration and retention
- check that updated instructions required are available
- check that requirements for delivery and branding are fulfilled.

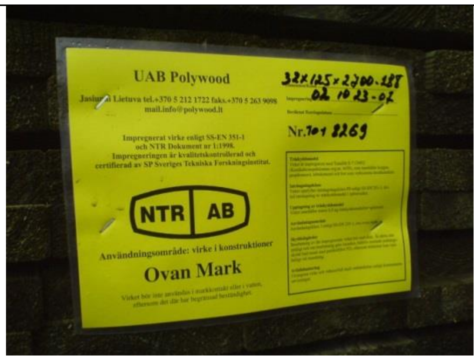
Wood protection class	Quality mark	Example of bundle marking
NTR M	NTR M	
NTR A	NTR A	
NTR A Pole	NTR A pole	
NTR AB	NTR AB	
NTR B	NTR B	
NTR GRAN (Spruce)	NTR GRAN	
NTR GW (Spruce)	NTR GW	

Figure 5. NWPC quality marks

A. B.

Figure 6. A. Measuring the moisture content. B. Samples from fence posts for checking the penetration.

FINAL WORDS

Times are changing and the wood preserving industry is constantly subject to new challenges. No system is perfect and this applies of course also to the NTR-NWPC system for classification and quality assurance of treated wood. Some examples:

- Efforts are required to make sure that the quality control bodies interpret the rules for the quality control and certification scheme in the same way. Some discrepancies have been seen over time and the NWPC has tried to compensate for this by organising regular workshops for the auditors in order to harmonise their interpretation of the rules.
- Competition between quality control bodies operating on the same market may be good for the treating companies. But will it be good for the consumers? If the competition is focused on price only instead of competence and service, it may be tempting for the quality control bodies to spend less time on the inspection visits and be less severe in their judgements of results from penetration and retention analyses in order to make their clients happy.
- The Factory Production Control is the most important tool for the treaters to secure the quality of their products. For modern treating plants with a high production capacity, fully automated control and running 24h per day, it is a challenge to have a good FPC and it requires competent operators and an understanding management to establish an FPC worth its name.
- Approval of wood preservatives has been one of the core activities of the NWPC. The Technical Expert Group has since its establishment consisted of one expert from each Nordic country. So far, each country has managed to supply the TEG with competent experts, but with the relatively few scientists active in wood protection and in testing of wood preservative products, this may be difficult in the future unless measures are taken.
- Modified wood, such as Thermally Modified Timber (TMT), furfurylated (trade name Kebony) and acetylated wood (trade name Accoya) have been on the market for some time, although in minor quantities compared to preservative-treated wood. The NWPC has recently introduced a classification package, similar to that of preservative-treated wood (Morsing *et al*, 2017). It remains to see what impact this package will have and if producers and consumers will embrace it.

It can finally be concluded that the NTR-NWPC system for classification and quality assurance of treated wood has served the Nordic wood preserving industry very well for more than 40 years. It has contributed to strengthen the confidence in treated wood and secure a high level of quality for the benefit of all consumers of treated wood in the private and public sectors. An awareness about the advantages of the NTR-NWPC system amongst treaters outside of the Nordic region for the possibility to export treated wood to Denmark, Finland, Norway and Sweden has resulted in affiliation of nearly 20 treaters in Estonia, Germany, Latvia, Lithuania and Poland to the NTR-NWPC system.

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EN 351 — Durability of wood and wood-based products. Preservative-treated solid wood
Part 1. Classification of preservative penetration and retention

	Part 2. Guidance on sampling for the analysis of preservative-treated wood
EN 599-1	Durability of wood and wood-based products – Efficacy of preventive wood preservatives as determined by biological tests. Part 1: Specification according to use class
European Union	The Biocidal Product Regulation (BPR, Regulation (EU) 528/2012)

Morsing N, Engelund Thybring E, Klamer M (2017). New Standards for Approval of Modified Wood within the Nordic Wood Preservation Council (NWPC). Proceedings IRG Annual Meeting, IRG/WP 17-20624

NWPC Standard 1.2.1./70	NWPC Standard for approval of pressure treatment preservatives against biological deterioration
NWPC Document No 1	Nordic wood protection classes and product requirements for industrially protected wood Part 1: Scots Pine and other permeable softwoods Part 2: Spruce (*Picea* spp)
NWPC Document No 2	Conditions for approval of wood preservatives for industrial wood preservation in the Nordic countries
NWPC Document No 3	Nordic requirements for quality control of industrially protected wood Part 1: Scots pine and other permeable softwoods Part 2: Spruce (*Picea* spp)

Performance of Eucalyptus globulus single family house in Spain after 15 years exposure. Example of building with bio-based materials

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Keywords: Wood, performance, design, bio-based materials, buildings.

ABSTRACT

Since the last century, it has been common to find wooden houses in the Spanish countryside. The reason is mainly due the improvements in glues, materials, design by computer and processing in factories. All these technological advances have facilitated the development of cheaper industrialized systems. However, the variety of row materials, designs and construction systems, combined with some hard climates, could have as resulted in some cases of pathological problems associated to wood destroying fungi, insects and aesthetics. The wood species selected and the design details are fundamentals for performance and durability of timber houses. The wood degradation depends foremost on the wood species selected but also depends on driven rain and winds, design details, joints and maintenance. This paper presents the performance of a *Eucalyptus globulus* single family house built in 2002 in north Spain, using entirely sawn and glued laminated *Eucalytus globulus* heartwood in all elements of the house: structure, flooring, stairs, windows, galleries, roofing, carpentries, etc., without using preservatives and it was designed considering very well detailed designs as well as maintenance during its service life. After more than 15 years, the performance of all wood elements of this single-family house is very good, without pathological problems and continues to serve their original purpose. This house constitutes a prime example of the versatility of this wood in structural and decorative wood elements. It is worth pointing out that all joins between structural components have been assembled with traditional techniques and without using metallic elements.

INTRODUCTION

Across Europe, it is very common to find wooden houses. Most of these houses use softwood species such as fir, spruce, larch and pine.

In Spain, wooden houses became more and more popular recently, when sawn and glue-laminated wood were utilized for building wooden structures across Spain.

This material, in the form of sawn and glue-laminated wood, are often made of softwood species from central and northern European origin and production. It is not common to find examples of local hardwood species used in wooden houses. This paper shows an example of a wooden house built using a local hardwood species, specifically *Eucalytus globulus*.

PERFORMANCE AND WOOD SERVICE LIFE

Use classes

The concept of use class defined in EN 350 is related to the probability that a wooden element is attacked by biological agents and basically depends on the difference in environment exposures.

Use class indicates a position of the wood element and its chance of sometimes being exposed over 20 % moisture content. It is emphasized that the approach really should be considered the period that a wood element remains above 20 % moisture content, since there is no doubt that for example an outside element, without contact with the ground (use class 3) in South Spain (hot an arid climatic conditions) would have the same risk of being moistened and consequently being attacked by wood destroying fungi that another wooden element in a similar situation in North Spain, where due to the rainfall, wet and warm climate conditions are very common.

Regarding the wooden single family house of this case, we find depending on the wood elements different uses classes: Use class 1 in wood elements inside the house, not exposed to the weather and wetting, use class 2 in wood elements under cover and not exposed to the weather and use class 3 in wood elements above ground and exposed to the weather, where even we can find wood elements in sub-class 3.1 (do not remain wet for long periods) and sub-class 3.2 (remain wet for long periods).

It is very important to correctly identify the use class to which a wood element is exposed, so that a wood species may be selected with the enough durability required for that particular situation.

Natural durability and treatability of wood

Wood, due to its organic nature, is supposed to be degraded and returned to nature because of the degrading action of biological and/or abiotic agents that directly or indirectly are involved in its degradation. Biological agents are composed by living organisms that degrade wood, including moulds, wood disfiguring fungi, wood destroying fungi and wood destroying insects; and abiotic agents comprising mainly atmospheric agents (sun and rain), as well as chemicals products.

Biological agents are responsible for attacks that cause reductions in the resistance of wood elements and consequently their physical and mechanical properties that will be taken into consideration when using the wood and its protection. The action of wood destroying insects is characterized by perforations and tunnels, while fungi attack produces a variety of defects, including destruction of anatomical elements.

Abiotic agents themselves do not cause serious damage. However, unsuitable environmental conditions, particularly temperature and humidity in the environment surrounding the wood elements allow biological agent attacks and affect the final service life.

The natural durability of a wood species is defined as the inherent resistance to attack by wood destroying organisms, while the treatability is the ability that a liquid penetrates inside the material. The natural durability and treatability are two fundamental aspects to consider in the selection of a wood species in a wooden house.

In terms of natural durability, heartwood of *Eucalyptus globulus* from Galicia, Spain, is classified in the European Standard EN 350:2016 as durable (durability class 2) regarding to fungi decay, as well as being durable against wood boring beetles (class D). This means that its use and performance without any preservative treatment for indoor and outdoor purposes, i.e. wooden, is enough and suitable.

The choice of a wood species with high natural durability is the first and most appropriate step of protection in the case of exterior timber structures such as wooden houses.

However, if the natural durability is insufficient, one should consider implementing a preventive preservation treatment, which increases the wood protection, in order to avoid the attack of biological agents and help keep the performance and service life.

Regarding the choice of wooden materials, the wood species used not only determines the mechanical properties of the structure, also their resistance to various wood destroying agents, because each wood species has specific mechanical properties and a natural durability and treatability different.

Climatic conditions

Weather conditions are a key consideration in the performance of exterior wooden elements. Climatic parameters such as rain, wind or UV radiation strongly affects the durability and susceptibility of wood to decays used in exterior conditions.

It has been precisely this diversity of wood species, designs and procedures construction, combined with the variability of different climatic zones, which could has led to the emergence of early pathological processes of decay fungi and insect attacks.
The high variability of the climate conditions affects the biological hazard to which the wood is exposed, particularly in exterior uses. Despite the great variations among geographical locations, climatic conditions associated with each region are key in the service life. Even within some countries such as Spain, environmental conditions are variable throughout the year and also depend on geographical location.

In Spain, the following levels of Scheffer Index have been defined as one of the parameters to approach and characterize climatic areas.

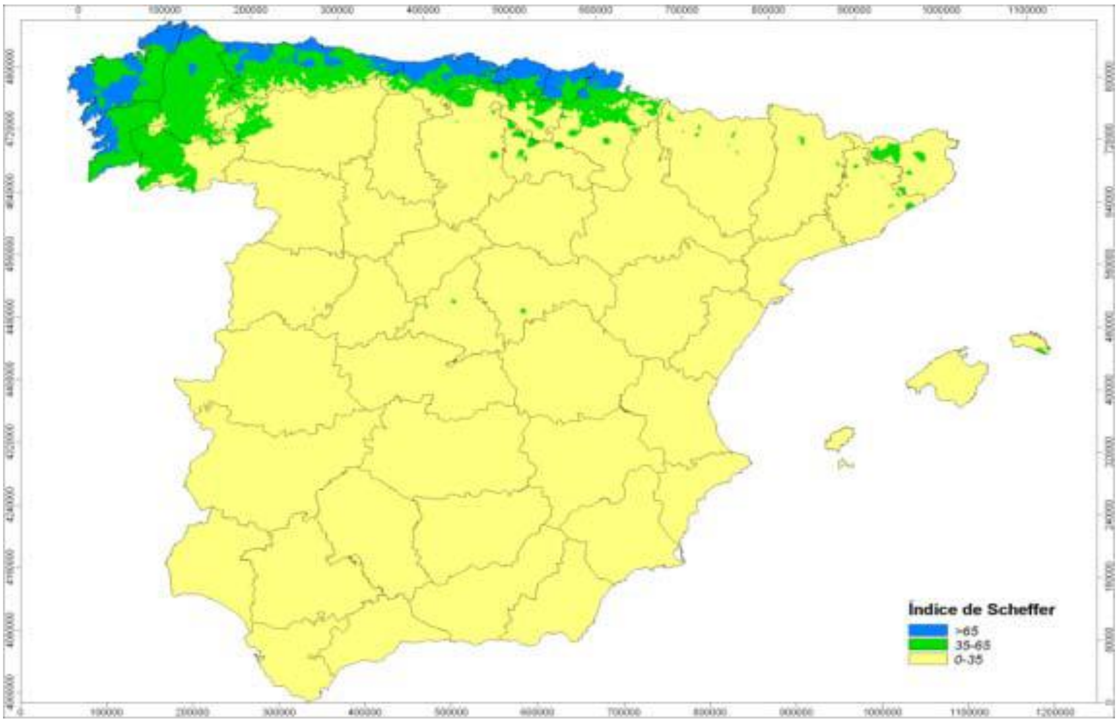

***Figure 1: Scheffer index in Spain*.**

However, it is also important to note the relevant local climates, in some locations. For example, high ambient humidity can occur (as a consequence for example of water resources such as riverbanks or oceanic coast or even in areas with frequent fogs) and orientations, etc., may negatively influence correct identification of the final climatic conditions at a given place.

The most important things to evaluate are the accuracy of project details and their adequacies to the service condition on the basis of the climatic parameters: rainfall, average seasonal temperature, sunlight, exposition, prevailing winds, driven rains, etc.

Design details

Another very important item to ensure service life and good performance of wooden elements and structures exposed to weathering (in the case of North-West of Spain, especially to rainfall) is the design details. This factor includes design details such as orientation of the fibres, exposure of the end grain, joints, etc. that avoids wet conditions may favor the attack of wood by wood destroying fungi. So, the design must ensure ventilation and rapid evacuation of water in different elements, especially the main structural components and joints and avoid the water traps.

The durability or service life of a wooden structure (wooden house) is defined as the period in which it is maintained under conditions of proper use. This depends mainly on the possible damage that may appear on the parts that constitute it. These damages are explained almost entirely by insufficient protection of wood. For that reason, all aspects of protection during the design, construction and maintenance have to be considered. Among them are the choices of wood species, measures of preventive protection and construction design details.

So, if protection issues have been adequately studied and solved, wooden houses can have a long service life and performance.

PERFORMANCE OF EUCALYPTUS GLOBULUS SINGLE FAMILY HOUSE

The single family house is located in Galicia, north-west of Spain, a wet and warm climate area. The house is located in a valley with high relative humidity most days of the year as well as frequent fogs. Local climate is also characterized by driven rain from the south-west.

Figures 2 and 3: North facade and south-west facades.

Wood species selected to build the single family house is *Eucalyptus globulus*, a non native tree introduced from Australia to north Spain and Portugal in the middle of the XIX Century. During the first decades, Eucalyptus was used in different industrial applications (sleepers, stakes, ships and civil construction). From the XX Century, Eucalyptus plantations were expanded rapidly due the pulp industry. Nowadays this is main destination as well as another industrial uses (sawn wood , glulam, flooring carpentry, etc.).

Eucalyptus globulus heartwood is characterized by its high natural durability, so using only heartwood does not require preventive preservative treatment in use class 3 situations to achieve good performance and the expected service life.

The single family house was built in 2002 using entirely sawn and glued laminated *Eucalytus globulus* heartwood in all elements of the house: Structure, flooring, stairs, windows, galleries, carpentries, roofing, carpentries, etc., without using preservatives and it was designed considering very well detailed designs.

Regarding design details, the perimeter eaves stand out around the house that protect the south- and west-exposed facades from driven rain. The end of the main beams (end grain) is physically protected. The structural supports are also protected from the rain and other parts as horizontal face of main beams have physical protection, so water is not retained. The decking in the gallery around the house has been designed with a separation of 1.5 cm to avoid water traps and allow fast drying. All the structure is raised from ground by more than 1 meter. One of the objectives of the design is avoid water traps.


***Figures 4 and 5: Roofing structure and interior all in glue lam Eucalyptus globulus.*.**

All wooden elements were finally coated with natural oil.

It is worth pointing out that all joins between structural glulam eucalyptus components have been assembled with traditional techniques and without using metallic elements, so the only structural material used in this house is wood.


Figures 6 and 7: Details of the wooden single family house.


Figures 8 and 9: Pillars and interior carpentry of wooden single family house.

After 15 years from the construction in 2002, the performance of the single family house in all wooden elements (interior and exterior) is perfect, without appearance of moulds, wood disfiguring fungi, decays, wood destroying insect attacks, aesthetics or other pathological processes.

CONCLUSIONS

The performance of this *Eucalyptus globulus* single family house built in 2002 in north Spain, using entirely sawn and glued laminated *Eucalytus globulus* heartwood in all elements of the house (Structure, flooring, stairs, windows, galleries, roofing, carpentries, etc.), without using preservatives and considering very well detail designs as well as maintenance during its service life is a perfect example of a building with bio-based materials, best practice and good performance

After 15 years, the performance of all wood elements of this single family house is very good, without pathological or aesthetics problems and continues to serve their original purpose. This house constitutes a prime example of the versatility of this hardwood in structural, carpentry and decorative wood elements.

This example confirms the ability of using high natural durability wood species in wooden houses without preservative treatments, in wet and warm climates like north-west Spain, where wood destroying fungi and other pathological processes can develop and attack the wooden elements during most of the year.

In any case, it is essential to identify correctly the real use class, choice a suitable wood species with enough natural durability and to consider the detail designs to avoid prolonged time of wetness in the wood elements.

All these factors and all the variables must to be considered to prevent decays and other pathological processes and help to achieve the desirable service life and performance in the single family house.

ACKNOWLEDGEMENTS

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Maintenance systems for wooden façades

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Keywords: durability, wooden envelope, timber building, maintenance.

ABSTRACT

In Italy, the diffusion of wooden buildings places greater emphasis on the durability of both the materials and the buildings built with them. In particular, envelopes are the most studied elements, because they are the ones more subject to environmental agents, like meteorological events or UV rays, which are the main causes of wooden deterioration, (Davoli, 2001; Rüther and Time, 2015). The aim of this research is to identify, through a set of case studies, some best practices for improving the maintenance procedures of wooden envelopes and to improve the overall element durability. Different case studies, with different functional models and different finishing solutions will be investigated to compile a list of designing suggestions for wooden façades.

INTRODUCTION

For a long time, architectural design has been tackling the problem of the aging and deterioration of construction materials in the last phase of a building life cycle, a key concept from the point of view of environmental sustainability, because it allows the dismantling of buildings by disassembling their components without any further energy use.

The aim of the design is to find solutions, both at procedural and designing level, to improve the durability of both the single components and the whole building, expecting to intervene with preventive maintenance cycles or replacement of components without damaging the rest of the building (Gaspar & Brito, 2003).

BACKGROUND AND STATE OF THE ART

Envelopes, so also buildings in general, are composed of different layers that reach the end of life service in different phases of the life cycle. Several authors (Gaspar and Brito, 2003; Hovde and Moser, 2004), subdivide the building in different durability levels, i.e. in different functional layers(skin, structure, service, space plan, stuff), that reach the degradation state at different times from their installation.

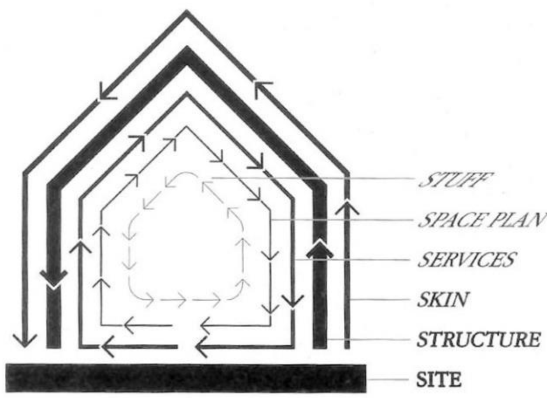

Figure 1: Shearing layers of buildings, adapted from

In order to provide durability to the technological element, it is important to guarantee both natural component durability and the possibility of skin management. In fact, the former is important to guarantee the durability of the individual skin components and their composition, while the latter is important for the possibility to plan inspection's cycles, maintenance's preventive cycle and/or substitution of element in case of damage (Hovde and Moser, 2004; Manfron and Siviero, 1998).

The new Italian Public Procurement Code requires that the designer not only guarantee *the energy saving solutions during the phases of construction and use of the building*, but *also be responsible for the assessment of its life cycle and maintenance solutions* (art. 23 Dlgs n 56, 2017).

Wooden envelopes are convenient for some particular features, for example:

- the possibility of linking and moving the component in an easy way,(i.e. Dry construction system)
- working with light material, so the construction site is the place where the construction is assembled, allowing less cost and major speed in construction, and also the possibility to use prefab components;
- the possibility of reusing the component after dismantling, if the disassembly process has been considered by the designer;
- the possibility of controlling and selecting the material and the origin, with a great advantage for environmental sustainability.

METHOD AND ANALYSIS CRITERIA

The façade will be investigated with against some key requirements, described by the Italian standard UNI 8290, which defines the provisions related to the requirement of building components. The requirements that will be used in the analysis are: accessibility, inspection, the ability of the component to be installed/assembled, and the possibility to replace the components.

Accessibility is the capability of examining the façade's layers after the building construction. This feature is linked to the functional model chosen for the considered technological element (e.g., ventilated facade, with continuous insulating element and continuous finishing), and is crucial in the user's ability to judge the degree of wear and/or damage of one of the components.

The inspection is the requirement that considers the possibility of changing or inspecting one or more façade's component, without damaging the rest of the element. This feature depends on the possibility of mounting and dismantling components.

The ability of the parts to be installed/assembled, is the possibility of disassembling the skin's components, if needed, without damaging the other elements, and with the possibility of reusing them after a temporary dismantling. This ability is related to the characteristics of fixings of the external finishing.
The reparability and the ability to be replaceable are the requirements which consider the possibility of assessing how the single parts can be disassembled without damaging the entire technologic element, by affecting only the local area of damage.
In conclusion, designing both elements and procedures to facilitate the maintenance and the possibility of changing parts of an envelope could increase the durability of wooden component façades.
The key design method of a good maintenance system could be compared to the Design for Deconstruction principles, i.e. designing the accessible connections and jointing method to ease the disassembling, designing a simple structure and standardizing components and dimensions (Rios et al., 2015). The aim is to improve durability by improving the possibility of maintenance, substitution and inspection of the entire external layer of the building envelope.

CASE STUDIES

First Case Study:Mixed-used building in Brescia, AbnormaArchitecture

Figure 2: Mixed-use building in Brescia, retrieved from http://www.abnorma.it/

The Brescia's mixed-use building is a project with the aim of collecting and linking in one building all the associations working on social service and on collective service in the province territory. The architects have designed a building with a central courtyard, to improve internal relationship between the different associations and to improve their reciprocal knowledge and interactions.
The project's surface is 2556 sq. m., and it is divided in three stories, with a public sector, and another area reserved only for workers.
The aim of the architects was to give a particular form and shape to the building facade, with wooden envelope, and in particular with the different shape and colour of the external finishing.
The decision to build the structure and the external finishing with wood is related to the will of the committee to create an edifice with high environmental sustainability features, that could guarantee good performance in durability, and with the possibility to perform easy maintenance. The sequence of case study's layers is described in Table 1.

Table 1: Stratification and width of the envelope layers

Functional layer	Components	Material Characteristic	Width(mm)
External finishing	Larch wooden Strips	Natural Larch	20
Fixing	Glue/Screws		
Windproof Membrane	Wind barrier		
Structure	Void for isolation	Wooden frame	60
Thermal insulation	Insulation	Fiber wood board	80
Structure	Wooden Panel	Clt	128
Internal finishing	Transparent paint		
Internal finishing	Larch wooden Strips	Natural Larch	20

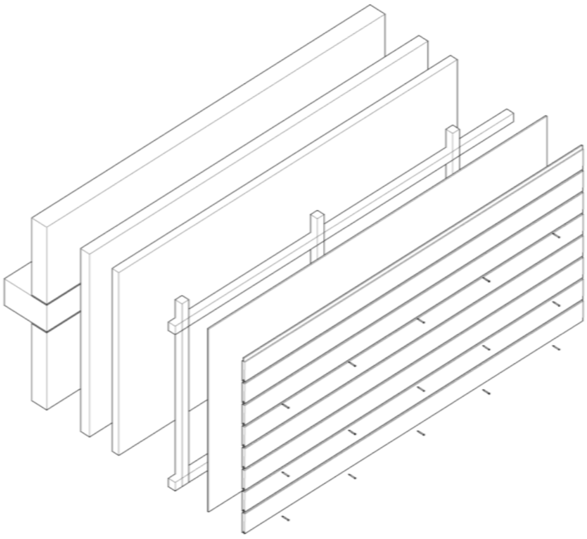

Figure 3: Exploded view diagram of case study envelope

The external finishing is in wooden larch ashes with tongue and groove joint, without pre-treatments of the material. This is related to the designers' choice of a material that changes its aesthetic colour during the exposition time, with the intention to avoid any possible pollution of the environment.

The external boards are glued/screwed to the layer behind, without ventilated air space.

The functional layout could be defined as a non-structural external vertical enclosure, with external finishing applied on the insulation.

This characteristic limits the possibility of user's inspection of the layer of the façade, so it is not easy to perform accessibility on this shell typology.

The inspection is also difficult: the tongue and groove joint does not allow dismantling small part of the envelope, because it has to be dismantled top-down. Furthermore, in some part of the building, the external plates are pasted to the layer behind and fixed with screw in other parts. Therefore, it is very hard to disassemble or change one component, if needed, without damaging other parts of the facade, because where there is glue the plates are impossible to disassemble without breaking them, and where there's the screw it's impossible to partially disassemble the component.

Also, the reparability of wooden slats is limited by the particular shape of the finishing joint, that makes changing single components very hard.

Second Case Study:*M+R house, Diverserighe Architects*

Figure 4: M + R house, retrieved from www.diverserighestudio.it, © DavideMenis

This building was constructed in 2011 in the suburb of Bologna city, and it is composed by two residential units on two floors.

External finishes are realized in two different ways. The part most exposed to external agents is designed with white plaster finishes on insulated panels, and the rest of the building envelope is composed of external wooden larch strip with no pre-treatments.

Table 2: Stratification and width of the envelope layers

Functional layer	Components	Material Characteristic	Width (mm)
External finishing	Wooden larch slat	Natural larch	30 x 40
Support	Vertical frame	Natural larch	60 x 60
Separation	White paint		10
Insulation	Thermal insulation	Woodwool panel	60 + 60
Structure	Wooden panel	Clt	147
Insulation	Thermal insulation	Rockwool panel	27
Internal finishing	Spruce panel	Natural spruce	25

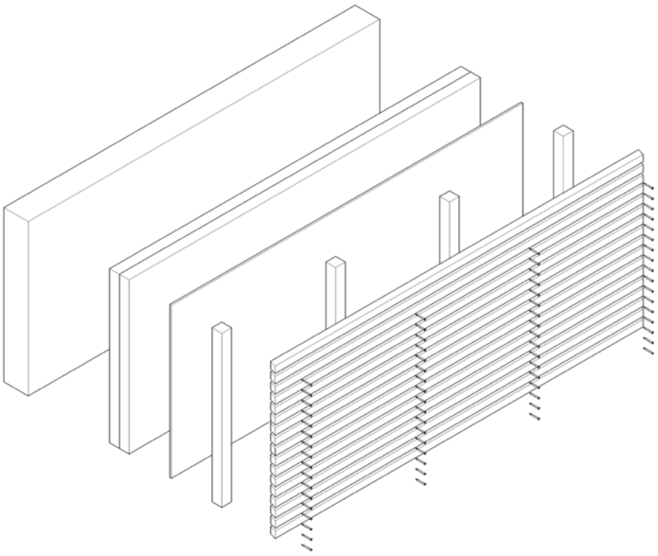

Figure 5: Exploded view diagram of case study envelope

The accessibility of the wooden envelope is good, thanks to a functional envelope layout, that is a ventilated façade. With this system, it is possible to inspect all external layers, both for checking and for replacing parts.
The inspection is good, because screws are in good and easy locations, compared to the length of the strips, and they allow using the component after dismantling.
The possibility for the component to be assembled/installed is also good: the external slats are easy to remove, due to the screws located on the vertical frame, easy to localize and dismantle, and this fixing allows to disassemble only one part of the wall, without touching the entire front. The components are in standard size, (slat 30x40 mm) and are easy to assemble, (external and visible screw), so the possibility for the single element to be replaced in case of damage is good.

Third case study: Social house in Caltron, Mirko Franzoso Architect

Figure 6: Caltron Social house, retrieved from http://www.marianodallago.it, © Mariano Dallago

This project is located in Caltron, Trentino Alto Adige. The architects wanted to develop a building that could be visible from the entire valley, embedded in the landscape, and at the same time, denoting a limit between the end of the building area (city) and the landscape.
The wooden envelope is designed with larch external vertical strips, with no pre-treatments on the material. The architect and the public delegate want to use a material

with a substantial sustainability feature, and without the artificial look that sometimes pre-treatments give to the material.
The external building envelope is a ventilated façade with two timber frame structures, and with vertical external board arrangement. The building envelope has two ventilated layers. The first one is composed by a horizontal frame, and it needs to support the external vertical board. The second frame is composed by a vertical frame, and it needs to obtain the vertical stack effect to fulfil the isolation requirement.

Table 3: Stratification and width of the envelope layers, west facade

Functional layer	Components	Material Characteristic	Width (mm)
External finishing	Larch board	Natural larch	60 x 32
Support	Horizontal wooden beam	Larch	40 x 40
Support	Vertical wooden beam	Larch	40 x 40
Membrane	Waterprooflayer		
Structure	Clt	Clt	95
Support	Horizontal wooden slut	Larch	80 x 60
Support	Vertical Wooden slut	Larch	40 x 40
Internal finishing	Larch matchboard	Natural larch	20

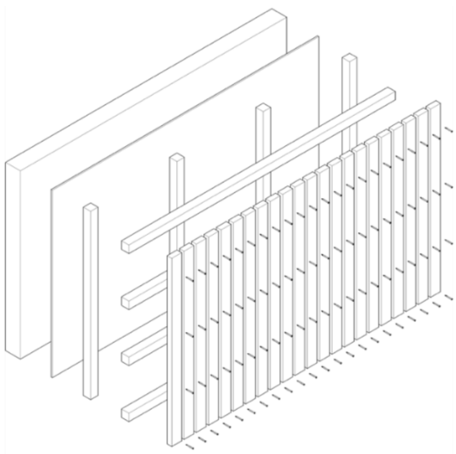

Figure 7: Exploded view diagram of case study envelope

The accessibility of the functional sheet is restricted, because the double timber frame structure is an obstacle to the easy access of the internal layer.
The inspection is also possible, but really complicated, due to the great number of fixings which make it difficult to disassemble part of the envelope without breaking some other part (external boards are fixed in vertical frame every 50-60 cm, and horizontal frame are fixed on vertical frame and also on the sustain layer behind with L-shaped fixings).
The ability of the external components to be installed/assembled or disassembled is good, because the external boards are fixed individually on the frame and are localized on the central line of the frame behind.
The repairability and the ability to be replaceable is also good, because external boards have regular size and regular screws, easy to find and to remove. The screws are in an adequate number, so it is also possible to reuse the component after dismantling.

CONCLUSIONS

In this paper, we analysed the characteristics of three different building envelopes solutions, with wooden components and external finishing in natural larch without any pre-treatments. The choice of designers to use materials without pre-treatments is related to the effect of the material's variation after years from the initial installation, in particular with the building effect of 'growing' with its inhabitants as time goes by.
We considered different solutions of façades, taking into account the accessibility, the inspection, the ability of the parts to be installed/assembled, the reparability and the ability to be replaceable.

Table 4: Comparison of analytical aspects on the three cases studio

Case study	Accessibility	Inspection	Ability to installed/assembled	Repairability
CS1- Mixed-used building in Brescia	Impossible	Impossible	Hard	Hard
CS2 – M + R house	Good	Good	Good	Good
CS 3 – Social house in Caltron	Hard	Hard	Good	Good

By assessing this characteristic, it is clear how important it is to consider the maintenance strategy in design and choose the possibility of developing façades that could be disassembled, with the right number of fixings to facilitate the use of the single component after the building envelope dismantling, or the substitution after damage.
The number, the position, and the size of screws influenced the ease of maintenance, the durability of the component, and the possibility to reuse the same component after dismantling.
The model façades, which are most easily subject to maintenance and inspection, are ventilated systems, thanks to their natural composition of assembled layers, and they allow a better conservation of wooden exterior finishing, for the ventilated camera, which allows the wood to dry.
It is hard to carry out maintenance on components that are glued on the inner layer, or with too much fixing in the façade. Fixings represent a potential problem for the board or strips, because there water or UV rays usually start the deterioration process in the component.
Fixing or joint can influence the possibility to inspect and disassemble only one part of the component, for their particular shape and the top-down connection, which avoid dismantling only part of the wall. This aspect should be considered in the first part of the project, in order to design possible solutions for partial dismantling, (e.g. modular interruption of system with steel joint to split the façade in sectors).
It is very important to choose standard size components, that allow not only a good forecasting of the expectancy of life of the element, but also can be easily substituted in case of local or total damaging.

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Towards high performance European wood materials for outdoors use

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Keywords: Wood, quality, protection, biocide, durability

ABSTRACT

Different wood materials for outdoor applications are currently available on the market. The majority of these materials consist of untreated or partially treated wood transformed into products. Despite the producers and resellers efforts to inform consumers about their products superior characteristics and performance there is usually evasiveness towards the actual performance and service life of the product, and ultimately towards guarantees. The complex structure of wood and the difficulty to convert timber into homogeneous assortments of wood raw material to suit different wood protection technologies are major factors influencing the performance of such products. The wood protection industry should focus more in obtaining specified raw material assortments, which allows for full potential in the respective wood protection technology. Wood from coniferous trees, particularly the sapwood, has limited resistance to rot and need to be protected through impregnation or modification to get higher durability in outdoor applications. These types of wood materials are benchmarked on the basis of standard tests of treated sapwood. However, the vast majority of wood being used for protective treatment consists of a mixture of sapwood and heartwood. Ultimately, the costumer ends up with wood material of treated and durable sapwood containing a portion of heartwood with less durability than the treated sapwood, or with wood material of untreated heartwood with accepted durability containing a portion of untreated sapwood with very low durability. In both cases the wood material contains a portion of less durable wood of which the performance cannot be more accurately predicted. A concept for an innovation in value chain towards high performance wood materials for outdoors use has recently been developed at RISE in Sweden. The proposed value chain is driven by the needs and requirements of public consumers and supported by technology innovations at sawmills.

INTRODUCTION

Wood is the most used biobased building material ever. In our modern world, strongly influenced by environmental issues and market economy, new buildings and constructions are expected to be less harmful to the environment, cost efficient, and deliver high profits while meeting customer expectations. However, cost-efficiency also accounts for long service life and low or no maintenance costs. That puts solid wood and wood-based materials under great pressure from other non biobased building materials. Variations in dimensional stability, durability and service life of wood-based building materials are important factors affecting consumers' choice. In many applications wood is successfully used with none or very little treatment. This is often the case of privately owned small constructions. The situation is different when it comes to bigger buildings and constructions, especially those executed with taxpayer's money by public consumers (i.e. authorities, municipalities, cities). The requirement from public consumers for building materials with predictable properties and service life is much harder.

Chemical wood protection allows the extension of the service life of wood, timber, wood structures and engineered wood to be used in hazardous situations where biological degradation may occur – exposure to high levels of moisture, in and above ground, and in the sea. In Europe, the use of biocides is regulated by the the Biocidal Products Regulation (BPR, Regulation (EU) 528/2012) which is putting pressure on all areas of wood protection that biocides are used. Powerful wood preservatives such as chromated copper arsenate (CCA) which is a powerful fungicide, and pentachlorophenol (PCP) which is a powerful insecticide used against termites, are forbidden in Europe but still in use in other parts of the world. These powerful wood preservers successfully confer great durability to wood to be used in extremely hazardous situations. In many countries and especially in Sweden, there still is a conflict of opinions regarding preservative treated wood. The experience of high durability and service life from older outdoors constructions treated with older generations of very potent wood preservatives and the experience of wood treated with todays' preservatives which are not as effective brings confusion to end users. Preservative treated wood is still the most cost efficient and overall best performing wood material for outdoors use, but is also among the cheapest. By letting profit come ahead of quality this sector chose to take the path of buying cheap lumber to upgrade by treatment leading to overall durable cheap products. That has also an impact on the perception of the material by the costumers. Wood may also be modified or heat treated to obtain better dimension stability and durability against biological attack (Hill, 2006). These alternative wood materials, often made of wood with specific quality requirements from outside Europe, are much more expensive than common preservative treated wood. Other wood materials for outdoor applications are also available on the market. The majority of these materials consist of untreated or partially treated wood transformed into products. Naturally rot resistant woods, many of which coming from tropical regions of the world, have become a common feature on buildings and structures outdoors. The lack of knowledge on consumers' demands and expectations on the appearance, performance and service life of wood materials leads often to misunderstandings, disappointment and economic loss. Despite the producers and resellers efforts to inform costumers about their products superior characteristics and performance, there is usually evasiveness towards the actual performance and service life of the product, and ultimately evasiveness towards guaranties.

THE CHALLENGE

To make European wood a sustainable choice of biobased building material for outdoors use, there is a need for improved wood quality only possible through changes in the value chain from harvest to final product.

Recent developments on the Swedish market show that end users are willing to pay more for higher quality and that low maintenance is pursued. This is also true for public consumers as well (i.e. cities, counties, authorities …). Focusing on public stakeholders and end users' needs and requirements instead of the needs and requirements of architects and consumers in general may create an opportunity to make protected European softwood a natural choice for biobased building material outdoors. Through several contacts and projects with public stakeholders and end users, it came to our knowledge that these groups are seeking ways to address an increased usage of wood. However, at the same time they seek a better understanding of the properties of the different wood materials available on the market to be able to make material choices. Many public end users are testing materials by themselves because of the clear lack and reliable guaranties on properties and service life of products. And that is not an easy task! The complex structure of wood and the difficulty to convert timber into homogeneous assortments of wood raw material to suit different wood protection technologies are major factors influencing the final properties of these products. The lack of demand on more suitable wood raw material contributes to the *status quo*. To improve the situation, the wood protection industry should focus more in demanding more specified wood raw material assortments from sawmills which allow for full potential in the respective wood protection technology. That would be a way to address the urge for wood materials and products with better predictable properties and performance.

Wood from coniferous trees, particularly the sapwood, has limited resistance to rot and needs to be protected through impregnation or modification to get higher durability. The heartwood has good durability and service life in a variety of applications above ground. The performance of these materials is benchmarked according to national and international standards (i.e. NTR-standards in Scandinavia). Wood protection through preservatives or modification technologies is benchmarked on the basis of standard tests of treated sapwood. However, the vast majority of wood being used for protective treatment consists of a mixture of sapwood and heartwood. Ultimately, the consumer ends up with wood material of treated and durable sapwood containing a portion of heartwood with less durability than the treated sapwood, or with wood material of untreated heartwood with accepted durability containing a portion of untreated sapwood with very low durability. In both cases, the wood material contains a portion of less durable wood that will compromise the performance. Other problems that influence performance may arise when treated wood is cut on site to fit constructions. The exposure of discontinuities in the treated wood like untreated sapwood or untreated heartwood may cause premature failure in outdoors applications. A possible way of changing this scenario is through innovation in sawmill technology, leading to the production of sawn wood consisting of 100% sapwood for further preservative treatment or modification combined with the targeting of a new market segment, the public stakeholders and end users. Trying to understand consumers' attitudes, preferences and expectations towards different types of wood materials is crucial. End users are willing to pay more for better performing wood materials. However, price and performance are not always directly correlated. Bringing together different stakeholder across the value chain is of major importance to secure and enhance the position of protected European wood as a natural choice for wood material for outdoors application.

PROPOSED INNOVATION IN VALUE CHAIN

The EU has some 177 MHa of forest and other wooded land and wood is by far the most important forest product (European Commission, 2017). Especially in northern Europe softwood forest are dominant. For example, Sweden's growing stock of conifer trees from older forest stands with larger dimension than 45 cm in diameter at breast height is steadily growing. The latest statistics show that growing stock of coarse living trees in the productive forest land 2011-2015 was 30 million m^3sk or m^3forest (SKOGSDATA 2016). Such tree assortment may be available in several northern European countries. The development of appropriate technology in order to sort out and cut wood from coarse logs in a way to meet the needs of the wood protection industry may open an opportunity for all actors involved in the production and commercialization of protected wood to deliver more robust materials and products with better predicted properties and service life. This is also expected to contribute to the reduction of maintenance costs and to safer construction designs, which are of great importance for public stakeholders and end users.

A shift in targeted market from *smaller scale private* towards *larger scale public* may provide the opportunity to reorient the market as such. After contacting several Swedish public stakeholders and end users, it became clear that these have a much higher degree of awareness about the advantages and disadvantages of using wood, and that their perception and attitude towards different wood materials are strongly influenced by political decisions. Environmental concerns seem to make this group less positive to import of wood materials and especially of non-native wood species. This group has also higher expectations on performance and cost-efficiency while handling taxpayers' money. However, private users, public stakeholders and end users are also confused regarding the properties of the wood products on the market. Taxpayers' money is being spent in expensive alternatives to preservative treated and modified wood with the promise of higher performance which is not being delivered. This means that there is room for further processing and optimisation towards more expensive but better performing protected wood products. The creation of a value chain based on the needs and expectations of public consumers may be the key to a shift in the value chain of treated wood towards high performance wood materials.

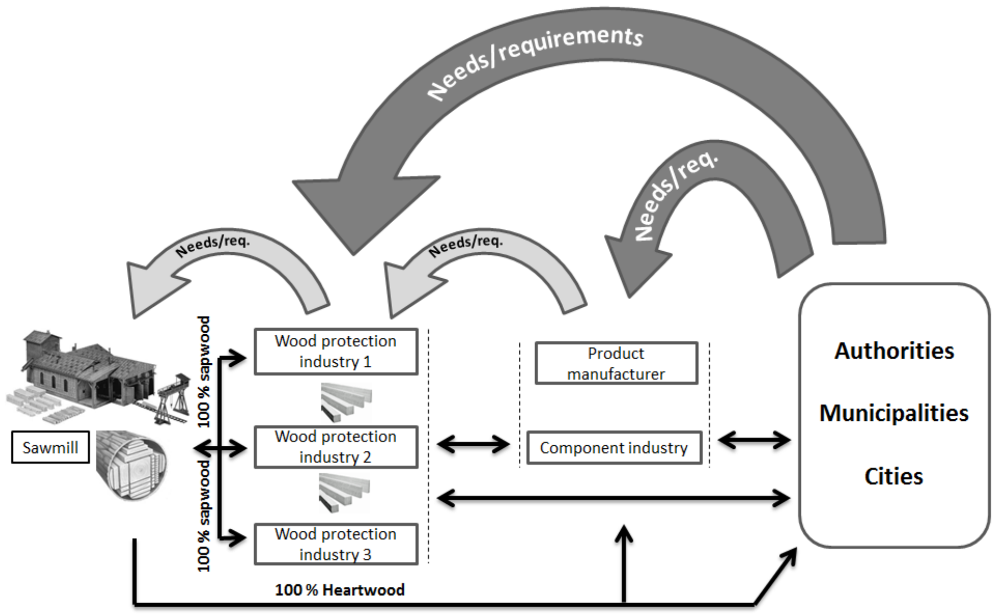

Figure 1: Proposed value chain towards high performance wood for use in public outdoor environment.

A concept for an innovation in value chain towards high performance wood materials for outdoor use has recently been developed at RISE, Sweden (Figure 1). The proposed value chain is driven by the needs and requirements of public consumers. This information is transferred to product manufacturers, component industry, and to the wood protection industry that demands specific wood assortments with varying specifications from sawmills to meet the requirements. To provide the demanded assortments sawmills invest in technology to cut large dimension logs. Sawmills provide the wood protection industry with demanded wood raw material that enables full potential in the respective technology. Heartwood elements may be commercialized directly by sawmills without the need of protective treatment. As a result, high performance wood products becomes available to public consumers, and consequently, to the market in general.

Extensive surveys have been carried out with different actors in this value chain by RISE to gather relevant knowledge and information. It became clear that more knowledge on the performance, durability and environmental impact of available wood materials and products are demand. At the same time, there is no clear picture of the public consumers' demands and expectations on the characteristics, performance and service life of wood materials among the industries involved in the value chain. It is of vital importance to understand the public consumers' attitudes towards various wood materials to be able to develop products to meet the requirements. Public consumers purchase products in large quantities, and that is the key factor that will drive the shift to high quality wood products with truly predictable properties and service life. This is something that the wood protection industry should pursue to ashore its future existence.

There is already a Swedish consortium willing to facilitate the development of the technology necessary at sawmills to enable the conversion of large dimension logs into different quality assortments. Swedish and foreign wood protection companies as well as technology and component companies are participating and showing their interests in this new concept. Several public Swedish stakeholders and end users are part of the consortium, willing to contribute and having great expectations. But, the question is if the work towards the implementation of this new concept should include other European countries as well. An innovation project with the proposed approach will offer an opportunity to increase the value of European softwood for use in outdoors applications.

CONCLUDING REMARKS

By targeting public consumers, an economical driving force is created. This driving force allows for the creation of a new value chain which will lead to an improvement in the quality of wood materials and products for outdoors use. Public stakeholders and end users are key players on building public opinion and by that influencing other markets.

To support the development of this new value chain there is the need for sawmill technology development and managing of specific issues concerning current knowledge and information on available wood materials contra novel wood materials. The first most delicate task would be to explain to the market why the novel products would be much better than what is currently available. This means that the wood protection industry will also need to experiment with new assortments in different ways to be able to answer this question. Another task would be to describe the impact on the environment of novel products treated with specific wood protection technologies and compare these to other alternative wood materials in an understandable and convincing way. Ultimately, for the benefit of the European forest sector, society and end users in general, high performance wood building materials for outdoors use made of European wood would be made available.

ACKNOWLEDGEMENTS

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Bio-based building materials: The need for evaluation of the effect on the indoor environment

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Keywords: Emission, indoor environment, bio-based building materials, VOCs

ABSTRACT

There is an increasing focus on implementing bio-based products in new building materials to improve the sustainability of future housing. The fibre resources come from wood or non-woody biomass resources combined with materials for adhesion and treatment. This result in new types of products that needs to be evaluated in terms of indoor environment and possible gas emissions: This is done to validate that the indoor environment is in no way affected by the release of potential hazarders compounds and preferential to live in. Despite their natural origin, there is still some emission of chemical compounds, especially when the substrates are further processed (*e.g.* hot-pressing) in combination with binders and glues in a composite material and possible treated with other additives such as fire retardants. This is a factor that needs to be addressed when doing research and development work on new alternative construction products and biocomposites from bio-based materials and follow-up measurements needs to be preformed in prototype housing after construction.

Thus, Centre for Wood Technology and Bio-based Materials at the Danish Technological Institute (DTI) focuses, both during the development and early use of bio-based building materials, on establishing knowledge on the quantities and qualities of the emissions from bio-based building materials. DTI was recently involved in a multi-partner, architect-driven Danish project called "The Biological House", in which a number of residual bio-based fibrous and particulate agricultural residues were utilised (upcycled) in structural and non-structural panel prototypes. The focus was to preform initial screening of "design potential" alongside technical performance. In this study, an evaluation of emissions was carried out (mainly VOCs and potential toxins such as ammonia and formaldehyde) from the prototypes made in the project (Klinke *et al*. 2016).

A demonstration house was later built in Middelfart, Denmark with a selection of commercially available bio-based materials (fibreboards, insulation materials etc.). To establish knowledge on the influence of these materials on the indoor environment post-construction, climate chamber testing of emissions according to ISO 16000-9 was performed on the main materials used in the house: boards of straw and recycled cellulose/gypsum, and wood fibre insulation. Measurements of volatile substances in the house were also performed.

Additional testing that is likewise relevant for new types of bio-based materials is sensory evaluation trials of intensity and acceptability of the material odour according to the DICL test method. In this test, an untrained panel of a minimum of 20 persons evaluate the intensity and the acceptability of the air. The median of odour intensity and acceptability is calculated. The sensory screening potential, from the bio-based panels developed in the Biological House project, showed an overall negative sensory impression of odour of all

five bio-materials tested due to the emittance of same odorous substances (aldehydes and carboxylic acids) from both the straw and the tomato stem boards tested (Klinke *et al*. 2016).

These testing methods and the data outcome is useful to designers of interior spaces in which there is often an "aesthetic" wish to show natural materials within that space and to "sell" a design concept on that basis. For instance, an unacceptable long-term odour may need to be considered at an early design phase. This is something that is highly relevant in the early stages of development, prototyping and construction with new, less familiar materials. Further, it is essential to implement these new types of materials on the market and for them to acquire a considerable market share. Then in reality contribute to an increased circular economy and meet the demand for bio-based housing materials.

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Optimal and reliable design of timber trusses considering decay degradation in aggressive environment

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Keywords: Optimisation, reliability, timber truss, probability of failure, decay.

ABSTRACT

The long term durability of timber structures depends on the effect of moisture that in combination with propitious temperature conditions and exposure time may deteriorate the timber resistance capacity. This paper focuses on the optimal design of a timber truss subjected to fungal decay. Time-variant Reliability Based-Design Optimization approach is applied to find the best optimal design with ensuring the target reliability level during the operational life by considering deterioration and the uncertainties related to material properties and loading. The performance of the optimized solution is compared, in terms of safety, with the optimal design estimated from Deterministic Design Optimization based on the partial safety factors. The overall results demonstrate that the performance degradation may be considered in the optimization process of the unprotected timber truss, the optimal and the reliable design may be ensure the target reliability level during the whole structural lifetime.

INTRODUCTION

The goal of Structural Optimization is the cost reduction and effective use of structural capacity (Šilih *et al.* 2005). Structural optimization of timber structures is usually defined with deterministic information on the timber material properties, dimensions and loads. The Deterministic Design Optimization (DDO) is based on minimizing an objective function as the structural cost subjected to geometric, stress and deflection constraints. These design conditions are considered in accordance with Eurocode 5, in order to satisfy the requirements of both the ultimate limit states (ULS) and the serviceability limit states (SLS). However, the design of timber structures involves several types of uncertainties related to material properties, structural dimensions and loading fluctuations (Köhler *et al.* 2007). All these uncertainties contribute to make the structural performances different from those expected. These uncertainties are considered in the design codes, as Eurocode 5, through the partial safety factors. The use of these partial safety factors in designing timber structures generally leads to safe structures. However, the timber resistance capacity is affected by the load duration, moisture content and biological activity. The exposition of the unprotected timber truss to high relative humidity and high moisture content of wood can lead to deterioration of timber with decay fungi. This deterioration reduces the strength capacity of timber structures and can lead to the structural failure (Brites *et al.* 2013). Unfortunately, the decay deterioration of the wood material is not appropriately taken into account in the calibration of the partial safety factors.
The rational approach consists in finding the best compromise between cost reduction and safety assurance. The safety measure is introduced with the structural reliability

theory, where is an appropriate approach to take account for uncertainties (Ditlevsen *et al.* 1995). The Reliability-Based Design Optimization (RBDO) aims to minimize the structural cost and ensure the safety requirement of the design limit states. (Aoues *et al.* 2010). The RBDO approach does not use the partial safety approach, because the parameter uncertainties are modelled as random variables. Thus, the design limit states are transformed on probabilistic constraints, where the probability measure of should be lower than the target probability of failure. When the material degradation is involved, the time dependant probability of failure is introduced in the RBDO approach. The Time-Variant Reliability-Based Design Optimization approach aims at finding the optimal design by satisfying appropriate safety level throughout the whole structure lifetime by minimizing the structural cost under time-variant reliability constraints (Aoues *et al.* 2009). This approach is applied to design optimization of an unprotected timber truss subjected to decay fungi. The overall results demonstrate that the performance deterioration of unprotected timber structures due to decay may be considered in the optimization process. The DDO approach based on the partial safety factors leads to unsafe timber truss. The TV-RBDO lead to an optimal and reliable design solution, where the target reliability level is guaranteed during the whole structural lifetime.

TIMBER DECAY MODEL

On the basis of previous in-lab experimental studies (Viitanen *et al.* 1991; Viitanen 1996), Viitanen *et al.* (2010) developed a model for the decay growth of brown rot in pine sapwood under climate variations. Such a model is divided into two processes: (a) activation process and (b) mass loss process.

Activation process

A parameter α is used as a relative measure of fungi deterioration activity. α is set initially to 0. Once it reaches the limit value α=1, the mass loss initiates. The parameter α varies with time according to:

$$\alpha(t) = \sum_{i=0}^{t} \Delta\alpha(i) \text{ with } \alpha(t) \in [0,1] \tag{1}$$

where

$$\Delta\alpha(i) = \begin{cases} \dfrac{\Delta t}{t_{crit}(RH(i),T(i))} & \text{if } T(i) > 0^{\circ}\text{C and } RH(i) > 95\% \\ -\dfrac{\Delta t}{17520} & \text{otherwise} \end{cases} \tag{2}$$

where $RH(i)$ and $T(i)$ are the i^{th} air relative humidity (in %) and temperature (ºC), respectively, Δt is the time step between two consecutive climatic records (hours), and t_{crit} (in hours) is estimated as follows:

$$t_{crit}(i) = \left[\frac{2.3T(i) + 0.035RH(i) - 0.024RH(i)T(i)}{-42.9 + 0.14T(i) + 0.45RH(i)}\right] \times 30 \times 24 \tag{3}$$

Eqn. 2 shows that $\Delta\alpha(i)$ increases when T>0ºC and RH>95%. Under dry and cold conditions $\alpha(t)$ decreases linearly from 1 to 0 in two years (17520 hours).

Mass loss process

Mass loss (in % of initial weight) occurs once the fungi activation process is reached, ($\alpha(t)$ = 1) and it is estimated as:

$$ML(t) = \sum_{i=0}^{t} \left(\frac{ML(RH(i),T(i))}{dt} \times \Delta t \times 1_{\alpha}(i) \right) \tag{4}$$

Where:

$$1_{\alpha}(i) = \begin{cases} 0 & \text{if } \; 0 \leq \alpha(i) < 1 \\ 1 & \alpha(i) = 1 \end{cases} \tag{5}$$

and

$$\frac{ML(RH(i),T(i))}{dt} = -5.96 \cdot 10^{-2} + 1.96 \cdot 10^{-4} T(i) + 6.25 \cdot 10^{-4} RH(i) \; [\text{% loss/hour}] \tag{6}$$

According to Eqn. 2, mass loss only takes place when the temperature is above 0°C and the relative humidity is above 95%. Otherwise the mass loss process is stopped.

Decay depth

The depth of decay attack is estimated on the basis of the mass loss. A simplified hypothesis is used, in that a uniform mass loss leads to uniform decay depth. Thus, the cross-section is estimated through the reduction of the breadth and the depth.

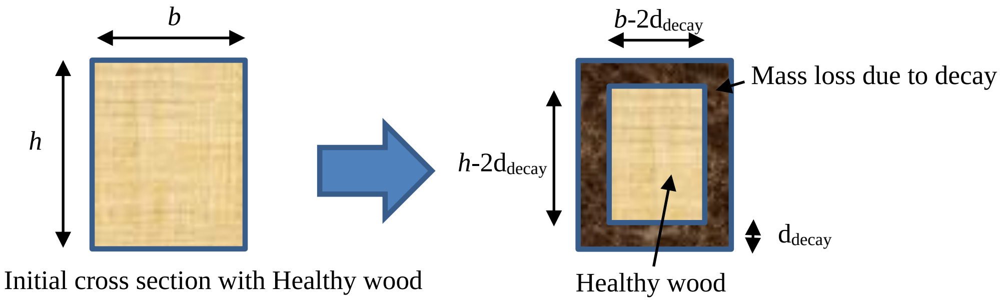

Figure 8: decay depth representation

DETERMINISTIC DESIGN OPTIMIZATION

The Deterministic Design Optimization aims at minimizing the structural cost under geometric, stress and deflection constraints, as defined in the design codes, for instance by the Eurocode 5 (NF-EN. 1995).

$$\min_{\boldsymbol{d}=\{\boldsymbol{h},\boldsymbol{b}\}} \sum_{i=1}^{n_b} \rho \, L_i \, h_i \, b_i$$
$$s.t \begin{cases} G_{ULS,i}(\boldsymbol{d}, \boldsymbol{x_k}, \boldsymbol{\gamma}) \leq 0 \\ G_{SLS,i}(\boldsymbol{d}, \boldsymbol{x_k}, \boldsymbol{\gamma}) \leq 0 \\ \psi_i(\boldsymbol{d}) \leq 0 \end{cases} \tag{7}$$

where, **d** is the vector of design variables, for rectangular cross-section **d** is composed by the depth **b** and the breadth **h** of the members, L_i is the length of the i^{th} member and ρ is the timber density. $G_{ULS,i}$ and $G_{SLS,i}$ are respectively the i^{th} Ultimate Limit State and Service Limit State. The limit stat functions are defined in terms of the design variables **d**, the characteristic values of load actions and material properties collected in the vector $\mathbf{x}_k$ and the partial safety factors γ. ψ are the feasibility constraints (e.g. upper and lower bounds of design variables).

TIME-VARIANT RELIABILITY BASED DESIGN OPTIMIZATION

For structural systems, The Time-variant Reliability Based Design Optimization is formulated as the minimization of the cost function under reliability constraints.

$$\min_{\mathbf{d}=\{\mathbf{h},\mathbf{b}\}} \sum_{i=1}^{n_b} \rho\, L_i\, h_i\, b_i \qquad s.t \begin{cases} \beta_i(\mathbf{d},\mathbf{X},\boldsymbol{t}) \geq \beta_i^{t,T_L} \forall\ t \in [0,T_L] \\ \psi_i(\mathbf{d}) \leq 0 \end{cases} \tag{8}$$

where, $\beta_i(\mathbf{d},\mathbf{X},\boldsymbol{t})$ is the reliability index at the time t taken the lifetime interval [0, T_L], β_i^{t,T_L} is the target reliability index at the allowable life time T_L, depending on the target reliability related to one year reference period by the following relation (NF-EN 1990 2003).

$$\beta_{T_L}^{c} = \Phi^{-1}(\Phi(\beta_1^t)^{T_L}) \tag{9}$$

where β_1^t is the target reliability index for an one year. For the ULS the β_1^t is taken to 4.7 and for the SLS β_1^t is taken to 2.9.

The TV-RBDO formulation given in Eqn. 8 is based on the time-variant reliability analysis, that it aims at computing the probability of failure during the whole structure lifetime, when the time dependency lies in the degradation phenomena. In this work, the SOTRA approach developed by Aoues *et al*. (2009) is used to perform the TV-RBDO problem.

RESULTS AND DISCUSSION

The design of timber roofs requires the verification of a certain number of rules resulting from the codes of practice, such as Eurocode 5. Where, these rules should satisfy given requirements related to their ultimate capacity in the ultimate limit state (ULS) and their deformation in the service limit state (SLS). In practice, roof trusses are made and composed of wood members connected by steel plates. Generally, the timber joints are considered completely flexible (free rotation hinges in the connections of the timber members). A traditional roof truss of 20 m length, and 5.77m of high, as shown in Figure 2. The distance between the next roof is 4 m.

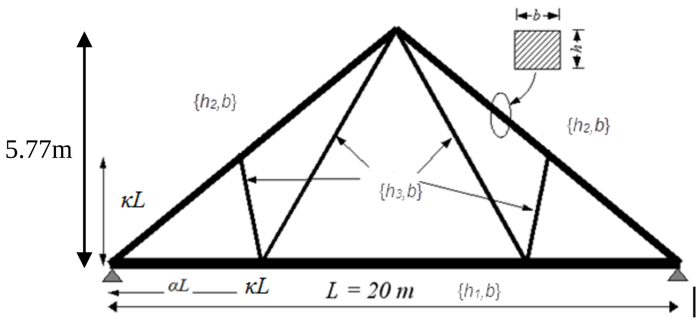

Figure 9: traditional roof truss

For plane timber truss, the ultimate limit state functions for each i^{th} member are defined as:

$$\sigma_{m,d}/f_{m,d} + \sigma_{t,0,d}/f_{t,0,d} \leq 1 \quad \text{in tension,}$$
$$\left(\frac{\sigma_{m,d}}{k_{crit} f_{m,d}}\right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z} f_{c,0,d}} \leq 1 \quad \text{in compression,} \tag{10}$$
$$\tau_d/\left(k_v f_{v,d}\right) \leq 1$$

where $\sigma_{m,d}$, $\sigma_{t,0,d}$, and $\sigma_{c,0,d}$ and are respectively the design values of bending stress, tensile stress along the grain and compressive stress along the grain. $f_{m,d}$, $f_{t,0,d}$, and $f_{c,0,d}$ are respectively the design values of bending strength, tensile strength and the compressive strength along the grain. k_{crit} and $k_{\text{c,z}}$ are respectively factors which take into account the reduced bending strength due to lateral buckling and compressive strength due to buckling about the y and z axes in accordance with Eurocode 5. τ_d is the design value of the shear stress and $f_{v,d}$ is the design value of shear strength and k_v is the reduction factor of the shear strength at the notched member. The strength design values are defined by :

$$f_d = k_{mod}\frac{f_k}{\gamma_m} \tag{11}$$

where f_d and f_k are respectively the design and the characteristic values of the strength, k_{mod} is the modification factor, which takes into account the effect of the duration of the load and the moisture content, γ_m is the partial safety factor for a material property. In the deterministic design the values for k_{mod} and γ_m are taken from Eurocode 5. The serviceability limit state functions for each i^{th} member are defined as:

$$\delta_{inst}/\delta_{inst,lim} \leq 1$$
$$\delta_{fin}/\left(\delta_{fin,lim}\right) \leq 1 \tag{12}$$

Eqn. 10 considers the following stress criteria: i) tension and bending: where the tension is parallel to the grain; ii) compression: where members are checked for compressive strength as well as for buckling; iii) shear: for all the truss members. Eqn. 12 considers the serviceability state functions corresponding to displacement of each truss members, where δ_{inst} and δ_{fin} are respectively the instantaneous deflection and the final deflection composed with the instantaneous and creep deflections. $\delta_{inst,lim}$ and $\delta_{fin,lim}$ are respectively the limit values for instantaneous and final deflections, taken respectively to L_i/300 and L_i /200 in mm for the i^{th} component.

To find the optimal design that minimizes the structural volume of the roof truss, three optimization methods are applied:

- The DDO method on the basis of the safety factors prescribed by the Eurocode 5.
- The TV-RBDO method using the SOTVRA approach considering decay model.

The depth b and breadths $\{h_1, h_2, h_3\}$ of the cross-section of the truss members are considered as design variables. The adopted random variables are presented in the Table 1, where the statistical parameters for the truss parameters, loading and material properties are given. The material parameters assume that all random variables follow lognormal distributions (Brites *et al.* 2013). The dead, snow and wind loads are considered as normal random variables. The modification factor takes into account the duration of load effect and moisture content and its value is considered as constant and equal to kmod = 0.60.

Table 1: Statistical parameters for materials and loads.

Name parameter	Characteristic value	Mean value	Coefficient of variation
f_m (MPa)	24	37.1	0.25
f_c (MPa)	21	29.7	0.20
$f_{c,90}$ (MPa)	2.5	3.5	0.20
f_t (MPa)	14	23.7	0.30
f_v (MPa)	4	5.65	0.20
E (MPa)	10908	11000	0.13
*Dead load (*kN/m²)	620	466.5	0.10
Snow (kN/m²)	1193	798.8	0.3
Wind (kN/m²)	1320	883.9	0.3

In the SOTVRA method, the target reliability for allowable lifetime T_L fixed for 30 years is estimated with Eqn. 9, corresponding to 1.60 for SLS and 3.95 for ULS limit states. For all the optimal solutions found by these methods, a time-variant reliability analysis considering the decay model is performed. The decay model is introduced in the lower part of each truss members and it was assumed as acting on the single side of the element. The time-variant reliability analysis of the ULS and SLS limit states are performed for each optimal design, where the partial safety factors are neutralized (Brites *et al*. 2013). Table 2 indicates the optimal solutions corresponding to DDO and SOTVRA methods. Figure 3 shows the time-variant reliability indexes of the optimal design of the three ULS and the SLS of the truss given of the DDO approach. The initial reliability index at $t = 0$ of the ultimate and serviceability limit states satisfy the target reliability index of one year fixed to 4.7 for the ULS and 2.9 for SLS. The use of the partial safety factors in the DDO approach allows us to ensure the reliability level at the initial time. However, when the timber degradation model is considered, the reliability indexes of the serviceability and ultimate limit state decrease, where the ULS reliability index of the rafter ($\beta_{ULS,2}$) reaches the ultimate target reliability level of 30 years (3.91) after 17 years. The SLS reliability index of the rafter (β_{SLS}) reaches the serviceability target reliability level of 30 years (1.60) after 28 years. Figure 4 shows the time-variant reliability profiles of the TV-RBDO solution, the reliability indexes for the ultimate and serviceability limit states at the initial time are checked regarding the target of one year (4.7 for ULS and 2.9 for SLS). Moreover, the reliability indexes of these limit states decrease, without reaching the target reliability level.

Table 2: Design optimization results of the roof truss.

Name parameter	DDO optimal design	TV-RBDO DDO optimal design
b (cm)	220	240
h_1 (cm)	294	320
h_2 (cm)	342	481
h_3 (cm)	293	320
Truss weight(kg)	1812	2418

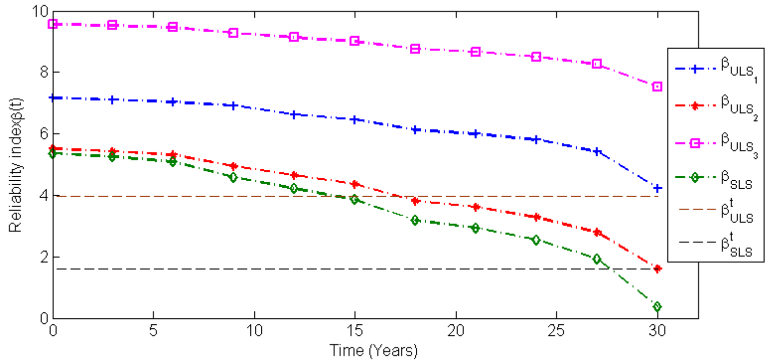

Figure 10: Time-variant reliability index of DDO optimal design.

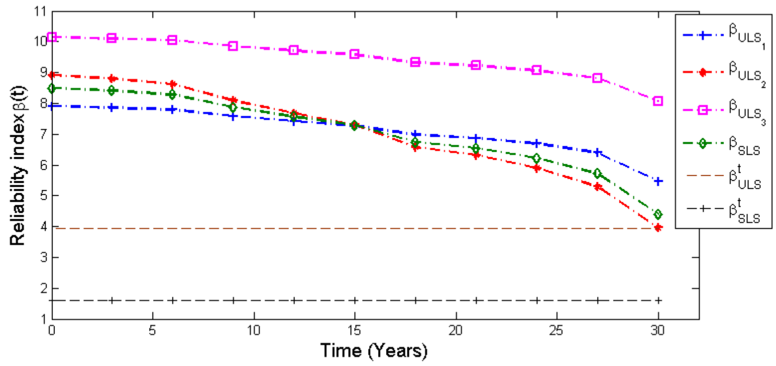

Figure 11: Time-variant reliability index of TV-RBDO optimal design.

Figure 4 shows that the TV-RBDO method gives the optimal design that satisfies the reliability lifetime requirement. In fact, the TV-RBDO design solution is more expensive, where the optimal weight is 1.33 times more expensive than the DDO weight. However, if the failure cost is introduced and considered, the total cost of the TV-RBDO may be lower, where this total cost is composed with the initial cost and the failure cost due to structural failure consequences.

CONCLUSIONS

This study focused on the design optimization of timber truss structures by accounting for uncertainties and decay deterioration. The results indicate that the TV-RBDO solution obtained by the SOTVRA approach ensures the reliability requirements of the limit states during the whole life cycle. The optimized solution needs a large material volume (larger construction costs) in comparison with DDO for the environmental exposure. The DDO based on the partial safety factors cannot guarantee a reliable and optimal design of degraded structures, because these partial safety factors are not calibrated regarding uncertainty quantification and the decay of the wood material. Thus, the use of these partial safety factors in the deterministic design optimization of degraded structures can lead to unreliable design. The TV-RBDO is the rational approach to the reliable and optimal design of timber truss with considering the decay degradation, where the time-variant reliability requirement is fulfilled.

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Creep and moisture interaction on tropical timber structures under outdoor conditions: spatial variability of mechanical parameters

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Keywords: Creep, *Baillonella Toxisperma*, Reliability, moisture interaction, Tropical climate

ABSTRACT

The present study is focused on the experimental characterization and modelling of the spatial variability of the physical-mechanical parameters (density, modulus of elasticity, compression and flexion) of a solid wood beam subjected to outdoor conditions in the south of Gabon into equatorial Region. Thus, from two Moabi wooden beams previously subjected to a long creep loading in a sheltered outdoor tropical environment, we have sectioned sections at equal distances from which we have taken samples for various mechanical tests. Thus, we were able to characterize the spatial variability of the density, the compressive strength and the flexural strength, and then the modulus of elasticity in flexion. The results obtained show a good correlation of the spatial variability of the various parameters along the beams studied. The study, which is only at its beginning, will allow the final objective to evaluate the influence of the spatial variability of these parameters in the structural response and thus in the reliability of the beams with or without cracks.

INTRODUCTION

The investigation of tropical behaviour woods in their environment is a real challenge for the prediction of the structural responses of tropical timber structures subjected to thermo-hygro-mechanical loadings. In central Africa and particularly in the equatorial region, the forest plays a key role in regulating our environment by sequestering greenhouse gases (Odounga *et al*. 2016). In the year 2000, Gabon produced over 4 million m^3 of timber (Medzegue *et al*. 2007), of which 72% was Aucoume (*Aucoumea Klaineana Pierre*) but also the Moabi species (*Baillonella Toxisperma*). These species are mainly used for plywood construction, in veneer, and finished or semi-finished products (Manfoumbi Boussougou *et al*. 2010, 2012, 2014). In addition, Moabi species is essential to the construction of timber structures including bridges, especially in this country's most remote places (Ikogou *et al*. 2016). However, with over 1900 mm of annual precipitation, around 85% relative humidity and a mean temperature near 27°C, the environmental conditions in Gabon are very arduous. Consequently, the mechanical behaviour of these species largely depends on temperature and moisture changes (Pambou Nziengui *et al*.

2016). Studying this tropical wood under cyclic loading is thus crucial to learning about the durability of timber structures designed using this species (Fournely *et al.* 2016; Pambou Nziengui *et al*. 2017).

In this case, in order to understand the mechanical behaviour of these tropical species, the study is focused on the experimental characterization and modelling of the spatial variability of the physical-mechanical parameters (density, modulus of elasticity, compression and flexion) of a solid wood beam of Moabi specie (*Baillonella Toxisperma*) subjected to outdoor conditions in the south of Gabon into equatorial Region. In the literature, the reliability methods have already applied on wood material to investigate the spatial variability of mechanical and physical parameters on wood material (Sudret and Kiureghian 2000; Ghanem 2003; Rakotovao Ravahatra *et al.* 2017). Among the methods available to represent this spatial variability, we considered the Karhunen-Lòeve Expansion or K-L (Ghanen and Spanos, 1991). For the matters of the present study, the K-L is the most accurate model to simulate a Gaussian stationary random field. In the first part, the tropical species and the experimental condition of solid beams subjected to long term loadings (creep) are described. In second time, the experimental protocol is detailed to show the proposed methodology to obtain the specimen from the solid beam. The experimental testing machine is used in bending and tensile condition. At the end the reliability analysis is applied in order to investigate the special variabilities of the mechanical parameters during bending test.

MATERIAL AND METHODS

Experimental protocol

The specimens of these tests are extracted from two beams of Moabi specie or *Baillonella Toxisperma* (dimensions: 90 x 180 x 3200 mm3) previously submitted to a creep-recovery test in sheltered outside tropical atmosphere during more than 5 years (Manfoumbi et al., 2011; 2012), see Figure 1. The experimental bending tests were performed at Franceville located in south-west of Gabon. The modelling of the experimental device corresponding to these experiments is posted in Figure 2. In fact, the experimental protocol is based on a four-points bending. The beams are loaded by pair of the same tropical species. Each pair of beam supports a load of 10 kN. This charge represents 5% of the Moabi estimated bending strength from bibliographic data (CIRAD, 2011). At the beginning of the test, the estimated moisture content average of timber is 18% for Moabi. Beams are wet and should dryed in service during the test. As shown in Figure 1, the deflection is measured with LVDT sensors in the lower beam face.

Figure 1: Beam in sheltered outside clima

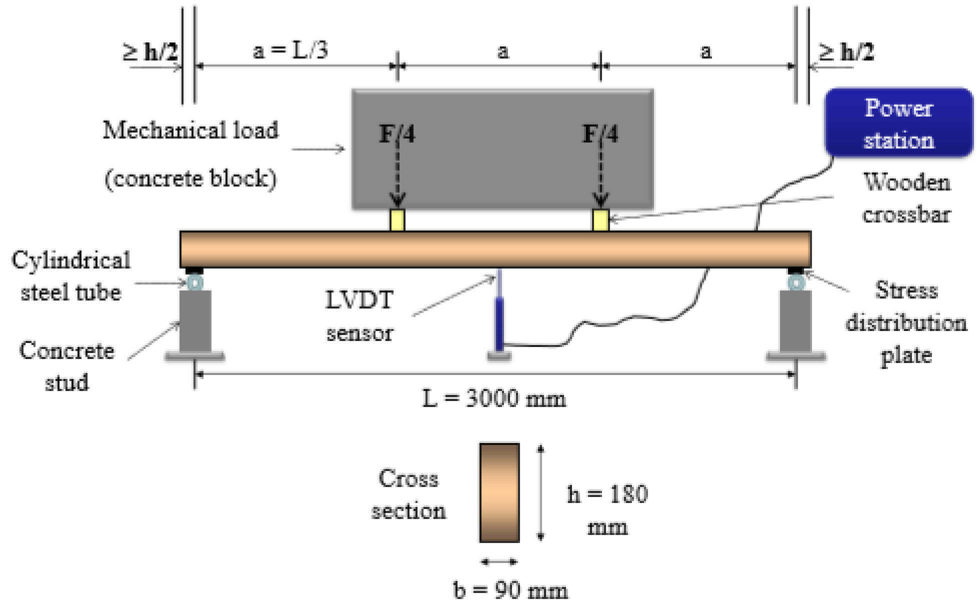
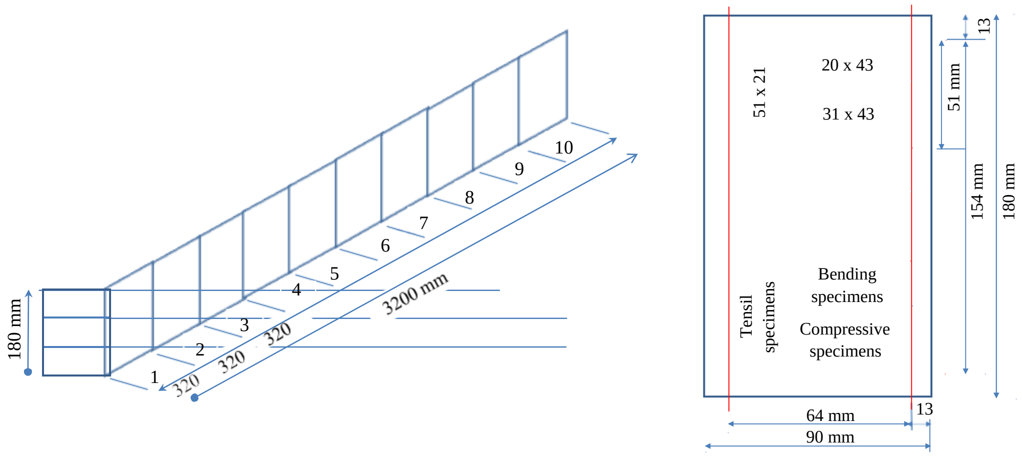


Figure 2: Experimental device

After the creep-recovery test, the beams of Moabi are cut up in 317 mm length sections, Figure 3. Those are also divided into three portions in the height direction, Figure 3 (a). From every portion, we extract least two specimens of traction, compression and bending tests. Thus, we obtain, for both beams, Figure 3 (b), the following information:

- Compressive tests: 112 specimens, section 20 x 20 x 120 (mm^3);
- Tensile tests: 104 specimens, section 10 x 10 x 100 (mm^3);
- Bending tests: 106 specimens, section 15 x 15 x 300 (mm^3), Figure 4.

The number and the dimensions of specimens (also the physical, the mechanical properties and the moisture content) are chosen according the NF EN 384 (AFNOR 2009a) and NF EN 408 (AFNOR 2009b) requirements respectively.



(a) (b)

Figure 3: (a) Modelling of spatial distribution of specimens; (b). Dimensions of specimens for bending and compressive tests.

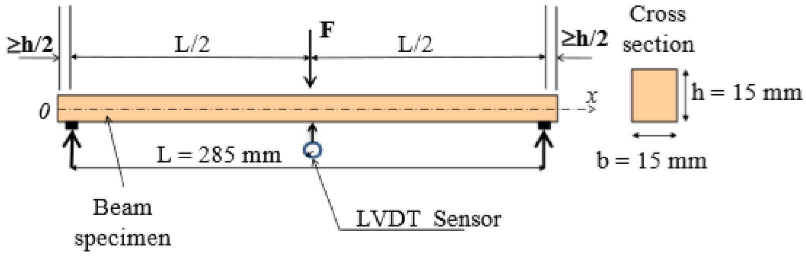


Figure 4: Modelling of experimental device for bending test.

Modelling spatial variability: the Krhunen-Loève Expension

K-L expansion is a series expansion method for the representation of random fields based on a linear combination of orthogonal functions, which are chosen as the eigen-functions resulting from the spectral decomposition of the auto covariance function of the field $C_{HH}(x, x') = \sigma(x)\sigma(x')\sigma(x, x')$ (Sudret and Kiureghian 2000), calling *H(·)* a random field. The K-L can be represented mathematically as follows:

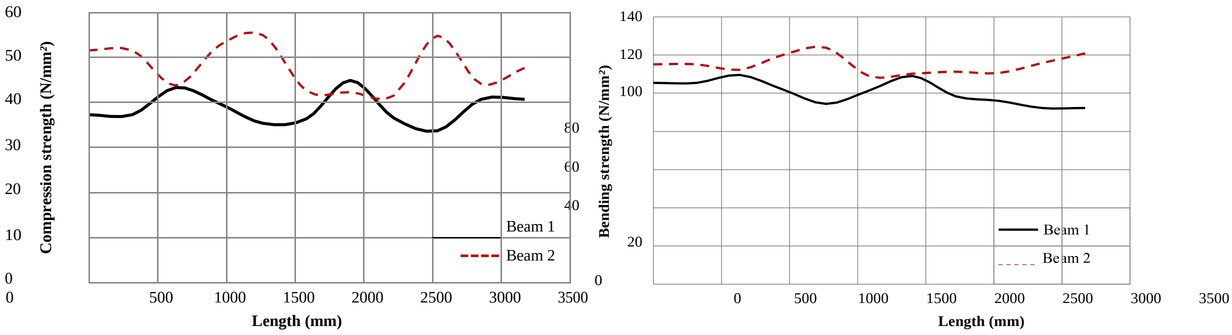
$$X(x, \theta) = \mu_X + \sigma_X \sum_{i=1}^{n} \sqrt{\lambda_i}\, \xi_i f_i(x) \qquad (1)$$

In this equation, n represents the number of terms on what is called the truncated expansion. ξ_0 is our (Gaussian) random variable after the process of standardization; λ_0 represents the eigenvalues and $f_0$the Eigen-functions of the autocorrelation function $\sigma(\Delta x)$ (Avellaneda 2017). Some authors recommend the use of an exponential correlation function when assessing the autocorrelation of materials properties like compressive strength of concrete when we work on simple geometries (Sudret and Kiureghian 2000; Rakotovao Ravahatra *et al.* 2017). Several studies had proven that the use of an exponential correlation function to represent autocorrelation of mechanical properties generally offers good results. We choose this type of function because of its proven effectiveness and the simple geometry of our 1D elements.

RESULTS AND DISCUSSION

Spatial variability of mechanical parameters

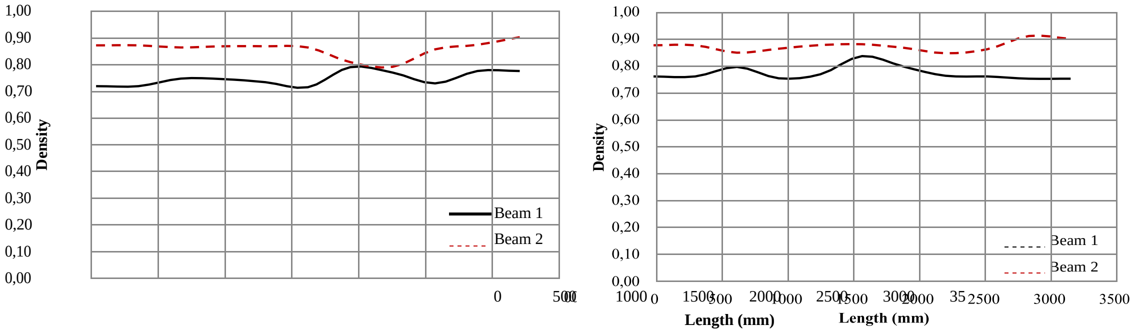
The values of the parameters, compiled by type of tests and section, are represented on curves giving the mechanic-physical parameters studied according to the special positions of samples posted in Figure 4. In this case, Figures 5 presents the spatial variabilities of strength in compressive (a) and bending (b) configurations for two beams. It observed that the loading history show some maximums at the different positions of two beams.



(a) (b)

Figure 5: Spatial variability of the physical-mechanical parameters: (a) Compressive strength; (b) bending strength.

Simultaneously, Figures 6 presents the same information in the case of density. The results show that, the beam 2 is denser than the beam 1. These results are in accordance with the results of Figures 5 and confirm a better behaviour in terms of strength and stiffness of the beam 2 compared to the beam 1. The density values of the beam 2 in bending (0.87 ± 0.020) and in compression (0.860 ± 0.030) correspond to those recommended by CIRAD (CIR, 11) which are about 0.87 ± 0.07 and by Prota (Prota 2008) about 0.82 to 0.94.



(a) (b)

Figure 6: Spatial variability of the physical-mechanical parameters: (a) Density of compression samples; (b) Density of bending test samples.

Reliability analysis of spatial variability

Figure 7 shows the trajectories of bending strength for the beam 1 and 2, according to the modelling posted in Figure 1 and 4. Figure present also the same trajectories for the compressive strength for the same beams. In the both cases, it was observed that different values were measured for a given length. As in other materials, the covariance kernel that best fitted modeling mechanical properties was the exponential kernel or the autocorrelation function. We have found values of the parameters for autocorrelation function for each timber property. Further work will focus on the propagation of uncertainty and spatial variability on the mechanical models for reliability assessment of the beams with or without cracks.

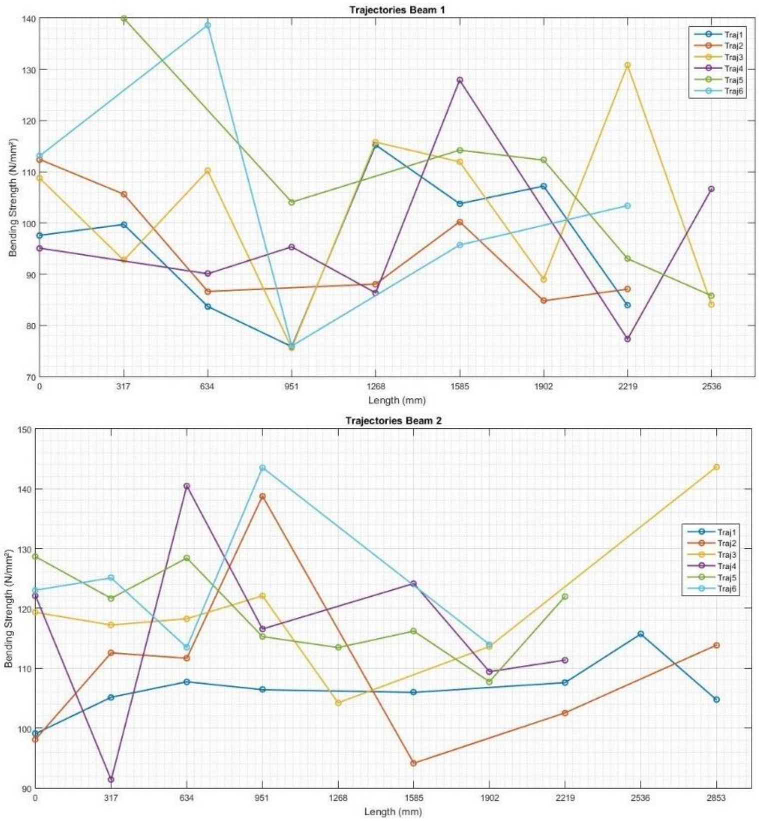


Figure 7: Bending strength trajectories for beam 1 and 2.

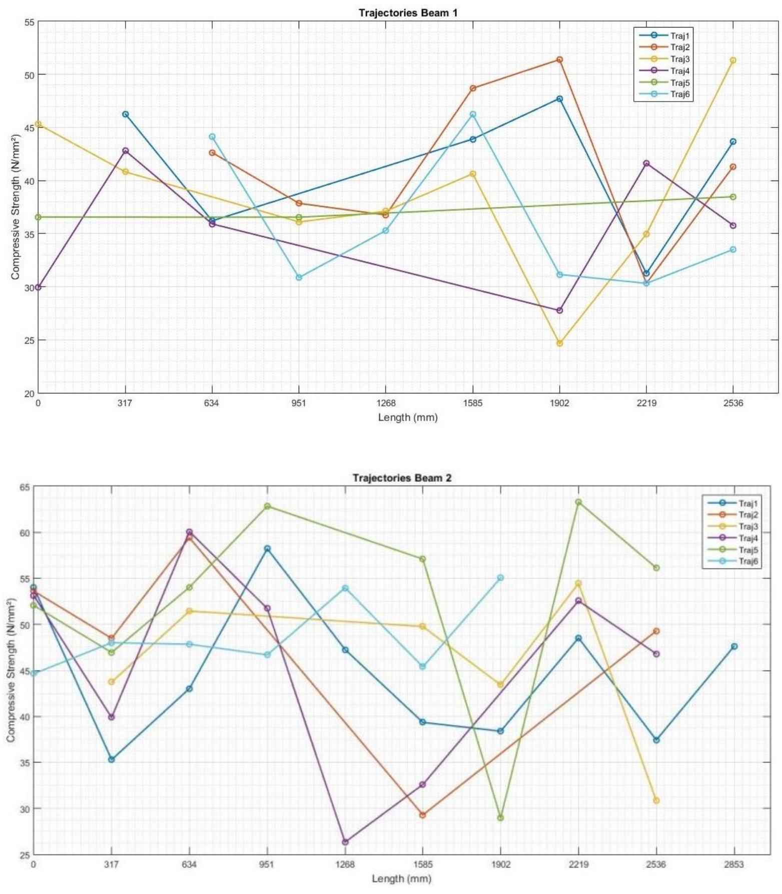


Figure 8: Compressive strength trajectories for beam 1 and 2.

CONCLUSIONS

The aim of this project was the characterization and modelling of mechanical properties of tropical wood, in the case of Moabi. Using different mathematical tools, a well known methodology and computational power, we were able to recreate those approaches used by several authors (Sudret and Kiureghian 2000; Rakotovao Ravahatra *et al.* 2017; Ghanem 2003) and give a solution to the problem we were facing. It is noted that this present work is a first attempt to represent the variability of mechanical properties of Moabi wood using Karhunen-Lòeve Expansion. That said, the future perspective of the work is to broaden its scope by comparing different methodologies for discretization and representation of random fields, like EOLE, Polynomial Chaos Expansions and others, in order to be able to say which model suits better with the case of study. We also encourage the realization of better controlled sampling and organization of data, which will allow the researches access to better information to treat the problem of study, having more satisfactory results in terms of the interactions between mechanical and physical properties.

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Surface finishing for improvement of thermally modified wood resistance to discoloration

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Keywords: thermally modified wood, surface finishing, weathering

ABSTRACT

Stability of visual appearance is of great importance for materials with decorative usage. In the present study, the efficiency of pretreatment with iron (II) sulphate and hydrogen peroxide on colour stability during outdoor exposure of thermally modified (TM) aspen and pine wood finished with non-film forming coatings was tested. Solvent-borne and water-borne as well as linseed oil based coating formulations containing transparent iron oxide pigment as UV/visible light absorber were laboratory-prepared for specimen finishing. Wood discolouration obtaining darker shade was observed suggesting that additional chromophores have been introduced as a result of pretreatment. However, after finishing with the non-film forming pigmented coatings only slight colour differences were detected between the specimens with and without pretreatment. Moreover, no difference of applied coating amount of the same formulation was found between specimens with and without pretreatment. However, considerably less discoloration was observed for the specimens with pretreatment in comparison with the specimens with the same finishing but without pretreatment, after one year of outdoor weathering. The results did not essentially differ for TM pine and aspen wood and the coating formulations used.

INTRODUCTION

Thermal modification improves wood dimensional stability and biological resistance. However, the application area of thermally modified (TM) wood is restricted by substantial loss in wood strength and usage of TM wood for non-structural purposes such as siding, decking, fences, exterior joinery and similar is mostly recommended. Besides, lighter or darker brown colour of wood acquired during thermal treatment has often been regarded as an additional advantage and application of TM wood as an alternative for tropical woods is considered (Miklečić et al. 2011).

A number of researches has established that due to chemical changes during thermal modification, TM wood discolours less/slower than unmodified wood (Ayadi et al. 2003, Miklečić et al. 2011). Nevertheless, the colour of TM wood cannot be regarded as weathering resistant as it gradually turns grey when exposed outdoors thus losing its visual appeal (Jämsa et al. 2000, Karlsson and Morén 2010). Therefore, development of protective surface finishing is important to prolong good appearance periods and reduce maintenance requirements.

It is found that the photo-discolouration of TM wood varies from that of unmodified wood (Ayadi et al. 2003, Miklečić et al. 2011). Moreover, the spectral sensitivity of TM wood is substantially red-shifted in comparison to unmodified wood and the visible region of the solar radiation up to 600 nm causes severe discoloration of TM wood (Cirule et al.

2016). Different approaches have been studied to reduce discolouration of TM wood during outdoor exposure. It is established that unpigmented coatings, even if they contain UV absorbers, cannot effectively protect TM wood against weathering (Jämsa et al. 2000, Saha et al. 2010). However, the weathering results of TM spruce treated with Fenton's reagent showed that such treatment can substantially reduce discolouration during outdoor exposure (Karlsson and Morén 2010). The objective of the present research is to test the efficiency of pretreatment with Fenton's reagent on resistance to discolouration of TM wood finished with pigmented non-film forming coatings.

EXPERIMENTAL

Aspen (*Populus tremula* L.*)* and pine (*Pinus sylvestris* L.*)* wood boards were thermally modified in a WTT pilot wood modification device in a water vapour medium under pressure for 1 h at 170ºC (aspen) and 180ºC (pine). The modified boards were cut into test specimens (370 × 90 × 25 mm) and their surfaces were planed. Half of the specimens were brush-pretreated with 10% water-solution of iron (II) sulphate ($FeSO_4 \times 7H_2O$) followed by spraying with 35% hydrogen peroxide (H_2O_2).
Three coating types were laboratory-prepared: solvent-borne (SB), water-borne (WB) and oil-based (OB). All coating types contained equal (30 %) amount of solid content. SB and WB formulations contained identical composition of the binder which included following industrially produced components: medium oil alkyd resin, long oil alkyd resin, and bodied linseed oil in weight ratio of solid mass: 2:1:1. The OB formulation included bodied linseed-oil diluted with solvent (white spirit). In order not to hide the wood grain, transparent red iron oxide pigment (4 % wt of wet coating) was included in all coating formulations as a UV/Visible light absorbing agent. Based on preliminary experiments, all coatings were brush-applied in such a quantity that no coating film was formed on the surface.
The specimens were exposed outdoors (location coordinates: N 56º58', E 24º11') on weathering racks inclined at 45° and facing south. The weathering of the specimens was regularly controlled by spectrophotometrical measurements applying Minolta CM-2500d spectrophotometer (D65, d/8º). The discolouration ΔE was calculated from CIELAB colour system parameter differences ΔL*, Δa*, Δb*.

RESULTS AND DISCUSSION

The quantity of the applied coatings did not substantially differ for TM aspen and pine wood. No disparity was recorded also for applied coating amounts for specimens with and without pretreatment. However, the loading of applied coating varied depending on the coating formulation. The spreading rate in grams (g) wet coating per square meter (m^2) for SB and OB coatings was similar and it was 188 ± 20 g/m^2 and 196 ± 12 g/m^2, respectively. Whereas 40% less coating (117 ± 5 g/m^2) was applied in case of the WB formulation to escape of excessive amount of the coating resulting in film formation on the surface. This agrees with the finding that water-borne paints penetrate less deeply into wood structure than solvent-borne paints (Rijckaert et al. 2001).
The visual observation of the TM wood surface after the pretreatment with iron (II) sulphate and hydrogen peroxide revealed that the original brown colour was changed to a darker shade, similarly as it was observed by Karlsson and Morén (2010). This is well illustrated by reflectance spectra which show reflectance decrease due to the pretreatment over the whole range of the visible light (360–740 nm) with more pronounced changes in

the range of longer wavelength suggesting that additional chromophores with characteristic absorbance in this region have been introduced (Figure 1).

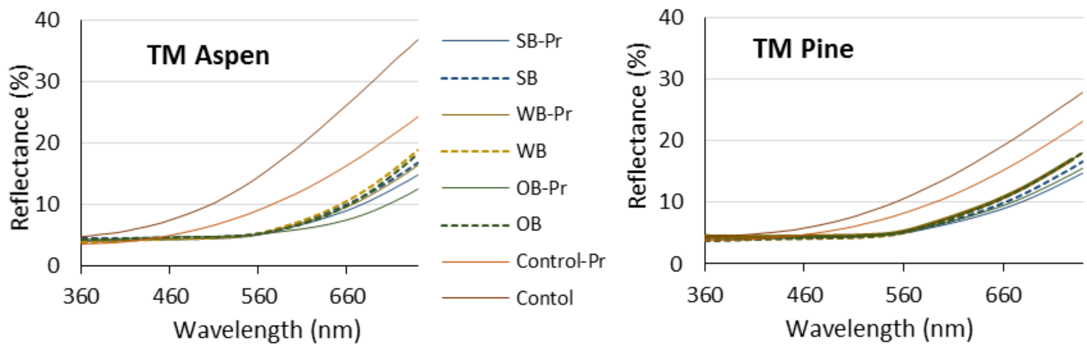

Figure 1: Reflectance spectra of untreated, pretreated and coated TM aspen and TM pine wood specimen surfaces: SB-solventborne, WB-waterborne, OB-oilbased, Pr-pretreated

Applying of the pigmented coatings also made all specimens substantially darker with the same trend in reflectance changes. However, after applying of coatings the resulting colour was quite similar for all specimens and no essential disparity in surface colour was detected between the coated specimens with and without pretreatment. Thus, the pretreatment had no much effect on the appearance of the coated specimens.
The results of the outdoor weathering for one year show that the discolouration of the specimens with pretreatment was considerably smaller in comparison with the specimens with the same finishing but without pretreatment and this tendency was observed for both tested TM wood species (Figure 2).

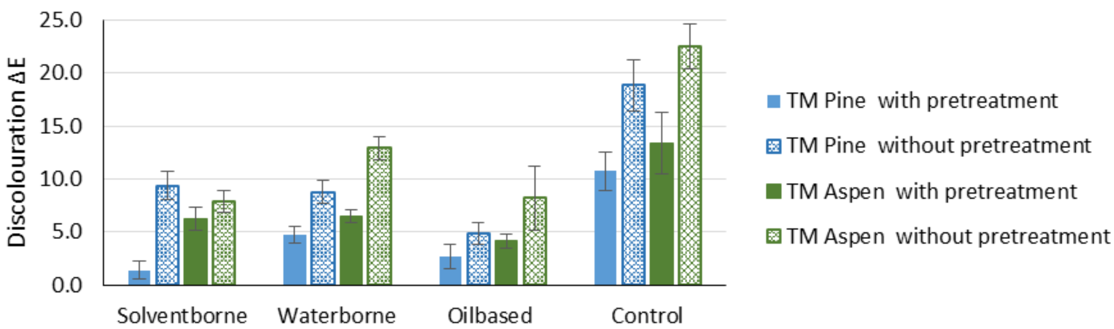

Figure 2: Discolouration of the specimens after one year outdoor exposure

The same trend was also true for the control uncoated specimens when discolouration of pretreated ones was smaller. However, while all the coated specimens had retained brown colouring after one year of outdoor exposure, the colour of all uncoated specimens had turned grey with more severe fading recorded for the specimens without pretreatment, which agrees with the tendency observed by Karlsson and Morén (2010). Comparing specimens with different coating types, slightly less discolouration was detected for specimens finished with the OB formulation. On the other hand, substantially less quantity of applied coating in the case of the WB formulation did not result in much severe discolouration. The improvement of colour stability due to the pretreatment did not differ essentially between the studied TM wood species. However, despite the first encouraging results, more prolonged weathering is required to evaluate the usefulness of the used pretreatment for reduction of TM wood discoloration during out-door exposure.

CONCLUSIONS

TM wood darkens due to pretreatment with iron (II) sulphate and hydrogen peroxide but it does not substantially affect the visual appearance of TM wood specimens when non-film forming coatings containing transparent iron oxide are used for finishing. However, the pretreatement improves TM wood colour stability during outdoor exposure as pretreated specimens discoloured considerably less during one year weathering in comparison with the specimens finished with the same coating formulation but without pretreatment.

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Development of an enzyme-linked aptamer-sorbent assay (ELASA) for the detection of a triazole fungicide in wood

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Keywords: Aptamer, ELASA, triazole

ABSTRACT

The development of sensitive methods for biocide detection gets more and more important because of their impact on human health and on the environment. However, conventional analytical methods (HPLC) are cost- and time intensive. The aim of this study was to develop a fast, simple and cost effective detection method for Tebuconazole based on aptamers. Therefore, the aim was to develop a competitive enzyme-linked aptamer-sorbent assay (ELASA) for the detection of Tebuconazole used for crop protection and in wood preservatives. Aptamers are single stranded nucleic acids that bind to a target molecule with high specificity. An aptamer that has been reported as specific for Tebuconazole by another research group was used in this study. The competitive assay was optimized in terms of concentrations, aptamer treatment, temperatures, incubation time and order of reagent addition. However, the experiments did not lead to highly repeatable results. In some experiments, an association between the signal intensity and the analyte concentration could be observed, in others not. Therefore, the ability of the aptamer to bind the analyte was assessed by experiments using graphene oxide (GO). GO is known to be able to bind DNA by π-π interaction, but the aptamer should have a lower affinity to GO than to the analyte. The detection of DNA that was bound to the analyte and therefore detached from the GO was carried out by NanoDrop measurement. Our results indicate that in the presence of GO, the aptamer did not bind the analyte. Since the aptamer-target interaction could not be clearly demonstrated the future objective is the selection of a new aptamer by the SELEX process.

INTRODUCTION

Biocides

Pesticides are widely used for protection of plants and materials against microbial infestation, insects or algae, although many of them are known to be harmful to human and animal health or to the environment. The permanently growing knowledge of the effects of pesticides leads to a permanent adaptation of statutes and regulations that define residue levels, the field of application and threshold values (e.g. EU No 2015/401, EU No 2004/115). To control the compliance of these regulations the development of new, sensitive methods for the detection of pesticides is highly important.

Tebuconazole is a systematic foliar fungicide used to control plant diseases in cereals, fruits, nuts, soybeans and vegetable crops (Cycoń *et al*., 2006; Konwick *et al*., 2006) and for wood protection (Gründlinger and Exner, 1990). The fungicidal effect of

Tebuconazole is based on its property to interfere with the ergosterol biosynthesis (Kahle *et al*., 2008; Konwick *et al*., 2006). Tebuconazole and other azoles are known to be endocrine disrupting pesticides. Different studies on rats have shown an effect on the reproductive development, virilization of female and a feminization of male offspring caused by the influence of Tebuconazole on the synthesis of steroid hormones (Hass *et al*., 2012; Taxvig *et al*., 2007).

Aptamers

Aptamers are single stranded DNA or RNA strands that can bind an analyte with high affinity and specificity by stacking of aromatic rings, electrostatic and van der Waals interactions or hydrogen bonds (Reinemann *et al.*, 2009). They can be selected *in vitro* by systematic evolution of ligands by exponential enrichment (SELEX) from a ssDNA (single stranded DNA) or RNA pool (Ellington and Szostak, 1990; Tuerk and Gold, 1990). Aptamers as molecular recognition elements can be applied in a broad range of methods like electrochemical sensors, different colorimetric or fluorometric methods or surface plasmon resonance (SPR) (Kim and Gu, 2014).
The detection method used in this study was the competitive enzyme-linked aptamer-sorbent assay (ELASA). It is comparable to the enzyme-linked immuno-sorbent assay (ELISA), where the analyte of interest can be detected using antibodies, whereas aptamers are used for ELASA. Studies report that the affinity of aptamers to the analyte can be compared with the affinity of antibodies to their antigen. Furthermore, aptamers are more stable and cost effective compared to antibodies, what makes them a promising tool for molecular recognition in the future (Jayasena, 1999; Kim and Gu, 2014). The aim of this study was the development of a competitive ELASA for the detection of Tebuconazole.

EXPERIMENTAL

Reagents

Tebuconazole ≥98% pure, NaCl, casein, 3,3',5,5'-tetramethylbenzidine (TMB), graphene oxide and methanol were purchased from Sigma Aldrich (Vienna, Austria), avidin, HRP-avidin and HRP-streptavidin were obtained from Thermo Fisher Scientific (Vienna, Austria). Streptavidin, bovine serum albumin (BSA) ≥98% were purchased from Carl Roth GmbH (Karlsruhe, Germany), aptamers and complementary sequences (HPLC grade) were synthesized by Eurofins Genomics (Ebersberg, Germany) and Na_2HPO_4 and KCl were supplied from Fluka. KH_2PO_4, H_2SO_4, Tween-80 and DMSO were purchased from Merck. All solutions were prepared using ultrapure water (Milli-Q water purification system, Millipore corporation).

Instrumentation

The ELASA was performed in 96-well high binding microtiter plates with flat bottom (Greiner bio-one, Germany), microtiter plates were washed using HydroFlex microplate washer for 96-well format (Tecan group). The absorbance was measured using Absorbance microplate reader Infinite F50/Robotic, 450 nm filter (Tecan group).

Method

The format applied was published by Gu et al. 2016 and was reported to have a low detection limit, a wide linear range, good recovery rate and repeatability for the detection of the mycotoxin ochratoxin A. They used a short, fully complementary sequence for competition with the analyte to bind to the immobilized aptamer.

The ELASA (shown in Figure 1) included the following steps:

1. Coating of the microtiter plate with avidin or streptavidin
2. Blocking of remaining binding sites with bovine serum albumin (BSA) to avoid unspecific binding
3. Immobilization of the aptamer via avidin/streptavidin-biotin binding
4. Hybridization of the biotinylated complementary sequence (CS) to the aptamer
5. Addition of Tebuconazole and competition with the CS for aptamer binding
6. Binding of the enzyme labelled avidin/streptavidin to the CS
7. Addition of tetramethylbenzidine (TMB) substrate and H_2O_2 for enzyme reaction
8. Stopping of the enzyme reaction using 0.5 M H_2SO_4
9. Measurement of the absorbance at 450 nm

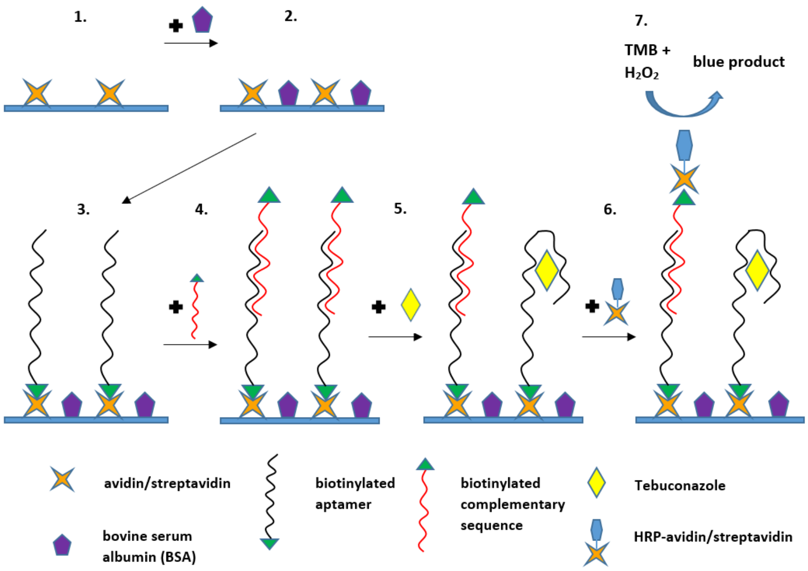

Figure 12: Illustration of the principle of the ELASA. (TMB: Tetramethylbenzidine, HRP: horseradish peroxidase).

The aptamer used in this work was found by Nguyen et al., 2014, who selected ten aptamers by graphene oxide based SELEX. Aptamer T1, that showed the highest specificity to Tebuconazole was used in this work. The sequence is shown in Table 1.

Table 1: Sequences of aptamers used in this study.

Name	Sequence
Aptamer T1	5`Biotin-TEG-CGT ACG GAA TTC GCT AGC AGC GTC CAC GAG TGT GGT GTG GAT CCG AGC TCC ACG TG-3’

position for the binding of CS
TEG= triethylene glycol spacer

The development of an ELASA is a complex matter, because of a high number of parameters that can be changed to obtain a suitable calibration curve. During practical work, several experiments were carried out, where coating reagent and concentration, blocking reagent and concentration, aptamer pre-treatment and concentration, modified complementary sequences and their concentrations have been varied for optimization.

Optimization of assay conditions for Tebuconazole standards

For the optimization of the coating step (1) several experiments were carried out at different concentrations of avidin solution (0.01-2 µg/ml) in PBS and different incubation conditions. An avidin-stock solution (1 mg/ml) was diluted in coating buffer (2.8 nM NaN_3, 15 mM Na_2CO_3, 35 mM $NaHCO_3$) and 100 µl of this solution were added to the wells of the microtiter plate and incubated overnight or over the weekend at 4°C or for 3h at room temperature (RT). After incubation, the plate was washed for three times with washing solution (PBS + 0.05% Tween-80).
For the optimization of the blocking step (2) casein and bovine serum albumin (BSA) in PBS (10 mM Na_2HPO_4, 2 mM KH_2PO_4, 2.7 mM KCl, 137 mM NaCl) were used in concentrations of 2% and 5% w/v in PBS. 200 µl were added to the wells and incubated by shaking for 1h at RT. The plate was washed for three times with washing solution.
Carrying out several experiments, the aptamer was optimized in terms of concentration (5-50 nM) and pre-treatment to guarantee an optimal folding behaviour for analyte binding. Therefore, experiments were carried out with three different treatments: a) untreated, b) denatured at 95°C for 5 min and cooled to RT or c) denatured at 95°C for 5 min and cooled on ice. It was diluted in PBS to reach the appropriate concentration and 100 µl were added to each well (3). After incubation for 30 min at RT on a shaker the plate was washed three times, followed by the addition of CS.
The concentration of CS was optimized by adding solutions between 5-50 nM of fully complementary sequence. Therefore, different experiments have been made with concentrations above and below the aptamer concentration. To facilitate the replacement of the complementary sequence by the analyte, different complementary sequences were designed, varying the base sequence, generating 2 (CSM2), 3 (CSM3), 4 (CSM4) or 5 (CSM5) mismatches between aptamer and CS or by generating a short fully complementary sequence (sFCS). The complementary sequences were diluted in PBS to the appropriate concentration and 100 µl of these dilutions were added to the wells and incubated for 30 min at RT under shaking (4).
After the incubation of the complementary sequence the plate was washed three times with washing solution and 100 µl of Tebuconazole standard solutions in PBS/MeOH ranging from 0.005-1000 µg/ml were added to the microtiter plate and incubated of 1h at RT on the shaker (5).
The plate was washed three times with washing solution and the concentration of HRP-avidin was adjusted to prevent fast colouring resulting in signal differences caused by delay in the addition of staining reagent. The concentrations of the HRP-avidin solution used for different optimization experiments lied between 0.01 and 0.5 µg/ml in PBS. 100 µl of the HRP-avidin solutions were added to each well and incubated for 30 min at RT with shaking (6). After washing for three times with washing solution 200 µl of substrate solution (25 ml citrate buffer, 500 µl TMB (in MeOH and DMSO), 100 µl 1% H_2O_2 were added to the wells. The plate was incubated for 1-20 min depending on the rate of colour development (7). The enzyme reaction was stopped by the addition of 100 µl 0.5 M H_2SO_4 (8) and the absorbance was measured at 450 nm (9).
Finally, different optimization steps were carried out by replacing avidin with streptavidin and HRP-avidin with HRP-streptavidin. The used concentrations of streptavidin were 0.5-25 µg/ml and the used HRP-streptavidin concentrations ranged from 0.05-1 µg/ml.

Verification of the affinity of the aptamer for Tebuconazole

The affinity of the aptamer for Tebuconazole was tested using graphene oxide (GO). Therefore 8 µl of 10 µM aptamer were incubated with 100 µl of 0.1 mg/ml Tebuconazole and 250 µl 2xbinding buffer (100 mM NaCl, 20 mM Tris-HCl, 2 mM $MgCl_2$, 5 mM KCl, 1 mM $CaCl_2$) for 1h at 37°C and 1400 rpm. After addition of 50 µl GO (2 mg/ml) the solutions were incubated at the same conditions again. They were centrifuged for 15 min with 14680 rpm at RT, the supernatant was collected and centrifuged again. The DNA concentration was determined using a NanoDrop instrument. To assess the DNA concentration remaining on GO a desorption step was carried out. Therefore, the GO pellet was washed with 250 µl ddH_2O, centrifuged for 15 min at 14680 rpm and the supernatant was discarded. 250 µl of 10 mM NaOH were added and incubated for 15 min at 37°C. After centrifugation, the DNA concentration in the supernatant was measured by NanoDrop.

RESULTS AND DISCUSSION

Optimization of assay conditions for Tebuconazole standards

(1) As shown in Figure 2A a concentration of 0.5 µg/ml avidin led to the highest signal and was therefore chosen as optimal concentration. Higher avidin concentrations led to a low signal (Figure 2B) caused by the binding of biotinylated CS to free avidin molecules. Consequently, the CS could not hybridize with the aptamer and thus, less CS-coupled biotin molecules were available for HRP-avidin binding. The optimal incubation time and temperature were selected to be overnight at 4°C, whereat with an incubation for 3h at RT similar results were obtained.

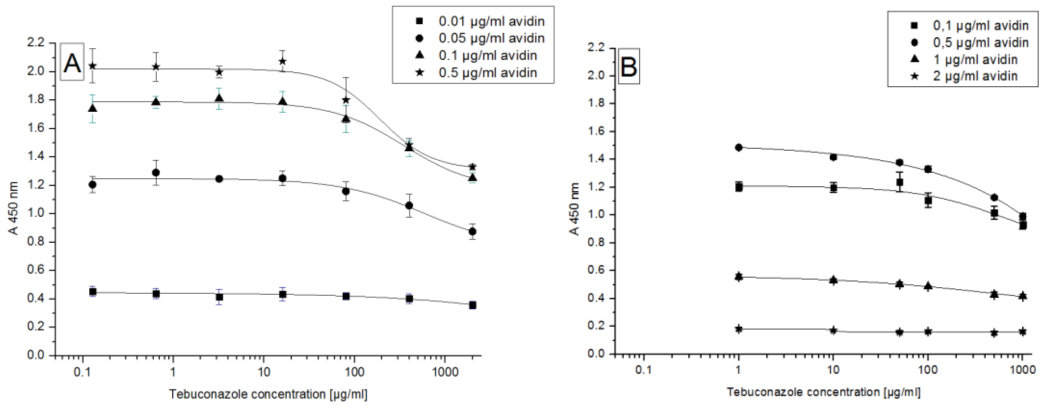

Figure 13: Influence of different avidin concentrations on the shape of calibration curve. A) 25 nM aptamer, 30 nM CS, 0.05 µg/ml HRP-avidin. B) 20 nM aptamer, 10 nM CS, 0.05 µg/ml HRP-avidin.

(2) The experiment for the optimization of the blocking step lead to no signal using casein, therefore 2% BSA in PBS (w/v) was chosen as blocking reagent (data not shown).
(3) The results obtained for the optimization of aptamer treatment showed that the kind of pre-treatment did not have an influence on the calibration curve. As shown in Figure 3A, sigmoid calibration curves could be obtained with different aptamer concentrations (25-31 nM) in a Tebuconazole concentration range from 0.05 to 1.2 µg/ml. However, when the experiment was repeated, the slope of the calibration curve was lower and the absorbance values were more scattered. Carrying out an experiment with aptamer concentrations of 5, 10, 20 and 25 nM and expanded Tebuconazole concentrations the

sigmoidal range shifted to higher standard concentrations. Since 10, 20 and 25 nM led to similar results (Figure 3B), 20 or 25 nM of aptamer were used for further experiments.

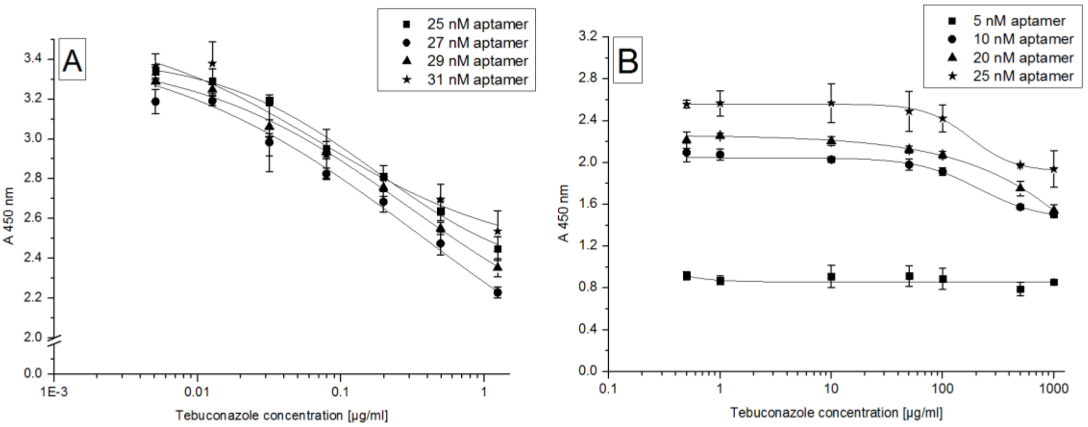

Figure 14: Influence of different aptamer concentrations on the shape of calibration curve. A) 0.5 µg/ml avidin, 34 nM CS for 25 and 27 nM aptamer, 40 nM CS for 29 and 31 nM aptamer, 0.25 µg/ml HRP-avidin. B) 0.5 µg/ml avidin, 10 nM CS, 0.05 µg/ml HRP-avidin.

(6) The experiment carried out for the adjustment of the HRP-avidin concentration resulted in a fast colouring for 0.5 and 0.1 µg/ml. Therefore, concentrations of 0.05 and 0.01 µg/ml were determined as optimal HRP-avidin concentrations.
(4) The optimization of the complementary sequence concentration resulted in suitable results for a concentration of 10 nM that was first chosen for further experiments (Figure 4A). However, the experiments showed low repeatability and the CS concentration was raised to 30 nM in later experiments.
Because of the low repeatability of previous experiments, it was assumed that the affinity of the aptamer to Tebuconazole is too low to ensure the replacement of the CS by Tebuconazole. Therefore, the affinity of the CS to the aptamer was reduced by the incorporation of mismatches. The assays where mismatched sequences were used showed clear signal differences between the sequences (Figure 4B), but again low repeatability between experiments. Table 2 shows the CSs used in this work.

Table 2: Complementary sequences containing mismatches.

Name	Sequence	Melting point [°C]
FCS	5\`Biotin-TEG-AAAACTCGGATCCACACCACACT	60.6
sFCS	5´Biotin-TEG-AAAACTCGGATCCAC	45.1
CSM2	5´Biotin-TEG-AAAACTCGGATAAACACCACACT	57.1
CSM3	5´Biotin-TEG-AAAACTCGGATAATCACCACACT	57.1
CSM4	5´Biotin-TEG-AAAACTCGGATAATAACCACACT	55.3
CSM5	5´Biotin-TEG-AAAACTCGGAAAATAACCACACT	55.3

Incorporated mismatches, TEG= triethylene glycol spacer

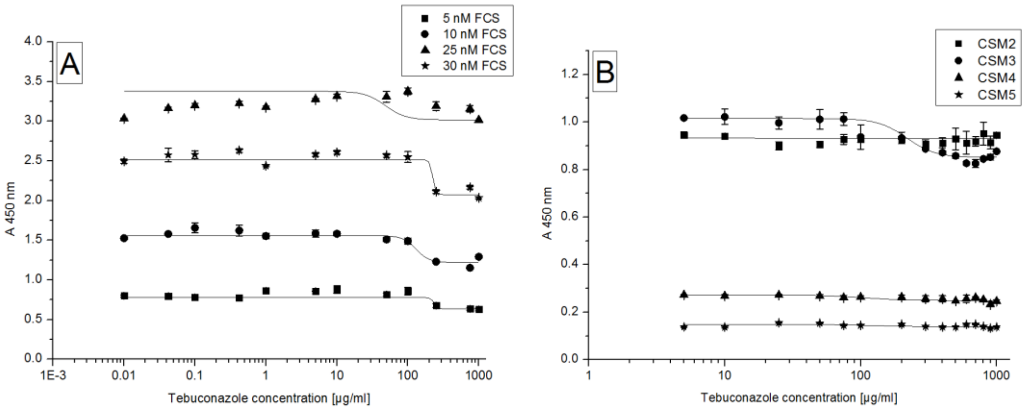

Figure 15: Influence of the complementary sequence on the shape of calibration curve. A) Influence of the fully complementary sequence (FCS), 0.5 µg/ml avidin, 25 nM aptamer, 0.05 µg/ml HRP-avidin. B) Influence of complementary sequences that contained mismatches, 0.5 µg/ml avidin, 30 nM aptamer, 50 nM CS, 0.05 µg/ml HRP-Streptavidin.

Since high absorbance values were obtained in previous experiments, which presumably were caused by unspecific binding to avidin, avidin was replaced by streptavidin (1), which is known to cause less unspecific interactions and HRP-avidin was replaced by HRP-streptavidin (6). The coating and HRP-streptavidin concentrations were optimized in addition to the concentrations of aptamer and complementary sequence (Figure 4B). However, although unspecific binding could be lowered, the repeatability remained low.

Verification of the affinity of the aptamer for Tebuconazole

The experimental conditions for the verification of the affinity of the aptamer to Tebuconazole are described in the experimental part. Figure 3 shows that aptamer could be detected in solution after incubation with Tebuconazole when no GO was added (Figure 3E). However, the figure shows that once GO is added, no aptamer could be detected in solution (Figure 3F). Therefore, the affinity of the aptamer to Tebuconazole is either too low to cause the release of the aptamer from GO or there is no interaction between them.

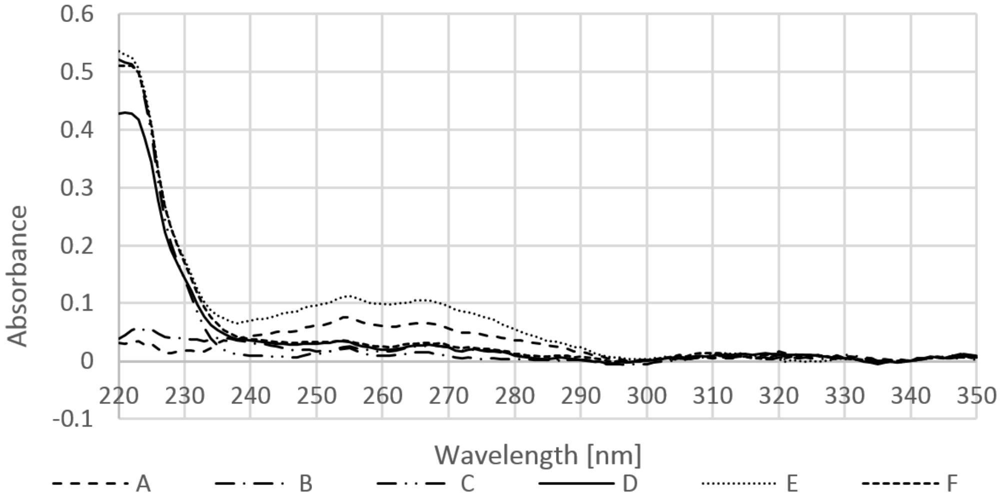

Figure 16: Absorption spectra obtained from NanoDrop measurement. A) aptamer, B) aptamer+ GO, C) Tebuconazole, D) Tebuconazole + GO, E) aptamer+ Tebuconazole, F) aptamer+ Tebuconazole+ GO

CONCLUSIONS

It was tried to develop an ELASA for the fast detection of Tebuconazole. Carrying out different optimization steps, promising results were received in some experiments, however, a repeatable method could not be developed. Additionally, only small differences of absorbance values could be obtained between high and low Tebuconazole concentrations.
Graphene oxide based experiments for the verification of the affinity of the aptamer to Tebuconazole were carried out. From the results, we concluded that the aptamer has a lower affinity to Tebuconazole than for GO, although GO had been used in the selection process of the aptamer. Therefore, the aptamer should have a higher affinity for Tebuconazole than for GO. The future prospect will be the selection of a new aptamer by the GO-SELEX process.

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Investigation of Deflection of Douglas Fir and White Fir Beams Subjected to Climatic Changes

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Keywords: environmental impacts, European species, Douglas fir, White fir

ABSTRACT

The use of wood in construction requires the mastery of several physical and mechanical mechanisms that can be limiting factors for timber structures at short or long term. Indeed, the hygroscopic behavior of wood, characterized by the sorption and diffusion processes, sometimes initiate cracks which can induce the final collapse. Experimental characterization of beam deflection of Douglas fir (*Pseudotsuga Menziesii*) and White fir (*Abies Alba* Mil) are investigated herein, especially the effect of relative humidity (RH) and temperature (T) on their behaviour. The creep tests were performed in an uncontrolled environment where the evolution of climatic parameters (RH and T) and deflection data are monitored. The results show that the deflection increases during the moistening process and the cracks propagate during the drying process.

INTRODUCTION

The literature background on timber structures show that the use of wood has benefits for the building domain (Asdrubali et al, 2017). Indeed, work on improving the mechanical properties of wood species offers many benefits, including a lower environmental cost. The benefits can also include energy savings, resource renewability, fossil fuel reduction and recycling (Macchioni *et al*, 2012). However, in the literature, wood also has some disadvantages, such as its sensitivity to water fluctuations, its multi-scale heterogeneity and its use in structures, compared with conventional civil engineering materials. Naturally, there is a link between the variations of climatic parameters (RH and T) and the propagation of crack tips in the lifetime of timbers structures. These variations, coupled with the loading, play a key role in the life process of timber structures by accelerating their aging (Teodorescu *et al*, 2017). Hence, to apprehend the mechanical behaviour of wood under the effects of climatic changes and the initiation of cracks is important to improve the durability and the design of timber structures (Pambou *et al*, 2017). In this way, the tests performed in this work on wood beams in uncontrolled environment will contribute to understand the coupled impacts of deferred loads and climatic variations. This work present the experimental impact on two softwood species of the changes of climatic parameters (RH and T) on the evolution of their deflections.

MATERIAL AND METHODS

Two species have been studied in this work, *Pseudotsuga Menziesii* (Douglas fir, PM) and *Abies Alba* Mil (white fir, AA), all the specimens have each the initial defects. The initial shape of the beams is presented in Figure 1a; each is loaded-unloaded in 4 point bending (Figure 1b) until a maximal value of 4.5kN.

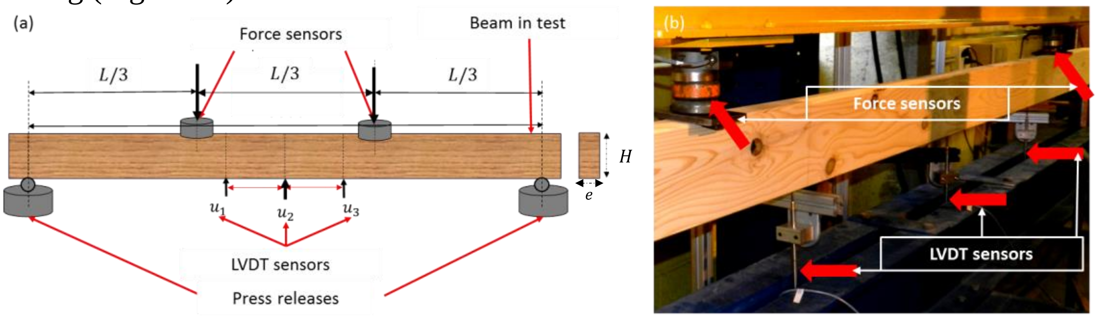

Figure 17: (a) typical beam use for the mechanical characterization; (b) beam in test;

Table 1 shows the mechanical characteristics of the beams used during the tests.

Table 3: value of Module Of Elasticity (MOE)

Beams	MOE (GPa)	Mean ± Standard deviation (GPa)
D9	14.16	14.36±0.20
D3	14.56	
S5	11.57	10.17±1.00
S9	8.98	
S1	10.77	

Figure 2 presents the different steps followed before and during the creep tests. Each beam, at first, is equipped with two tranducers (Face A and Face C) to follow the crack opening (Figure 1a), while marks spaced every 1cm allowed following the crack tip propagation during the tests (Figure 1a). Figure 2a shows the typical specimen used for the creep tests, Figure 2b presents the way that is used for loading the beam with concrete blocks, Figure 2c show the beams during the creep tests. The tests were all performed in an uncontrolled environment.

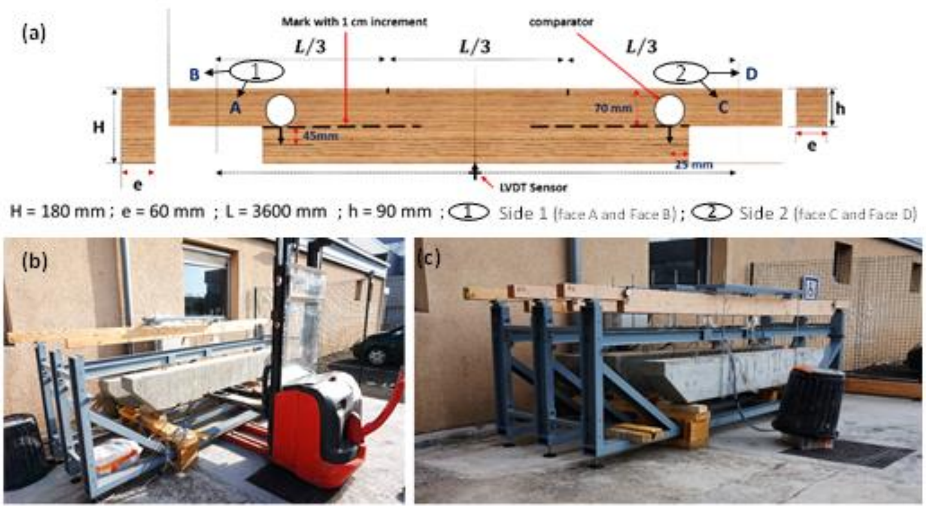

Figure 18: (a) type of specimen used; (b) application of concrete blocks; (c) specimens in creep tests.

RESULTS AND DISCUSSION

Figure 3 presents at an enlarged scale the typical impacts of climatic parameters (RH and T) on the deflection for PM (FD3) and AA (FS1). In Figures 3a and 3b, the increase of deflection corresponds to the beginning of RH rise. In both cases, the deflection increases during moistening, and during drying it seems to return to its initial position (Figures 3c and 3d). According to this figure, there are two cyclic phases of the evolution of deflection: the softening of the beam which correspond to the time $\boldsymbol{\theta}^{S1}$ and the stiffening of the beam which correspond to the time $\boldsymbol{\tau}^{S1}$.

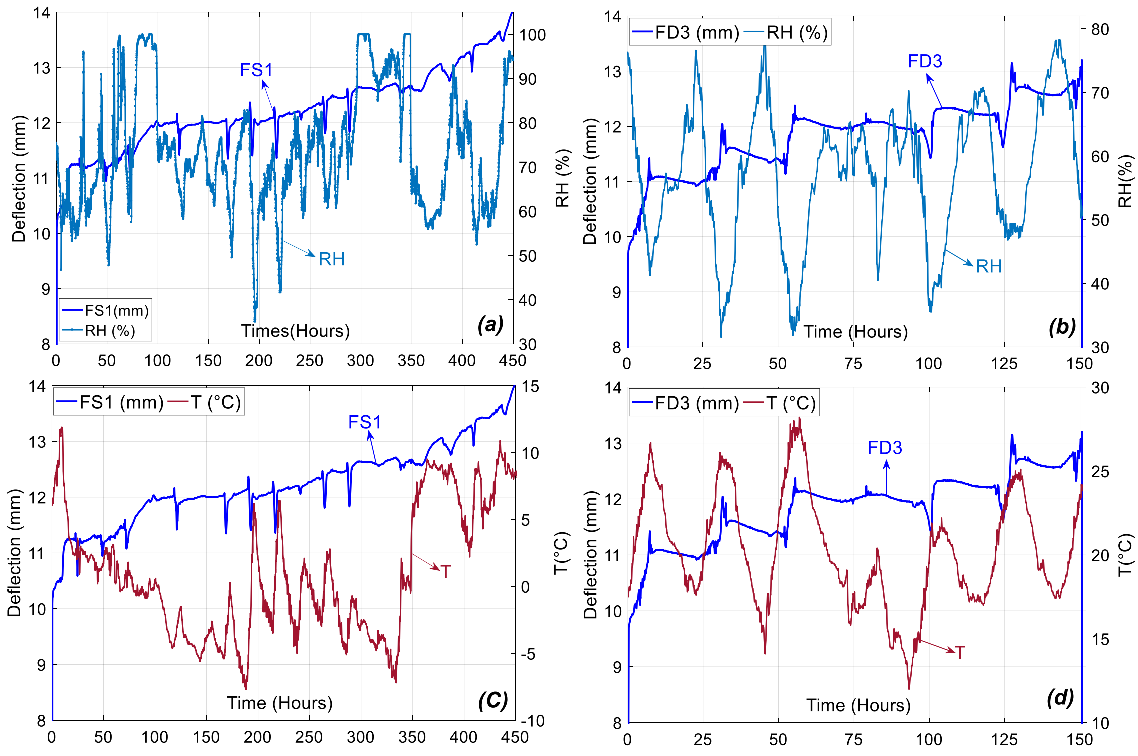

Figure 19: (a) relationship between the deflection (FS1) and RH; (b) relationship between the deflection (FD3) and RH; (c) relationship between FS1 and T; (d) relationship between FD3 and T.

Figure 4 shows the evolution of deflection (FS1) of beam S1 versus the evolution of the tips of cracks appeared during the tests.

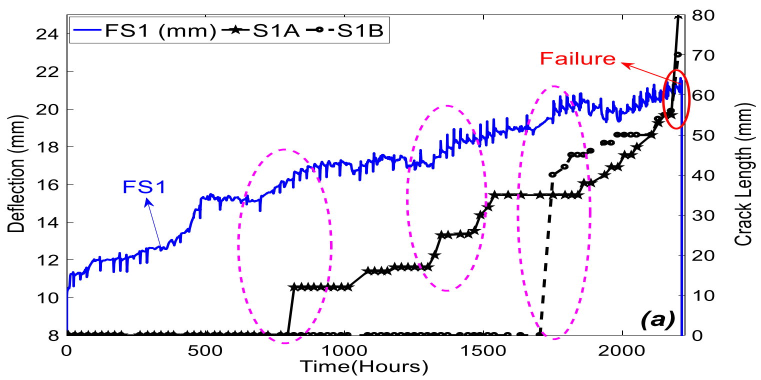

Figure 20: Evolution of deflection (FS1) versus tips of cracks appeared during the test of beam S1

By coupling the results obtained on Figure 3 and Figure 4, it appears that the deflection evolves in two different ways: during the moistening process with the increase of RH and during the drying process with the increase of cracks propagation which creates some disturbance on the evolution of deflection by amplifying its increase (Figure 4).

CONCLUSIONS

The performed experimental studies show the links between RH and T, and the cracks opening and propagation. According to the results obtained, during the moistening process (RH increase) there is a softening of wood which favours the increase of deflection. During the drying process (T increase), there is a stiffening of wood and some crack initiation. These cracks appeared during the drying process, and are also propagated during the heating cycle of beams. The consequences of such crack initiation and propagation are perceptible in the evolution of deflection. Indeed, the investigations carried out show that the crack propagation induces some disturbance of deflection by increasing quickly its evolution and the risk of beam failure. On the basis of the observations made on the tests and the results performed, the risk of failure in wood structures is grown by the increase of RH (or MC) during the moisture process and the propagation of cracks during the drying process. The next phase of this work will allow to propose an analytical model of the evolution of deflection versus the evolutions of climatic parameters (RH and T).

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Monitoring of Pressing Process in Advanced Formwork Composites - II.

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Keywords: formwork composites, pressing process, mechanical properties

ABSTRACT

The paper is aimed to the evaluation of the mechanical properties of formwork composites produced as the result of time optimization of the technological operation of their pressing. Experimental research demonstrated that three-layer composite formwork should have firm solid surface layers; birch plywood is a suitable material for this purpose. The bending strength is at least about 7.5% higher in the case of birch plywood in the composite surface layers is used compared to the spruce slats in the composite surface layers. According to the experts in application practice, it is important increase of the mechanical strength of the whole formwork composites.

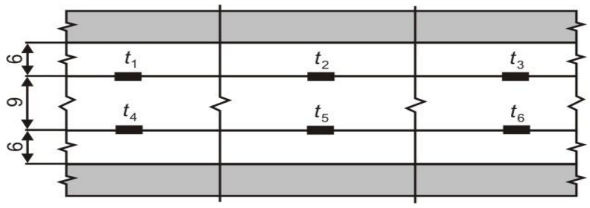
INTRODUCTION

The paper “Monitoring of Pressing Process in Advanced Formwork Composites - I.” was published in the Proceedings from the COST Action FP1303 Conference, which was held in Kranjska Gora in 2014 (ISBN 978-961-6822-22-0). The aim of our long-term research was to optimize the pressing process of wood composites used for the production of formwork. The first paper of the research (2014) was aimed to the time optimization of the technological operation of pressing. This second part of the research is aimed to the evaluation of the mechanical properties of formwork composites produced as the result of time optimization of the technological operation of their pressing.

EXPERIMENTAL

Four structures of three-layer formwork composites were produced. Spruce slats with a thickness of 9 mm were used in all structures as the core layer. The surface layer were formed by four alternatives: three-ply birch plywood with a thickness of 4 mm (PL 4), three-ply birch plywood with a thickness of 6 mm (PL 6) and OSB board with a thickness of 6 mm (OSB). RB1 is the marking for the reference type of boards with spruce slats of 6 mm in the surface layer that have been pressed in the laboratory. RB2 is the marking for the reference type of boards with spruce slats of 6 mm in the surface layer that were taken from the factory and it was just tested in the laboratory. The thickness of the final composites was 21 mm with the exception of thin birch plywood (17 mm). Moisture content of all materials during the time of experiment was $w = 10 \pm 1\%$.

In order to measure dependence of temperature upon molding time, thermocouples were installed into a glue line during the production of all composites in the laboratory. In each molding process, six pieces of constantan (copper-nickel) thermocouples were installed. The position of thermocouples is shown in Figure 1.



Press plate
Surface wood layer
Central wood layer
Surface wood layer
Press plate

Figure 1: Location of thermocouple for temperature measurement in glue line.

RESULTS AND DISCUSSION

Experimental research demonstrated that three-layer composite formwork should have firm solid surface layers. Birch plywood is a suitable material for this purpose; OSB is less suitable material for this purpose.

The bending strength is at least about 7.5% higher in the case of birch plywood in the composite surface layers compared to the spruce slats in the composite surface layers (Figure 2). According to the experts in application practice, it is important increase of the mechanical strength of the whole formwork composites.

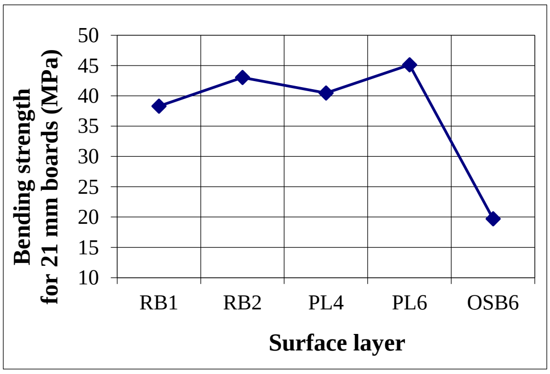


Figure 2: Bending strength of four formwork composites depending on the alternative surface layers used

All of the above mentioned bending strength properties of composite formwork tested can also be interpreted using modulus of elasticity values having identical characteristics (Figure 3).

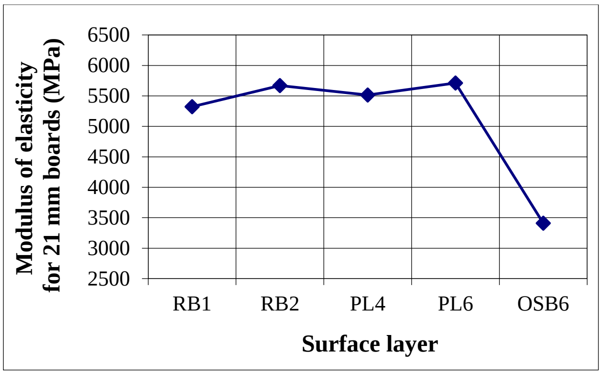


Figure 3: ***Modulus of elasticity of the four formwork composites depending on the alternative surface layers used***

Dry specimens have double strength according to the bonding quality test (EN 13354) compared to the values used in practice (Zwick/Roell Z020); specimens boiled in water did not lag very much with their strength (Figure 4).

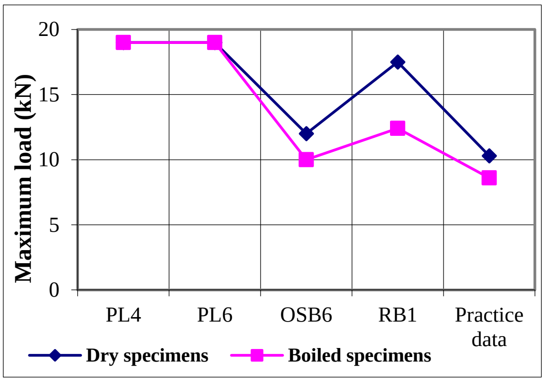


Figure 4: *Bonding test of the four formwork composites depending on the alternative surface layers used*

Thin OSB/3 is less suitable material for the surface layers of formwork composites.

The requirements of the technical standard EN 13353 have been met; requirements of the technical standard EN 13354 were almost double exceeded using time optimization of their pressing.

Modified pressing diagram for formwork composites is applicable.

CONCLUSIONS

The research was aimed to the evaluation of the mechanical properties of formwork composites produced as the result of time optimization of the technological operation of their pressing. Experimental research demonstrated that three-layer composite formwork should have firm solid surface layers; birch plywood is a suitable material for this purpose. The bending strength is at least about 7.5% higher in the case of birch plywood in the composite surface layers is used compared to the spruce slats in the composite surface layers.

ACKNOWLEDGEMENTS

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Polylactide-polydroxybutirate blends as bonding agent in multi-layered composites

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Keywords: multilayered composites, bio-based polymers, wood veneers

ABSTRACT

Structural composites based on multilayered structures have gained attention because of their good mechanical properties and overall mechanical stability because of the stress-transfer between individual layers (ply) and the bonding agent (resin). However, the composition of these materials presents challenges as the traditional resins used as bonding agent contain phenolic and formaldehyde components. These can be hazardous for humans, therefore methods that substitute or eliminate the use of these substances are of great interest for research.The present work presents the evaluation of a polylactide/polyidroxybutirate blend as bonding layer in a multilayered bio-composite. Physical-mechanical properties, such as mechanical and thermal properties of the polymer blend were analyzed as first step prior to multilayered structure processing, in order to determine the mechanical behaviour of the blend as well as the processing conditions for the composite.

INTRODUCTION

Bio-based composites are one of the most studied materials worldwide, as they are used in diverse fields, which range from packaging to aeronautics, with several studies focused also on structural applications as well as on building materials. In this sense, bio-based composites are mainly based in wood or wood-based materials. For such materials, the most common adhesives used are formaldehyde-based such as urea-formaldehyde (UF) resins, phenol-formaldehyde (PF) resins, melamine urea-formaldehyde (MUF) resin and so on, representing about 46% of formaldehyde world consumption (Rovira et al., 2016). However, although these materials present good adhesive properties, the emission of formaldehyde during the production and service life of such materials represents an important hazard to human health. This is due to formaldehyde being catalogued as a highly carcinogen product (Group 1) by the International Agency for Research on Cancer (IARC: International Agency for Research on Cancer, 2012), and as a known human carcinogen by the U.S. National Toxicology Program (NTP: National Toxicology Program, 2016). Exposure to formaldehyde may also cause eye and respiratory tract irritation, as well as skin sensitization. The main indoor sources of formaldehyde are wood-pressed products, insulation materials, paints, varnishes, household cleaning products, among others. The use of formaldehyde-based resins in wood-based products has been a major issue for the health of workers (Bono et al., 2016) but also for families during service life (Bradman et al., 2017).

In this work the study of composite materials including bio-based polymers as matrix was studied. These materials result in environmentally friendly and low-cost materials but with similar properties than those of wood or plastic-based. The blend of two or more polymers with different properties to produce composite materials is a well-known strategy to obtain specific physical properties without the need of complex polymeric system. Ideally, such blending can offer diverse structured morphologies either isotropic or anisotropic; therefore, a wide range of materials can be built bespoke. The present work presents the evaluation of a polylactide (PLA)/ polyidroxybutirate (PHB) blend as bonding layer in a multilayered bio-composite. Polymer blends were obtained through hot melt mixture inside a twin screw extruder in a constant ratio of 30 % PHB and 70 % of PLA.

EXPERIMENTAL

Composite elaboration

PLA-PHB masterbatch was blended in 75:25 w/w which has been proven a good ratio in several works (Dasan, Bhat, and Faiz 2017; Arrieta et al. 2015). Composites were manufactured using a twin-screw extruder (LabTech Engineering M250) being mixed at 180 ºC and 30 rpm and extruded with a 3-step screw having screw speed of 200-100-100 rpm and temperature profile of 185-190-195 ºC. All blends were extruded twice to ensure dispersion and then pelletized. Pellets were then press-moulded at 185 ºC and 10 bar into sheets with 250 μm thickness (S.D. = 8%).

Composite characterization

Differential scanning calorimetry (DSC) was realized in a N_2 atmosphere with a 4 stage cycle: (1) 5-10 mg samples were heated from 25 º to 250 ºC at 5 ºC min^{-1} (2) temperature was held for 3 min with constant temperature, (3) temperature was decreased to 25 ºC at 5 ºC min^{-1} and (4) reheated from 25 º to 250 ºC at 5 ºCmin^{-1}. Tensile tests of the composites were performed using MTS Insight 10 equipment provided with pneumatic clamps (Advantage Pneumatic Grips), with a speed of 5 mm min-1. Samples were prepared according to ASTM D3039 / D3039M-14. The set distance between the clamps was 20 mm. The values quoted are the average of ten measurements.

RESULTS AND DISCUSSION

Results for thermal analysis are presented in Figure 1, for further thermal processing 180 ºC were used to ensure the complete melting of the polymer blend. Moreover, melting temperature of the blend was also altered, as the calorimetric analysis shows 2 different peaks at 159 ºC and 174 ºC, which are concurrent with the melting temperatures of the used PLA (162 ºC) and PHB (177 ºC).

	Tg [ºC]	Tc [ºC]	Tm1 [ºC]	Tm2 [ºC]
PLLA-PDLA	59.05	111.95	153.3	162.41
PHB	-	54.55	177	-
PLA/PHB	61.29	96.77	159.65	174.48

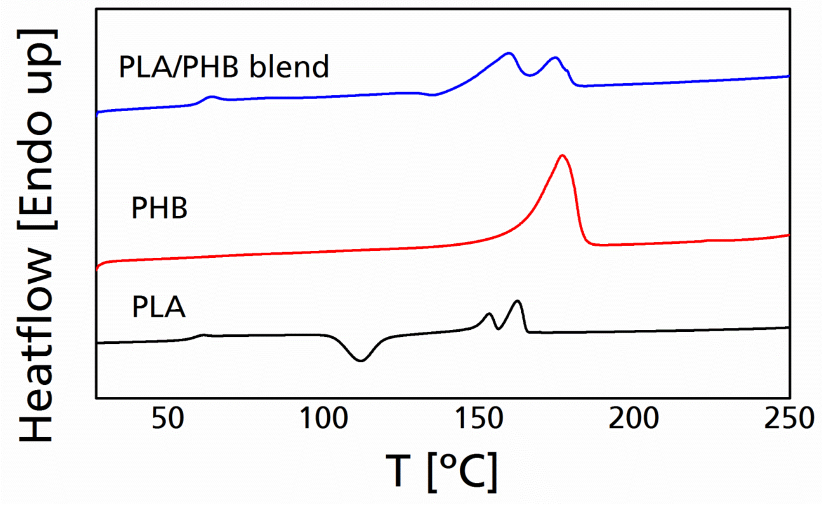

Figure 1: Temperatures of the different polymers and DSC thermograms.

Physical-mechanical properties of the polymer blend were assessed prior to the elaboration of the multilayered composites, mechanical analysis showed thay the elastic modulus of PLA-PHB blend was of 1.374 GPa, compared to the 2.69 GPa of PLA and 1.27 GPa of PHB, it can be seen that the PHB contributes significantly to this property. With the obtained information, the processing parameters for the multilayered composites could be achieved, as shown in Figure 2. Composites were prepared using a hot press, with 10 bar of nominal pressure and with processing temperature of 180 ºC. A polymer sheet was firstly prepared with a controlled thickness of 1.2 mm, following this; the sheets were put between two 0.9 mm wood veneers to be further hot pressed under controlled thickness (3 mm).

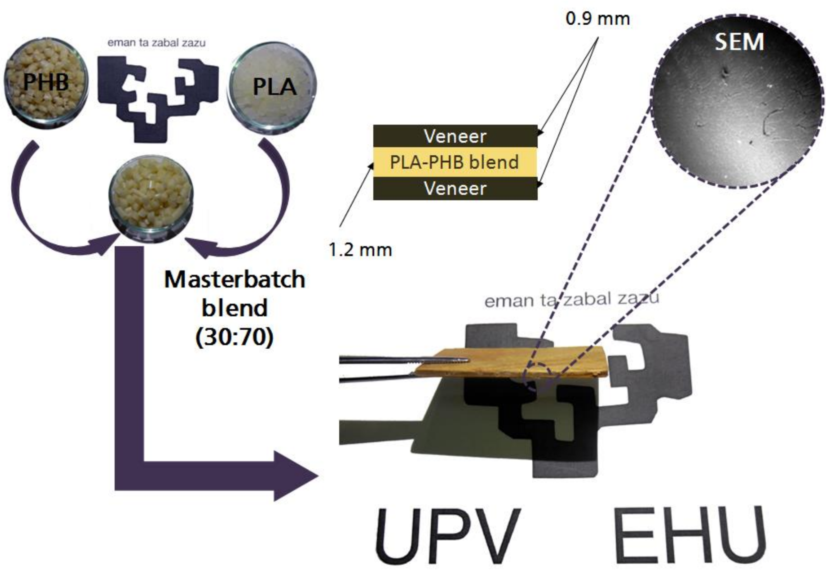

Figure 2: Schematic description of the composite elaboration.

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Surface roughness and power consumption – two criteria for wood processing optimization in furniture industry

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Keywords: alder, power consumption, processing roughness, sanding

ABSTRACT

The wooden finished products, furniture especially, represent mainly personal goods for everyday use. Consequently, such products must have a pleasant appearance, but they need to meet also the quality standards to be maintained on the market. The product quality is influenced by a rational fabrication based on some specific technologies (Pahlitzsch 1970). The sanding process is the last processing operation applied to wood surfaces before the finishing step. The selection of an optimal cutting schedule demands a synthesis of elements related to the machine-tool type, abrasive belt and technological conditions (Saloni *et al*. 2005, Varasquim *et al*. 2012). The present paper aims to identify the best cutting schedule of the sanding process applied to under-utilized wood species for a better use in furniture industry. The surface roughness and power consumption have been considered the two most important optimization criteria of the sanding process. Wood samples made of alder wood native in Romania were processed at 45º angle to the grain orientation on a wide belt sander machine. Two cutting variables and three grit sizes were used while the contact pressure was kept constant. A MicroProf FRT profilometer was employed to measure the processing roughness and for the power consumption a specific electronic device connected to the sander machine and an acquisition board were used. The study revealed that the optimal sanding schedule was obtained when using low feed speeds and light cutting depths. Findings of this work may have brief industrial application in furniture manufacturing.

INTRODUCTION

The wooden finished products, furniture especially, represent mainly personal goods for everyday use. Consequently, such products must have a pleasant appearance, but they need to meet also the quality standards to be maintained on the market. The product quality is influenced by a rational fabrication based on some specific technologies (Pahlitzsch 1970). The sanding process is the last processing operation applied to wood surfaces before the finishing step. The sanding of wooden surfaces was extensively studied during the last decade. Most of the results focused on the surface quality of sanded specimens under various influences considering the interaction of wood-machine-tool, such as: the wood species (moisture content, density), sanding parameters and conditions (pressure, belt speed, feed speed, cutting depth, processing direction), and abrasive tools (Carrano *et al*. 2002, Gurau *et al.* 2004, Salca and Hiziroglu 2012, Demirkir *et al*. 2014, Javorek *et al*. 2015, Gurau and Irle 2017). Dynamic parameters were also considered, such as the cutting force and power consumption (Saloni 2003, Javorek *et al.* 2006, Badescu *et al*. 2015). The selection of an optimal cutting schedule demands a synthesis of elements related to the machine-tool type, abrasive belt and technological conditions (Saloni *et al*. 2005, Kilic *et al.* 2006, Varasquim *et al*. 2012). The present paper aims to identify the best cutting schedule of the sanding process applied to under-utilized wood species for a better use in furniture industry. The surface roughness and the power consumption have been considered the two most important optimization criteria of the sanding process.

EXPERIMENTAL

Defect free samples of alder wood (*Alnus glutinosa* L.Gaertn) provided by a timber Company in Romania were used for the experiment. The samples having 8% moisture content were cut at dimensions of 300 by 95 by 16 mm and they were sanded at 45° angle to the wood grain orientation on a wide belt sander machine. Wooden frames were used to keep the specified sanding direction. The sander presents the following technical characteristics: abrasive belt dimensions of about 1900x1130mm, sanding speed (against the feed direction) of about 16m/s, contact pressure of about 4.5 bar and feed speed between 4 and 20m/min. Two cutting variables, such as the feed speed (8, 12, and 16 m/min) and cutting depth (0.1, 0.2, and 0.3 mm) for a sequence of three grit size abrasives (60, 100, 120 grit size) were used to sand the samples. The factorial experiment with two variables was applied.

Power measurement

To measure the power consumption a specific electronic device connected to the sander machine and an acquisition board of ADC11 type were used. The power consumption of sanding and feeding was recorded at milisecond (Figure1). The efective power during sanding was calculated as a difference between the recorded power and the power during idle running.

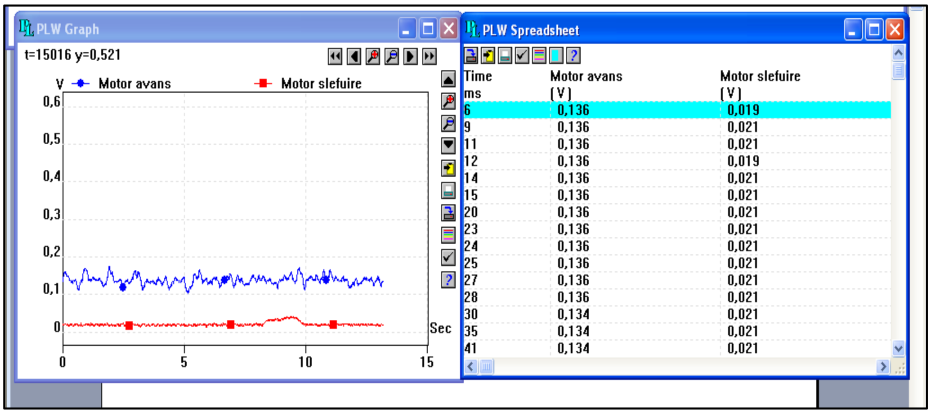

Figure 1: Display of power recordings during sanding(blue/feeding and red/sanding)

Roughness measurement

A MicroProf FRT profilometer (Figure 2) was employed to measure the processing roughness of the samples perpendicular to the processing direction with respect to the recommendations for wooden surfaces given by Gurau *et al.* (2004).

Two roughness parameters, namely *Rk* (parameter for the processing roughness evaluation) and *Rpk* (parameter for the fuzzy grain evaluation) were selected according to ISO 13565-2: 1996 standard. To filter the recorded data a Gaussian filter was automatically applied.

- 2D profile method
- 750 µm/s scanning speed
- 10000 scanned points
- 50 mm evaluation length
- 2.5 mm sampling length
- 5 µm measuring resolution

Figure 2 : MicroProf FRT roughness device with the specified scanning parameters

All data were processed by using a 2nd degree non-linear regression model with two variables.

RESULTS AND DISCUSSION

The variations of power consumption and surface roughness of alder specimens sanded at an angle of 45° to the wood grain orientation are presented in Figure 3. Generally, the power consumption during sanding increased with the increase of both cutting parameters. An almost constant trend of power consumption was noticed during the sanding at the feed speed of 8 m/min for all cutting depths, the power values did not exceed 0.5 kW. The best quality of sanded surfaces was obtained for the same cutting schedule. Under such sanding conditions, for the two roughness parameters, *Rk* and *Rpk*, values ranging from 21 to 22.3 µm and 6.4 to 9.1 µm, respectively were achieved. In case of using higher feed speeds (12 and 16 m/min) and a light cutting depth (0.1 mm), lower values for power consumption were recorded when compared to the previous case, but such results did not fit the requirements in terms of surface quality. Thus, a low feed speed and a light cutting depth represented the optimal cutting schedule.

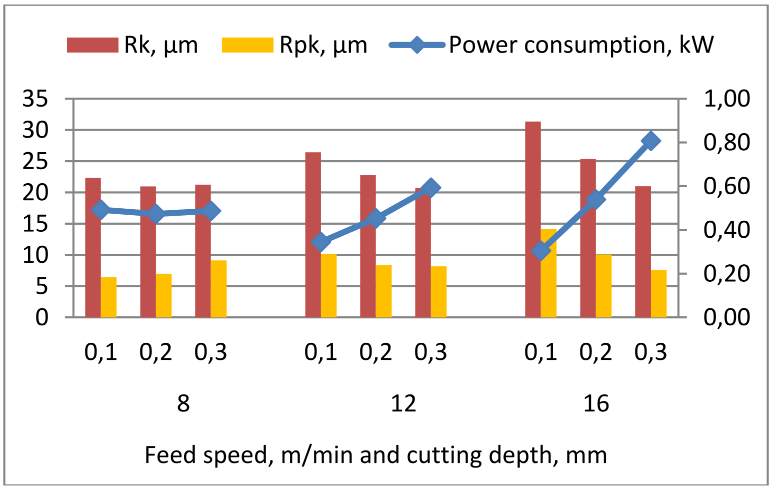

Figure 3: Variation of the surface roughness and power consumption as a function of cutting parameters

CONCLUSIONS

The study revealed that the optimal sanding schedule was obtained when using low feed speeds and light cutting depths. Findings of this work may have brief industrial application in furniture manufacturing.

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Bio-based building skin – best practice examples

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Keywords: bio-based materials, facades, best practice, sustainable architecture

ABSTRACT

The use of timber as a construction material dates back to ancient times. In regions where stone was a rare resource, timber architecture has been developed for centuries, being directly applied for various type of building. Wood, but also other bio-materials, defined here as materials derived from organic sources, become recently recognized as attractive alternatives to many traditional building materials. The push for sustainable buildings and increasing environmental awareness observed nowadays helps to reactivate bio-architecture as an interesting alternative to other construction trends. This abstract is an invitation to join this initiative and to demonstrate successful use of bio-based materials applied as a building skin.

INTRODUCTION

The expansion of bio-based products availability and their wide utilization in modern buildings is one of the components of the Europe 2020 strategies and societal challenges. Bio-based materials are considered as a building material of the 21st Century due to their sustainability and versatility. Progress in efficient wood harvesting, manufacturing, and designing techniques allows sustainable use of renewable resources. Moreover currently developed engineered wood materials, such as glued laminated timber beams and cross-laminated timber panels, allow using wood for building long-span and/or multi-storey buildings. In the same time progresses in the field of wood modification offer innovative products with enhanced properties of natural timbers. These include novel bio-based composite materials, as well as more effective and environmentally friendly protective treatments. Also other fibre-based materials (such as flax, straw, hemp, wool, jute, ramie, sisal, etc.) having low specific weight, good thermal and acoustic properties, become interesting alternative for biodegradable and recyclable building composites.

Unfortunately, very few architects and civil engineers are correctly trained in the aspects of using wood and other bio-materials as a material for building facades. Therefore, an intensive campaign within Bio4ever project was recently conducted in order to demonstrate performance of alternative solutions. The overall goal was to promote the bio-based materials and to demonstrate the best examples of architecture that use such sustainable resources (Figure 1). All the know-how developed within this project will be available for direct technology transfer in a form of technical handbook dedicated particularly to designers and contractors, providing compendium of the material properties but also inspiration for designing novel solutions.

BOOK CONCEPT

This book is an outcome of BIO4ever project, which promotes sustainable development of the wood-related construction industry, taking into consideration environmental, energy, socio-economic and cultural issues. The book will provide technical and scientific knowledge but also contribute to the public awareness, by evidencing the benefits to be gained from the knowledgeable use of bio-based materials. The book content provides an encouragement for investors, architects, contactors and demonstrates several successful examples of bio-based materials application for building skin.
State-of-the-art, as well as newest trends regarding materials selection, assembling systems, and functions of facades are briefly described. Factors influencing performance of materials are presented from various viewpoints: aesthetics, functionality and safety. Special focus is directed into performance of facades along the service life of buildings. Case-studies presenting buildings from all over the world, representing various architectonic styles and having different purpose (public/residential) are collected and classified from aesthetic perspective of architects.

Figure 1: Examples of successful application of bio-based materials for building facades (up: Paris, France, middle left: Copenhagen, Denmark, middle right: London, United Kingdom, down left: Delft, Netherlands, down right: Stara Kiszewa, Poland)

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Using self-locking carpentry joints in plywood to model dragon skin shell and its strength properties

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Keywords: plywood, dragon skin shell, self-locking, squinted scarf joint

ABSTRACT

As known through research by Forbes (2010) and others, added value in the construction industry has not grown since last 50 years, whilst in the manufacturing industry it has increased over two times. To make building industry more able to compete, it is urgent to automate construction as much as possible. Using plywood in building structures means using ordinary straight cutting and screwed connections. Today, together with CAD/CAM-software and CNC-workstation, it is possible to produce industrially more complicated prefabricated details for the building industry and thus more effective construction if the details can be mounted as LEGO on the building site without or minimal additional metallic fasteners. It can avoid fast decay of bio-based materials around the fastener because of condensation occurring under ordinary conditions.

INTRODUCTION

There are a lot of difficult designing and structural problems needed to be solved to construct shell structures, and one of them is a formwork for concreting what will be normally constructed of bio-based materials as for example plywood and the need for a special supporting system. It has led to increasing the time and material cost.
The paper will be based on a concept idea of author's PhD Thesis about self-locking dragon- skin shell system (Figure 1) and research of strength properties at the Estonian University of Life Sciences.

Figure 1: Semi-globe type dome-shell with self-locking under squinted scarf joints. (Montage and photo T.Teppand)

Some topics that were taken into consideration for working out the producing/construction technology:

A. Shell structure is the most optimal geometric shape for carrying loads;

B. If such type of shells are made of concrete, it needs to have the formwork system normally constructed of bio-based materials as for example plywood and the need of a special supporting system;
C. Plywood has very good properties especially for tension and compression to make different details for construction works and even for shear stress to use scarf-joints;
D. Using self-locking carpentry joints can avoid metallic fasteners;
E. Dragon-skin method with prefabricated details allows the construction of double-curved structures without additional supports.

CONSTRUCTION TECHNOLOGY

Details

Details were made by handicraft, whose quality was not comparable to the ones produced on CNC-Workstation of 12mm thick birch plywood „Interior“ (VU FC Novator, Russia) with help of electrical saw and hand-routers.
Three different trapezoid-shape of details has made for three levels (A, B, C) of semi-globe type dome-shell.

Carpentry joints

Self-locking system of under squinted scarf joint (Figure 2) have been worked out to mount the semi-globe type dome-shell without supporters. Bolts M5 in the hole of diameter 8mm with washers and nuts used only to fix details together to avoid sliding joints. Bolts did not take on the inside forces.

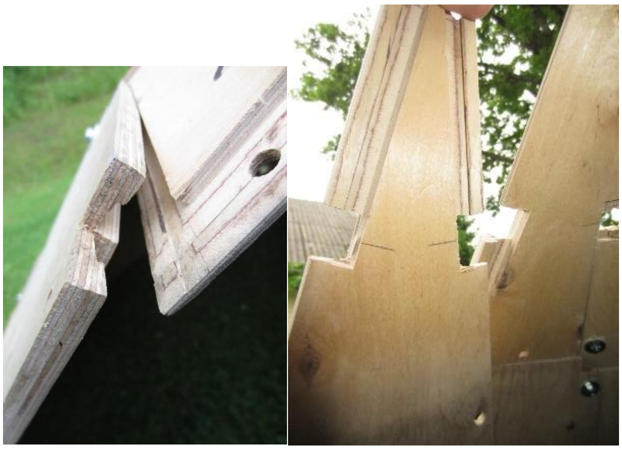

Figure 2: Under squinted scarf-joint between vertical details (on the left) and between horizontal details (on the right). (Montage and photo T.Teppand)

Self-locking works because of half- opposite joints on the vertical edges (Figure 2, right) and finally after mounting next detail to the level. Vertical locking works because of 180° turned joint after every next detail on the level (Figure 2, left).

Mounting

Mounting will start from the A (lower) level with fixing together two neighbouring details with scarf-joint until the ring is closed. By following the same procedure with details of other levels, it is possible to complete the dome-shell (Figure 3). The amount of the details and levels depend of the lower diameter and of the angle of climb of the shell.

Figure 3: Mounting the dome-shell of details with prefabricated under squinted scarf-joints at the edges). (Montage and photo T.Teppand)

EXPERIMENTAL

The strength tests were carried out on the three levels of details separately to understand the behaviour of the different parts of dome-shell model and to check the under squinted scarf joints mode of failure. Compression/load were given with the press Lucas LZM 25/200 and saved with Ahlborn Almemo 5690-2. Calculation of distributed forces was done with help of data about failure load, horizontal transition and the geometry of scarf joint. The transition was measured with help of displacement sensors Ahlborn Almemo FWA050T separately of the lower and upper parts from four directions placed after every 90 degrees (Figure 4).

Figure 4: Compressive test of A (lower) level of dome-shell. (Photo T.Teppand).

RESULTS AND DISCUSSION

Test results (Table 1) from specimen at different levels got separately and are not comparative to each other but they are good enough to go ahead with this research.

Table 1: The distributed forces of the edges under the failure load (Turk et al. 2015)

Level of the dome-shell/ specimen	Vertical angle [deg]	Failure load [kN]	Distributed forces		Behaviour of squinted scarf joint
			Peripheral tension [kN/m]	Peripheral compression [kN/m]	
A (lower)	58	22.55	236.57	-27.81	Glossed over

B (middle)	45	12.69	123.32	-6.69	Glossed over
C (upper)	44	10.53	379.27	-282.98	Broken

If all the levels are mounted together as dome-shell (Figure 1) the tension in the lower edge of one level will reduce compression in the upper edge of another.

CONCLUSIONS

After different failures during producing details of specimen became obvious that such technology will be possible only for CNC-workstations. The concept idea proved itself well and the test results showed development potential. Together with pre-stress at mounting time and after locking scarf-joints, the structure become stiff. Even partly mounted dome-shell has enough strength to carry dynamic loads (Figure 5).

Figure 5: Field test of partly mounted dome-shell. (Photo T.Teppand)

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Water sorption ability of acetylated wood assessed by mid infrared spectroscopy

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Keywords: water sorption, acetylated wood, mid infrared spectroscopy

ABSTRACT

The purpose of this study was the evaluation of the interactions that appear between water molecules and chemically modified wood structure and the mechanism of adsorption of water by mid infrared spectroscopy. The acetylated wood samples with various WPGs and untreated reference sample were kept at different RH values. Their weight gain and the spectra were recorded at each step.

By increasing the WPG values the moisture content decreased and the bands assigned to stretching vibration of water molecules also decreased in intensity.

Introduction

Wood is a hydrophilic material and its water sorption ability is an important aspect which may affect the end material performances. The variation of the moisture content in wooden material results in dimensional and conformational instability. Thus, different modification methods (thermal or chemical) have been used in order to reduce the water uptake.

By thermal methods the wood is modified, degradation of low molecular compounds and hemicelluloses takes place and a reduction of hydroxyl groups has been observed.

By chemical methods, the hydroxyl groups in the cell wall are partially substituted. This substitution reduces the number of primary sorption sites – it is generally assumed that the hydroxyl groups are the primary sorption sites (Popescu *et al*. 2014).

Mid infrared (IR) spectroscopy is a useful and simple tool applied to get rapid information on the structure of different materials, and also of wood structure (Pandey, 1999; Chen *et al*. 2010; Popescu *et al*. 2011), to evaluate the chemical changes which takes place during different treatments (Tjeerdsma and Militz, 2005; Popescu *et al*. 2013) or degradation mechanisms (Popescu *et al*. 2017) or identify the inter- and intramolecular interactions (Pandey, 1999; Popescu *et al*. 2013).

The aim of this study was to evaluate the sorption properties of acetylated wood by infrared spectroscopy and identify the possible sites where the water molecules link to the wood structure.

Materials and methods

Pine wood samples of dimension of 20x20x5 mm (radial x tangential x longitudinal) were used for the experiments. The weight percent gain (*WPG*) of the wood samples due to acetylation was determined (Table 1).

Table 1: Reference and acetylated pine wood samples

Samples	WPG %
Reference	0
Acetylated	4
	8
	13
	17

Tested wood blocks were kept 24h in the oven at 105 ºC for measuring the dried material. On a second step, the same samples were exposed over three different saturated salts solutions in a medium of 11, 40, and 76% relative humidity at 24 ºC, for a period of 48h.

The moisture content in the samples was calculated using the following equation:

$$MC(\%) = \frac{W_f - W_o}{W_o} * 100 \qquad (1)$$

where: MC – equilibrium moisture content, W_f - the weight of samples after exposure to a certain RH value, and W_o - the initial weight of the dried sample (Popescu *et al*., 2014).

The infrared spectra were recorded by means of a Alpha Bruker instrument in the spectral range 4000-400 cm-1, by diffuse reflectance method. Processing of the spectra was performed using the Grams 9.1 program (Thermo Fisher Scientific).

Results and discussion

The moisture content in the samples varied both, with the increase of the acetylation degree and the relative humidity percentage. Therefore, the extracted pine wood samples presented a maximum amount of about 27% moisture content, while for the acetylated samples were recorded values of about 22, 20, 18 and 16% moisture content at 98% RH.

The infrared spectra of the extracted (A) and acetylated (B-E) wood samples dried and presenting different moisture contents are shown in Figure 1.

As can be seen from the figure, the spectra present most futures of the wood, indicating two main regions, namely: 3800-2700 cm^{-1} assigned to hydrogen bonds stretching vibrations and to methyl and methylene groups stretching vibrations and the fingerprint region (1800-900 cm^{-1}) assigned to stretching or deformation vibrations of different groups from the main components in wood. Moreover, the increase of the intensity of the band from 1740 cm^{-1} indicates the success of acetylation process in wood samples. In infrared spectroscopy, a certain band in a spectrum is direct proportional with the amount of the groups which are vibrating giving that certain signal, therefore its increase in intensity indicates an increase of the amount of the groups in the sample.

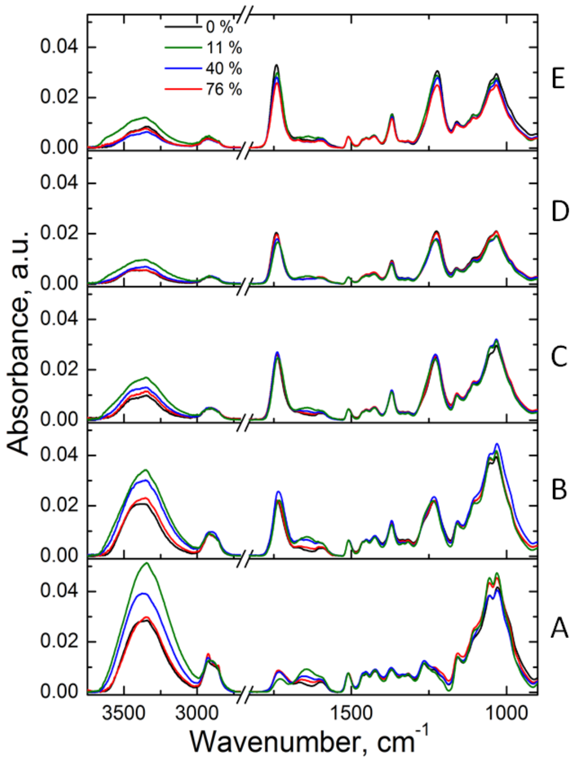

Figure 1. FT-IR spectra of the extracted and acetylated wood samples exposed to different RH values

The presence of a certain amount of water in the samples is observed by the increase of the intensity of the bands located at 3360 and 1640 cm^{-1} (assigned to OH stretching vibration from water molecules). The intensities of these bands increased proportionally with the increase of the RH values and decreased with the increase of the WPG values.

Generally, second derivative spectra improve the spectral resolution and indicate the presence of overlapped bands, therefore in order to obtain further detailed information, the second derivative spectra of the bands located in 3700-2750 cm^{-1} and 1700-1520 cm^{-1} region were performed and are presented in Figure 2a and 2b.

In Figure 2a, in the 3700-2750 cm^{-1} region the presence of water molecules is indicated by the increase in intensity of the bands from 3411, 3343 and 3278 cm^{-1} assigned to stretching vibration of O(2)H···O(6) intramolecular, O(3)H···O(5) intramolecular and O(6)H···O(3) intermolecular bonds. This is an indication that the water molecules are associated to these bonds.

In figure 2b, the band from 1650 cm^{-1} is assigned to absorbed water molecules. This band increase in intensity with the increase of the RH values, and decrease with the increase of the WPG values.

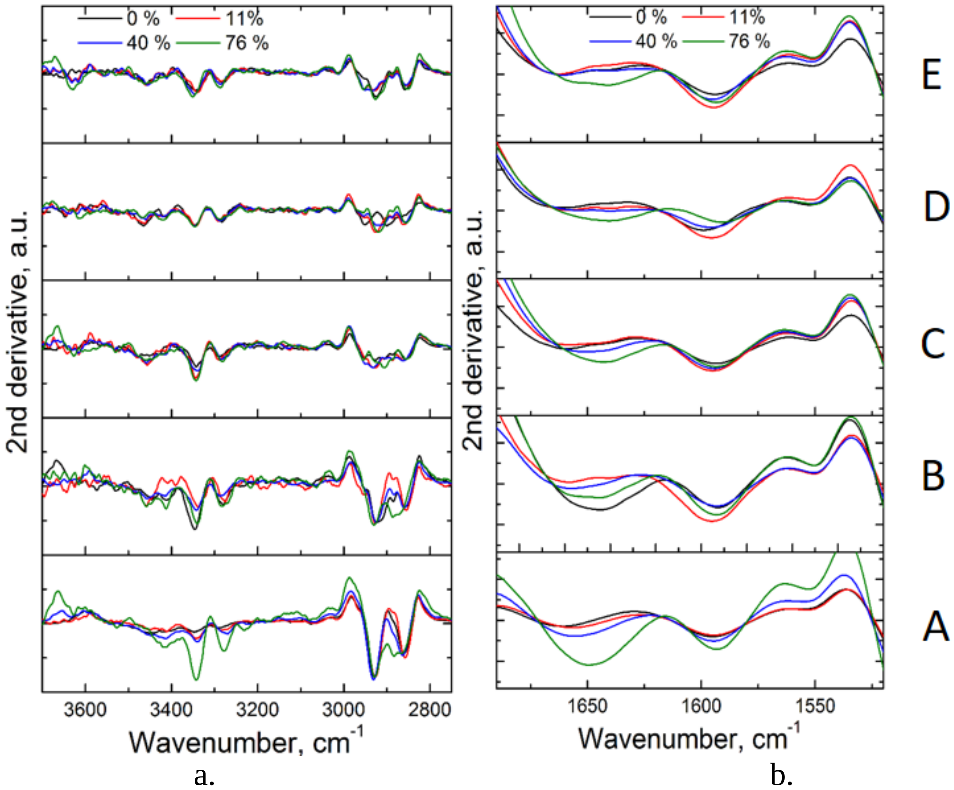

Figure 2. Second derivative spectra in the 3700 – 2750 cm^{-1} (a) and 1690 – 1520 cm^{-1} (b) regions of the extracted and acetylated wood samples exposed to different RH values

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Initial research on the natural durability of red meranti for window frames as a function of gross density

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Keywords: Window frames, Red Meranti, Natural Durability, Gross Density

ABSTRACT

Meranti is a wood species belonging to the family Dipterocarpaceae, in the genus Shorea (*Shorea* spp.). The genus has approximately 196 species with four subgenera. The subgenus Rubroshorea is commonly named red meranti (RM) and is found on the Malayan Island of Sarawak, Indonesia, with approximately 65 varieties (Symington 1943). According to Brazier (1956), the distribution of gross densities within wood of the RM group varies between 0.310 and 0.950 g/cm^3.
The aim of the project was to investigate the relationship between the gross density of RM wood used in the manufacture of window frames and its resistance to wood-destroying basidiomycete decay fungi.
Wood was sorted into ten groups according to gross densities within the range 0.330 to 0.730 g/cm^3. The wood was sourced from Mueller (1997) and the window frames from Indonesia. Wood of density 0.450 g/cm^3 was especially significant in our research.
European Norms EN 113, EN 350-1 and CEN/TC 38 N 1214 were used as evaluation criteria in our biological analyses.
Fungal exposure tests included *Coniophora puteana* (Schum.) Karst., *Gloeophyllum trabeum* (Pers.) Mur., *Tyromyces placenta* (L.: Fr.) Pilat and *Trametes versicolor* (Fr.) Ryv.. Resistance to fungal decay was determined by measuring mass loss after incubation of wood specimens with each wood decay fungus.
An inverse relationship was determined between gross density and mass loss with the fungal species *C. puteana* ad *G. trabeum.*

INTRODUCTION

Wood is a very important basic material in all cultures. Wooden structures are preserved and examined as important components of our studies of civilizations
(Schniewind et al., 1989; Unger et al., 2001; Ridout 2001). New research deals with the modification of wooden products to improve their durability (Goodel et al., 2003; Hill 2006).
The window frame industry has opened up new opportunities and applications for the use of wood, and the timber industry in South-East Asia has taken advantage of this in order to improve local economies.
Meranti is a wood species belonging to the family Dipterocarpaceae, in the genus Shorea (*Shorea* spp.). The genus has approximately 196 species with four subgenera. The subgenus Rubroshorea is commonly named red meranti (RM) and is found on the Malayan Island of Sarawak, Indonesia, with approximately 65 varieties (Symington 1943).

From an economic standpoint, the red meranti group is the most important group.
According to Brazier (1956), the distribution of gross densities within wood of the RM group varies between 0.310 and 0.950 g/cm^3, providing many opportunities for different commercial applications, but also emphasizing the need to prevent damage caused by biological organisms, especially wood decay fungi.
The Malaysian Grading Rules (MGR) for Sawn Hardwood Timber (1984) assign RM timber into groups for different uses (Geske 1987) according to gross densities, as seen in Table 1.

Table 1: Demarcation of the Red Meranti Groups after MGR (1984)

Assortment MGR (1984)	**Gross density group at u = 15 % g/cm^3**
Light Red Meranti (LRM)	0.385 … 0.755
Dark Red Meranti (DRM)	0.560 … 0.865
Red Balau	0.800 … 0.880

The systematic determination of the gross density groups can be performed using both macroscopic and microscopic methods of analysis (Fengel and Wegener, 1984; Gottwald and Parameswaran, 1966).

A cross section of meranti (*Shorea* spp.), as seen using transmitted light microscopy, is seen in Figure 1.

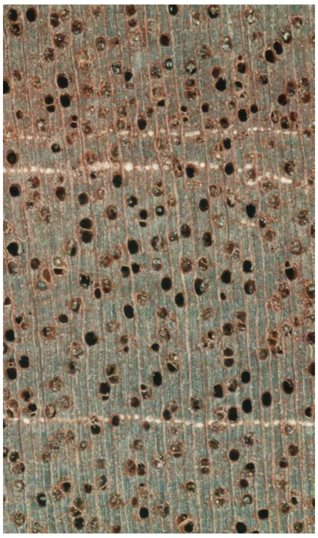

Figure 1: Cross section of meranti (Shorea spp.). Photo: Schmidt, J.

EXPERIMENTAL

Materials

<u>Sampling of the red meranti group</u>

Red meranti window frames were produced – cutting, sorting and bonding – in Indonesia. The triple laminates came from the Holz Henkel factory in Göttingen (Mueller 1997).

<u>Sampling of the reference wood species</u>

Studies on the resistance of new wood species or wood products to fungal decay, using EN 350-1 and CEN/ TC 38 N 1214 testing guidelines, almost always include, as controls, known wood species whose behaviour in such tests is predictable and well known. The degree of destruction is measured by the mass loss of wood after fungal attack and is well defined for every wood species in the abovementioned testing norms.
We used the following reference wood species (Table 2):

Table 2: Durabilty classes of reference wood species in EN 350-2

Reference wood species	**Durability Class**
Oak	2
Pine heartwood	3 to 4
Beech	5
Pine sapwood	5 [1)]

1) Sapwood is highly suscetible to fungal attack.

For coniferous wood species, pine sapwood is used as the benchmark. Beech is used as the reference for deciduous wood.
EN 113 and EN 350-1 both describe the criteria for mass loss in order for the biological decay tests to be acceptable.

Fungi species
Table 3 describes the fungal species and strains used in the decay tests (Schmidt 2003).

Table 3: Fungal test kinds for the research

Latin term	**Strain number**
Coniophora cerebella (Schum.) Karst.	BAM Ebw 15
Gloeophyllum trabeum (Pers.) Mur.	BAM Ebw 109
Tyromyces placenta (L.:Fr.) Pilat	FPRL 280
Trametes versicolor (Fr.) Ryv.	CTB 863 A

Methods

Determination of the natural durability of red meranti
The natural durability of wood is a measure of its resistance against attack by insects and fungi. EN 350-1 provides a description of the different durability classes (DC 1 to DC 5). EN 350-2 provides descriptions of the durability of the most important commercial wood species against different pests. Natural durability is normally not strongly related to gross density; for example beech with a gross density of 0,710 g/ cm^3 is not durable. Beech is rated in durability class DC 5.
The different density classes of red meranti provide an exception to the general rule. The durability of high density dark red meranti is better than that of light red meranti.
The Quality assurance body for wood window frames in Germany requires that light red meranti (LRM) have a gross density of 0.450 g/cm^3. In the Malaysian Grading Rules for Sawn Hardwood Timber (1984), dark red meranti (DRM) must have a gross density of 0.865 g/cm^3. Within our project, we worked with 10 groups of different gross densities varying from 0.330 g/cm^3 to 0.730 g/cm^3, as seen in Table 4.

Table 4: Arrangement of the gross densities groups of RM in g/cm^3

0,360 ↓ 0,370	**0,390** ↓ 0,400	**0,420** ↓ 0,430	**0,450** ↓ 0,460	**0,490** ↓ 0,500	**0,550** ↓ 0,560	**0,600** ↓ 0,620	**0,630** ↓ 0,640	**0,700** ↓ 0,730

The prepared laminates of Mueller (1997) included the practical assortment for window frames of some kinds of the red meranti group (as described in the Introduction). From these prepared laminates, test specimens for the biological trials were cut with dimensions of 15 mm x 25 mm x 50 mm. The texture of the test specimens is described in EN 113 and CEN/ TC 38 N 1214.

The density of a material is the relation of the mass to the volume. The gross densities of the test specimens were determined after air-conditioning in a special room at 20°C and 65% relative humidity for 4 weeks to arrive at a wood moisture content of u = 12% (Niemz 1993). The mass of the test specimens was measured to the nearest 0.001g and lengths of the edges were measured to the nearest 0.001mm. All data were recorded twice.

Biological experiments

16 test specimens per fungus were used for both the wood of the red meranti group as well as for the reference wood species. The amount and distribution of all test specimens in the gross density groups and the different fungi were also determined. Additional wood specimens were prepared for the kiln-dried determination of theoretical dry weights.
All test specimens were sterilised using ionizing radiations - 117 h with 20.82 kGy - at the Hahn-Meitner-lnstitut in Berlin. Test specimens were incubated before sterilization in polyethylene foil.
The biological experiments were carried out for 16 weeks in a special dark chamber at 22°C and at 70% relative humidity. In all, a total of 768 test specimens were incubated.
At the end of the incubation period, the intensity of mycelial growth on the surface of the test specimens was estimated using a special schema.

Calculations of the biological experiments

The mass of the test specimens was determined with a precision of 0.001g directly after the removal from the Kolledisc. The dry mass of each test specimen at the end of the trial in ($M_{o/End}$) was determined after drying at 103°C. The moisture content of each test specimen at the end of the trial (U_{End}) was calculated and the water content ($M_{U/End}$ – $M_{o/end}$) stated as percent of the dry mass. The test specimens for the scientific trials could not be dried by heating; sterilization was accomplished using ionizing radiations. Special moisture content specimens were employed for the determination of mass loss of the test specimens after the incubation period with fungi. After drying of the MC test specimens the special wood moisture (m_u — m_0) can be calculated. This is the special MC index according to CEN/ TC 38 N 12 14.

Validity of the biological experiments

Special parameters are necessary for publishing and accepting the biological results of experiments with new wood species. First, the biological activity of the fungal strains must be verified. For every reference wood and for every test fungus the main mass loss after 16 weeks incubation must be not lower than 20%, as explained in CEN/ TC 38 N 1214. For *Coniophora cerebella* the main mass loss after 16 weeks incubation must be at least 30%.
After 16 weeks, test specimens with wood moisture contents greater than 80% or less than 25% were sorted out. Other special requirements are also explained in CEN/ TC 38 N 1214.

Classification of the test results

EN 113 provides guidance on determinations of mass losses of wood of reference and experimental types. EN 350-1 provides guidance on determination of wood durability class (DC), as a quotient of both.
According to CEN/ TC 38 N 1214, the natural durability of the tested wood species is described by the median mass loss (Van Acker et al 1999). Table 5 gives an overview of the classification.

Table 5: Durability classes after EN 350-1 and CEN/ TC 38 N 1214

Durability Class (DC)	Description	EN 350-1 Value "X"	CEN/ TC 38 N 1214 Mass loss (%)
1	Extremely durable	X ≤ 0.15	≤ 5
2	Durable	X < 0.15 to ≤ 0.30	> 5 to ≤ 10
3	Moderately durable	X < 0.30 to ≤ 0.60	> 10 to ≤ 15
4	Somewhat durable	X < 0.60 to ≤ 0.90	> 15 to ≤ 30
5	Not durable	X < 0.90	> 30

RESULTS AND DISCUSSION

Mass loss of the test specimens

Mass loss of all test specimens was determined at the end of the research.

<u>Mass loss of the reference wood species</u>

To validate the red meranti project, the mass loss of the reference woods was determined. An overview is given below (Figure 2).

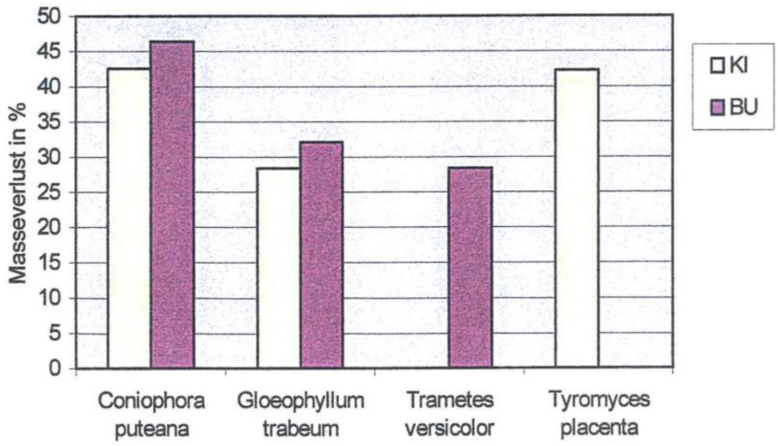

Figure 2: Mass loss of the reference woods: pine sapwood (KI) and beech (BU)

As shown in Figure 2, all fungi caused mass loss of greater than 20% in reference woods after incubation for 16 weeks. *Coniophora cerebella* caused mass loss of greater than 30% (cf. Methods). All fungi were proven virulent and valid for experimentation according to the test norms.
Intensity of mycelial growth on the surfaces of reference wood species after 16 weeks incubation is shown in Figures 3 and 4.

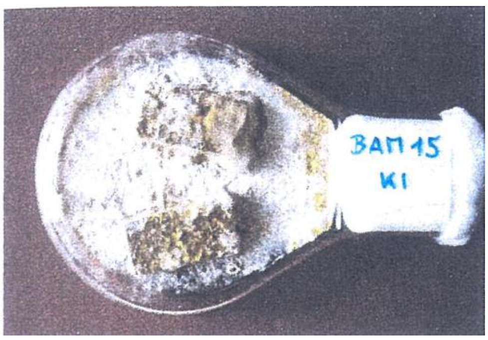

Figure 3: Mycelium of C. cerebella on pine

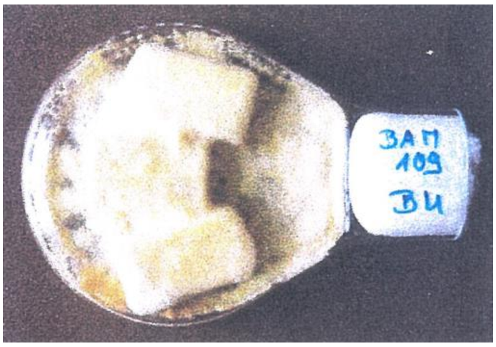

Figure 4: Mycelium of G. trabeum on beech

Considering the mass loss and mycelial growth of the reference wood species (pinus sapwood and beech), the wood moisture contents (Table 6) are in accordance with the testing norms:

Table 6: Wood moisture content of the reference woods after 16 weeks incubation time

Reference wood kinds	***Coniophora puteana*** u in %	***Gloeophyllum trabeum*** u in %
Pine sapwood	72.7	68.3
Beech	62.2	66.8

Mass loss of the Red Meranti Group

The results of biological trials with the various groups of red meranti demonstrate the very high virulence of *Coniophora puteana* and *Gloeophyllum trabeum* on this species. *Trametes versicolor* and *Tyromyces placenta* did not cause sufficient mass loss.

Mass loss according to CEN/ TC 38 N 1214 for the important fungi *Coniophora puteana* and *Gloeophyllum trabeum* are shown in a graphic form in Figure 5.

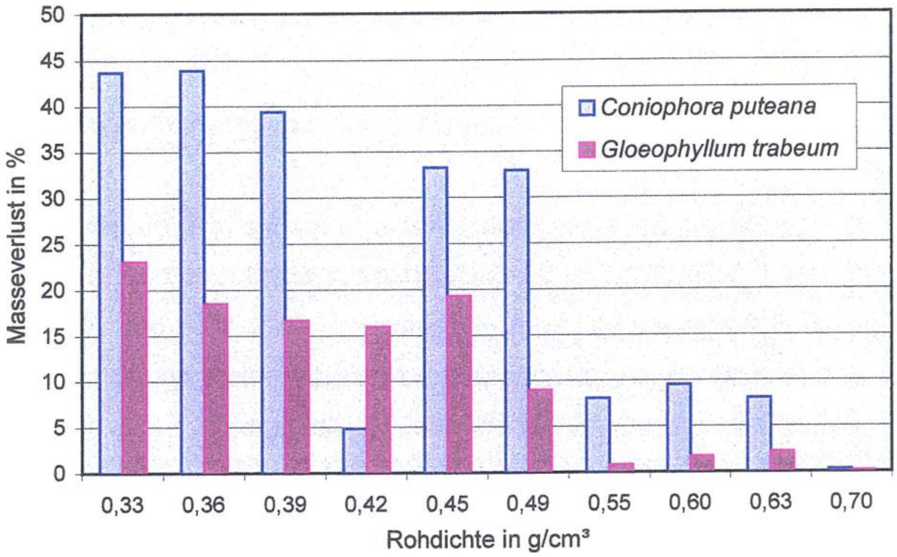

Figure 5: Main mass loss of the gross density groups for RM

Figure 5 demonstrates that the durability of red meranti (and the durability class) increases with increase in gross density.

In the gross density group **0.390 g/cm^3,** the main mass loss by *C. puteana* is 39.4% and by *G. trabeum* is 16.7%. According to CEN/ TC 38 N 1214, the RM of this gross density group is not durable (DC 5) by *C. puteana* and less durable (DC 4) by *G. trabeum*.
Similar results are present in the gross density group **0.450 g/cm^3**, which is the minimum gross density for RM window frames.
Beyond a gross density of **0.550 g/cm^3**, the red meranti test specimens fall into durability classes DC 2 or a DC1. These gross densities satisfy the demands of the MGR (1984).

It is difficult to interpret the results for the gross density group of **0.420 g/cm^3**. In this group, the mass losses caused by both fungi are lower. At this time, we have no direct explanation for this result. The reason could be the practical uses of different wood kinds coming from the industry. An anatomical analysis showed that all test species belong to the red meranti group (Family Dipterocarpaceae, Subgenus Rubroshorea, Genus *Shorea*). Another reason could be that within the density group of 420 g/m^3 there occurred single test specimens with a higher durability class. An overview of the distribution of different durability classes within the group of 16 test specimens is presented in Figure 6.

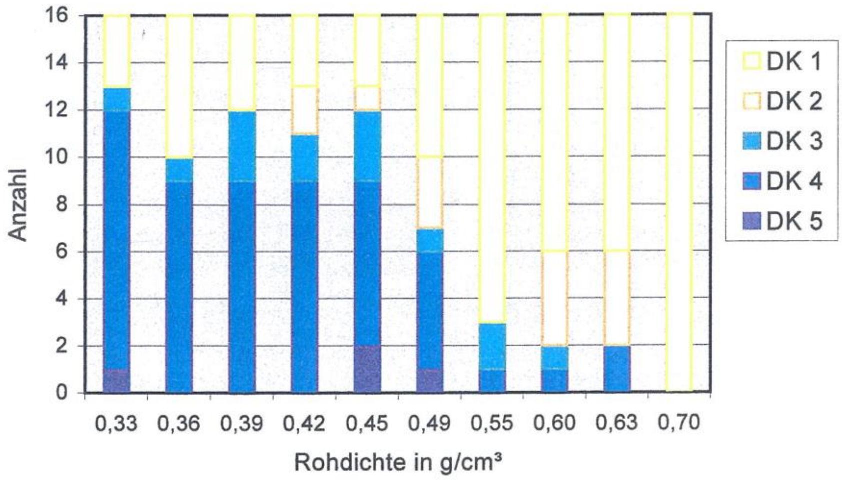

Figure 6: Durability classes (DK) within the 16 specimens from G. trabeum in gross density

Single test specimens with a higher durability class were present in every group tested.

CONCLUSIONS

Figure 7 gives the results of the mean mass loss by *C. puteana* and *G. trabeum* as dependent upon the gross densities and the distribution in durability classes (DK).

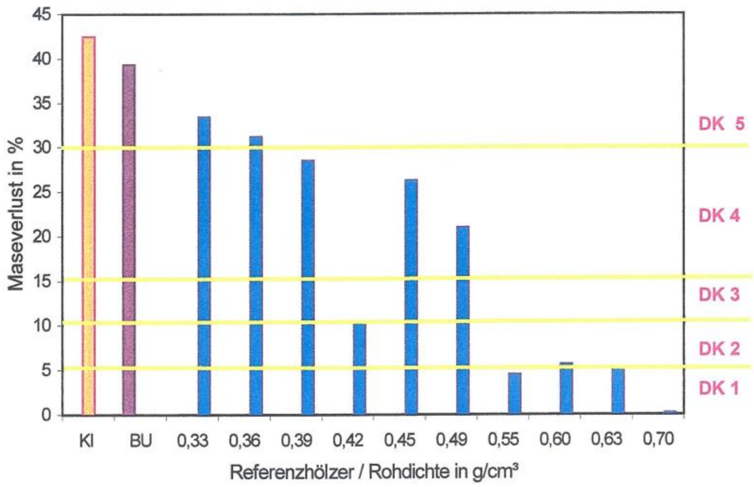

Figure 7: Distribution of biological results in durability classes (DK)

The results of all biological trials showed definitively that the natural durability of Red Meranti with gross densities of **0.550 g/cm³** is high and very high (DK 2 and DK 1).

Wood samples with lower gross densities (0.390 g/cm³ until 0.490 g/cm³, with the exception of 0.420 g/cm³), fell into the low durability class (DK 4).

The gross density groups of 0.330 g/cm³ and 0.360 g/cm³ were not durable (DK 5).

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Visco-elastic properties of archaeological oak wood treated with methyltrimethoxysilane

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Keywords: waterlogged wood, archaeological wood, methyltrimethoxysilane, visco-elastic properties, DMA

ABSTRACT

Conservation of archaeological waterlogged wood primarily aims to consolidate its structure and preserve its original shape and dimensions after drying. However, enhancing various wood properties such as durability (in terms of resistance to biological degradation), moisture sorption, fire performance, as well as mechanical properties is also important. As chemicals used so far for archaeological wood conservation are having numerous disadvantages, new consolidants are being investigated. The study on new substances for waterlogged wood conservation revealed good consolidating properties of some alkoxysilanes. The aim of this research was to evaluate the visco-elastic properties by means of dynamic mechanical analysis (DMA) in order to characterise archaeological waterlogged oak wood consolidated with one of the alkoxysilanes - methyltrimethoxysilane (MTMOS).

The obtained results showed a clear correlation between the level of wood degradation (translated into wood density) and mechanical strength in the case of treated wood. This was due to the consolidating effect of MTMOS, which reinforced wood structure and helped to sustain its natural spatial cell wall network, shape and dimensions. Treated sapwood, as the most degraded and therefore the softest material, was the most susceptible to compression, while the values of the mechanical parameters measured for MTMOS-treated heartwood were generally similar to those obtained for contemporary oak heartwood. In view of the results obtained in the study it could be stated, that MTMOS treatment of waterlogged oak wood have not deteriorated its mechanical properties. This fact, combined with good properties of MTMOS to consolidate wood, makes it an interesting agent for archaeological wood conservation.

INTRODUCTION

Conservation of archaeological waterlogged wood primarily aims to consolidate its structure and preserve the original shape and dimensions after drying. However, enhancing various wood properties such as durability (in terms of resistance to biological degradation), moisture sorption, fire performance, as well as mechanical properties is not without significance. The solutions being utilised by conservators are mainly based on polyethylene glycol (PEG), commercially available in a range of molecular weights. Penetrating waterlogged wood tissue, PEG can replace water molecules and reinforce wood structure, thus improving its dimensional stability (e.g. Bjurhager et al. 2010, Hoffmann 1988, Jensen and Schnell 2005). Recently, however, there have been several reports on significant drawbacks associated with the use of PEG, such as its high leachability from wood, degradation to acidic by-products over time causing chemical degradation of wood, increased hygroscopicity at high air relative humidity which leads to strong swelling and cracking of the impregnated wood, or plasticising effect on treated wood (e.g. Almkvist and Persson 2007, Hocker et al. 2012, Almkvist 2013, Olek et al. 2016). Therefore, the research has been started to find new effective substances for effective preservation of wooden cultural heritage. In the first stage of the research the consolidating effect of some alkoxysilanes was checked. As methyltrimethoxysilane proved to be quite a promising wood consolidant, its other main features were planned to be evaluated.

The aim of this study was to characterise visco-elastic properties of archaeological waterlogged oak wood treated with methyltrimethoxysilane and compare them to properties of untreated waterlogged wood. The evaluation was done by means of dynamic mechanical analysis (DMA) which is commonly used to study the visco-elastic properties of polymers.

EXPERIMENTAL

Materials

The studied material was archaeological waterlogged oak (*Quercus robur*) pile excavated from the Lednica Lake in the Wielkopolska Region, Poland. Dating back to the 10th-11th century, the wooden pile was the structural element of the early medieval "Poznań" bridge. The pile was cut into 1 cm thick slices. Each slice was subdivided into four zones: sapwood (S) and three heartwood zones, differing in the level of wood degradation: outer (H1), middle (H2) and inner (H3) (Fig. 1).

Figure 1: Cross-section of waterlogged archaeological oak wood divided into four zones: S – sapwood, H1 – outer heartwood, H2 – middle heartwood, H3 – inner heartwood

Small square samples (20×20×10 mm – radial (R) × tangential (T) × longitudinal (L) direction) were cut out from each zone and divided into two sets. One set of samples was dehydrated with 96% ethanol for four weeks. It was treated then with a solution of 50% MTMOS in ethanol by a vacuum-pressure method. The treatment consisted of 6 cycles: -0.1 MPa for 0.5 h and 1 MPa for 6 h/cycle. After that treated samples, as well as untreated ones from the second set, were placed in a fume hood and allowed to air-dry for 1 week at ambient pressure and room temperature. Untreated contemporary oak (*Quercus robur*) heartwood from the Wielkopolska Region was used as a control.

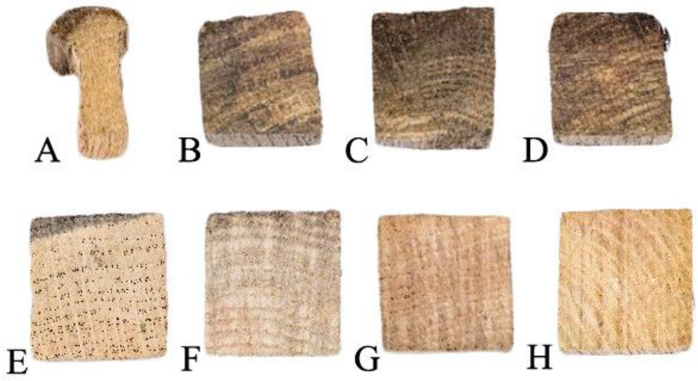

Figure 2: Air-dried examined wood samples: A –untreated sapwood, B-D –untreated heartwood (H1-H3), E –MTMOS-treated sapwood, F-H –MTMOS-treated heartwood (H1-H3)

Small cuboid twin-specimens were cut from each dry sample (from the same annual rings) with the dimensions of 6×8×9 mm (radial × tangential × longitudinal direction). The upper specimen surface was cut using a microtome to obtain a plain surface within the latewood layer. The opposite side of the specimen was paper-sanded to get plain, parallel surfaces. The samples were stored at 22°C and 45% ± 10% RH for 24 hours before measurement.

Methods

Measurements were performed by using the Dynamic Mechanic Analyser 242 model DMA 242 E by NETZSCH-Gerätebau GmbH. The specimens were tested in radial direction using compression mode. The DMA analyses were conducted for 1 h under the parameters presented in Table 1. The storage modulus (E'), the loss modulus (E''), the loss factor (tan δ = E''/E') and changes in sample length (Δl) were measured, as well as static force at sample (F stat. s) and a real amplitude at sample (As') for more detailed characterisation of visco-elastic properties of the studied material. The data were analysed using Proteus61 software.
Physical parameters such as conventional density, maximum moisture content and loss of wood substance, useful for rough evaluation of the state of wood degradation, were measured and calculated according to standard procedures and calculations described before (Broda and Mazela 2017).

Table 1: DMA measurement parameters

Parameter	Value
Target amplitude	10 µm
Max. dynamic force	7 N
Static force	2 N
Proportional factor	1.1
Oscillation frequency	1 Hz
Temperature	25°C
Relative humidity	35 ± 8%

RESULTS AND DISCUSSION

The properties of archaeological waterlogged wood, including its mechanical strength, depend on the degree of its degradation. The loss of wood substance, resulting from degradation of main chemical components (cellulose, hemicelluloses and lignin), is reflected, among others, in the cell wall thickness. The more degraded the wood is, the thinner and more vulnerable to collapse is the cell wall. This is clearly reflected in the way of waterlogged oak wood behaviour during drying. In the case of the most deteriorated sapwood samples (S), for which conventional density was about 127 kg×m^{-3} and the loss of wood substance was estimated around 80%, air-drying caused drastic dimensional changes (sample A, Fig. 2).

Table 2: Density and DMA parameters of air-dried samples at 60 minute of measurement; S – waterlogged sapwood, H1-H3 – respective waterlogged heartwood layers, CO – contemporary wood, t – MTMOS-treated samples

Wood sample	**DMA parameters at 60' of measurement**						**ρ_t [kg×m^{-3}]**
	E' [MPa]	**E'' [MPa]**	**tan δ *10^{-3}**	**Δl [μm]**	**As' [μm]**	**F stat. s [N]**	
S	146.33±52.17	18.33±9.29	0.12±0.02	-16.50±3.56	6.97±2.62	9.55±0.05	483.54
H1	134.57±38.01	20.57±8.46	0.15±0.02	-7.99±3.08	4.44±1.05	9.59±0.02	720.52
H2	163.00±65.08	29.29±18.96	0.17±0.04	-6.59±2.48	3.99±1.83	9.60±0.03	760.45
H3	165.57±68.93	32.57±21.74	0.18±0.06	-7.26±3.30	3.96±2.20	9.60±0.04	792.39
tS	43.75±18.30	3.75±2.22	0.08±0.02	-8.38±2.82	9.87±0.19	7.73±2.03	203.16
tH1	142.50±32.02	23.25±10.40	0.16±0.03	-3.08±1.19	3.78±0.99	9.60±0.02	687.44
tH2	140.25±74.08	28.00±23.62	0.17±0.08	-3.10±1.98	4.92±3.52	9.56±0.10	778.76
tH3	178.00±35.00	36.00±13.14	0.20±0.04	-3.30±1.20	3.12±0.90	9.61±0.01	840.29
CO	138.50±20.27	21.00±5.72	0.15±0.02	-6.900±1.61	4.24±0.81	9.59±0.02	624.17

Collapse and shrinkage of the degraded cell wall network due to drying made the sapwood structure more stabilised, harder and stiffer. By densification, the original mechanical properties of this material were changed. The final density of air-dried archaeological sapwood was similar to the density of CO, resulting in comparable stiffness (Table 2), despite of the high level of sapwood degradation. However, the archaeological air dried sapwood exhibited E' with a larger variation with a standard deviation of 52 compared to a standard deviation of 20 for the CO samples. Moreover, their deformation (Δl) during mechanical tests was higher, which indicates the increased diversity in the structure of collapsed sapwood specimens. Less degraded heartwood parts (basic density from 500 to 600 kgm^{-3} and loss of wood substance from 20% to 3% towards the pith) preserved their dimensions much better and only slight shrinkage was observed. Also here, some densification of wood material occurred, which resulted in the stiffness comparable or even higher than in the case of CO samples (Table 2).

In the case of MTMOS-treated samples, however, the situation was entirely different. The obtained results revealed a clear correlation between the level of wood degradation (translated into wood density) and mechanical strength. This is due to the consolidating effect of MTMOS (Broda and Mazela 2017). Silane reinforced waterlogged wood structure and allowed the treated samples to sustain their natural spatial cell wall network, shape and dimensions (samples E-H, Figure 2). Treated sapwood, as the most degraded and therefore the softest material was the most susceptible to compression. It was visible in the changes of sample thickness during the measurement (Δl was -8.38 µm, the highest value among measured treated samples), as well as in the value of the force used to achieve the desired amplitude during compression (F stat. was about 7.7 N in comparison with about 9.5 N for other samples) and the higher real amplitude value for sapwood than for other wood types (As' was 9.9 µm for sapwood in comparison with about 3-4 µm for other samples). The destabilised state of the treated sapwood cell walls, resulting from the high degree of wood degradation, is reflected in a lower stiffness in comparison with less degraded heartwood samples (E' about 44 MPa versus over 140 MPa for heartwood samples). This is typical for wood with weaker cell walls (Takahashi et al. 2006). The values of the mechanical parameters measured for MTMOS-treated heartwood were similar to those obtained for contemporary oak heartwood. The only exception was inner heartwood layer (H3), which was characterised by the highest density and therefore the higher stiffness than other heartwood samples (however, taking into consideration the standard deviation, no statistical significance is in this regard).

Finally, high dispersion of the obtained results, particularly for archaeological wood, should be mentioned. It resulted from the fact that wood, and especially waterlogged wood, is a highly inhomogeneous material (early and late wood, rays, uneven degradation). Additionally, the drying process caused shrinkage and cracks, unequally changing wood structure. Moreover, the sample preparation process, included cutting and sandpapering, was also the potential source of small internal cracks in wood specimens, which possibly translated into variation in their mechanical properties. This observations should be considered while preparing archaeological wood samples for this kind of measurements and perhaps different drying methods (like freeze-drying) should be applied to avoid further, additional differentiation within wood structure.

CONCLUSIONS

The results of the research showed that MTMOS treatment of waterlogged wood did not deteriorate its mechanical properties. No plasticising effect was observed as in case of PEG treatment (Bardet et al. 2012), and the visco-elastic properties of silane-treated wood were statistically similar to those of contemporary wood and just slightly higher than untreated wood. This fact, combined with the results of previous experiments, which proved good properties of MTMOS to consolidate waterlogged wood (Broda and Mazela 2017), makes it a promising agent for archaeological wood conservation.

ACKNOWLEDGEMENTS

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Influence of reaction conditions on the properties of phenolic resins

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Keywords: liquefied Kraft lignin, bio based-phenol formaldehyde resin, renewable resource

ABSTRACT

Phenolic resin is widely used because of its excellent properties and versatility and thus can be applied in a wide range of products. However, the synthesis of this resin occurs through the condensation polymerisation between phenol and formaldehyde, both of which are petrochemical and toxic. On the other hand, lignin has a great potential to replace phenol in resins due to its phenolic characteristics, as well as being easy to obtain (as an example from the Kraft process). As a drawback, lignin is less reactive than phenol and to make them more reactive some modification is needed. In our previous study on PF resin synthesis, liquefied Kraft lignin was used to replace phenol in different percentages by weight and different molar ratios of formaldehyde/phenol and NaOH/phenol. All reagents were placed at the same time in a three-necked flask reactor equipped with a reflux condenser, thermometer and magnetic stir bar. The reaction temperature increased to 85 °C when the reaction time was adjusted to 3h. From these runs, the PF resin called LPF9 with a replacement of 40 wt% liquefied Kraft lignin to phenol, a molar ratio of formaldehyde/phenol (F/P) 1.5 and a molar ratio of NaOH/P 0.5 showed the lower FFC (0.73%). After this, other four resins formulations were made with the same reaction conditions of LPF9 resin only varying the way of adding the reagents as followed: The first, were added phenol with 1/3 of formaldehyde and 1/3 of concentrated NaOH and after more two time of 1/3 of formaldehyde and 1/3 of concentrated NaOH (LPF9-1). The second, were added phenol with 1/2 of formaldehyde and 1/2 of concentrated NaOH and after the other part of formaldehyde and NaOH (LPF9-2). The third resin (LPF9-3) were added the phenol with all formaldehyde and 1/3 of concentrate NaOH and after more two time of 1/3 concentrate NaOH. The last resin (LPF9-4) is similar to LPF9-3, the only difference is that concentrate NaOH was added in two parts.

Table 1: Properties of the liquefied Kraft lignin-based PF resin.

ID	FFC (%)	SC (%)	Viscosity (mPa s)	pH
LPF9	0.73 (0.010)	64.26 (1.308)	1555.6	11.39
LPF9-1	0.22 (0.056)	64.73 (0.233)	1831.4	11.20
LPF9-2	0.50 (0.029)	64.63 (0.343)	1364.0	11.25
LPF9-3	0.58 (0.065)	63.23 (0.290)	894.6	11.28
LPF9-4	0.59 (0.004)	64.16 (0.644)	1465.3	11.46

This study aimed to investigate the influence of the way adding the reagents on the properties of phenolic resin such as FFC, SC, viscosity and pH. The results are presented

in Table 1. This study aimed to investigate the influence of the way adding the reagents on the properties of phenolic resin such as FFC, SC, viscosity and pH.

The results presented in Table 1 show that the manner of adding the reagents influences the FFC. It can see that all results for FFC are lower than LPF9 where the reagents were placing at the same time. LPF9 presented higher FFC (0.73%) and LPF9-1 the lowest with 0.22% FFC. This last one, the formaldehyde and NaOH were added in three parts. Zhao *et al*. (2016) found smaller values for FFC as verified in this study. They mixed NaOH, phenol and water by stirring for 20 min and then the formaldehyde was added in two parts. Solid content (SC) and pH showed the same results in all cases, around 64% and 11 respectively. The lower viscosity was verified at LPF9-3 where the phenol and formaldehyde were placed together and the NaOH in three parts and the higher in LPF9, with all reagents added at same time.

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Analysis of wood-destroying fungi in TMT samples

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Keywords: natural durability, thermally modified timber, outdoor exposure, mycology diagnostics

ABSTRACT

These studies with the subject "performance of wood – especially TMT for outdoor applications" focused on testing the applicability of wood as a building material for outdoor applications. Therefore the durability of samples of thermally modified timber as well as untreated soft- and hardwoods was considered. The natural durability of wood refers to the resistance to attacks by wood-destroying organisms, e.g. fungi, insects and marine organisms. Within the test field, situated in the Botanical Garden of the Eberswalde University for Sustainable Development, the applicability of wood in the outdoor environment was focused. Following the common 0.5 year test-interval considerable fungi-activity was obtained in the test-field which was installed according to EN 252 (2014). The test set up of samples (stakes) consisted of thermally modified timber and untreated soft- and hardwoods as references. After 4.5 years of exposure the detected degradations in the thermally modified samples were higher within batches of lower treatment intensities. Also, the deviations of these specimens were greater compared to samples of higher treatment intensities.
The aim of this study was to determine the types of the appearing wood-destroying fungi and to estimate their impact on wood products in different applications, e.g. terraces and facades or in ground contact. The intention was to assess the performance of TMT assortments. Concerning the aspects of inventory and analysis of decays and fungi in selected specimens the investigations were carried out in collaboration with the Technological Institute for forest based and furniture sectors (FCBA) in Bordeaux, France. In order to determine the occurred fungi the analysis at FCBA covered microscopic analysis and DNA extraction. It was the aim of this study to be able to conclude from these observations which specimens were affected by which fungus. These results should help to facilitate the understanding of the performance of wood as building material in outdoor applications. Contrary to expectations, the main goal – the identification of these fungi by mycology diagnostics – could not be reached. Due to too low fungal DNA quantity, PCR amplifications were difficult and the validation of results was not feasible.

INTRODUCTION

In the production of thermally modified timber (TMT = eng. Thermally modified timber) natural timber is exposed for a specific period at a temperature of 160-250 °C in a closed treatment chamber with inert atmospheric conditions. The heat treatment causes a change in the physical-technical and biological properties of wood. Because of the improved material properties TMT is primarily used outdoors, e.g. as cladding or as garden furniture.

EXPERIMENTAL

Specimens of beech (Fagus sylvatica) and spruce (Picea abies) were heat-treated at 3 different temperatures (180, 200, and 220 °C) and for each temperature at 5 different remaining times (2, 4, 6, 8 & 10 h) at the respective maximum temperature. The samples were produced in nitrogen atmosphere in the pilot plant at University for Sustainable Development Eberswalde. As references stakes of pine (Pinaceae) were implemented in the test field. Parameters of the test set are shown in Table 1.

Table 1: Experimental test set-up for EN 252 (2014), treatment parameters, batch size

Species	Format [mm]	Temperature [°C]	Duration [h]	Specimen [no.]/ Batch
Beech/ Spruce/ Pine	500 x 50 x 25	0, 180, 200, 220	2, 4, 6, 8, 10	12

According to EN 252 (2014) specimens were installed in the soil of the test field and arranged in 5 single departments with a recurrent pattern. This differentiation was applied to prevent the results from being influenced by local prerequisites of the soil. Assessment was repeated every 0.5 year in spring and autumn. Therefore, the rating system according to the EN 252 (2014) was applied, as shown in Table 2.

Table 2: Rating System for the assessment of attack caused by microorganism on test stakes EN 252 (2014)

Rating	Classification	Definition
0	No attack	No change perceptile by the means at the disposal of the inspector in the field. If only a change of colour is observed, it shall be rated 0.
1	Slight attack	Perceptible damages but very limited in their intensity and their position or distribution: changes which only reveal themselves externally by superficial degradation, softening of the wood being the most common symptom.
2	Moderate attack	Clear changes: softening of the wood to a depth of at least 2 mm over a surface covering at least 10 cm², or softening to a depth of at least 5 mm over a surface area less than 1 cm².
3	Severe attack	Severe changes: marked decay in the wood to a depth of at least 3 mm over a wider surface (covering at least 25 cm²), or softening to a depth of at least 10 mm over a more limited surface area.
4	Failure	Impact failure of the stake in the field.

The experiment design for mycology diagnostics started with the choice of samples on the test-field at the University for Sustainable Development Eberswalde. All specimens of the different thermal treatment intensities and natural wood were chosen after 4.5 years of exposure. Due to the criteria of failure - rating of 4 according to EN 252 (2014) - in total 24 samples were chosen. Since all stakes were broken in the Ground-Air-Zone, where high degradation was found, the samples where cut out here axially.

At FCBA in Bordeaux the mycology diagnostics (via microscopic observation and DNA extraction) analysis has been performed for all 24 specimens according to the foreseen workflow: Microscopy analysis and sampling, isolation of genomic DNA, specific

amplification of its sequence, sequencing of PCR Products, allocation and validation of fungi.
At the initial point microscopy was applied to thin slices, which were removed from the samples with a razor blade. Using a camera (Leica DFC 295) and imaging-software (LAS V4.2) the localized mycelia and further symptoms of attacks were photographed. Subsequently the samples were disrupted using a pointed knife and an amount of 2 mg was removed as small particles from the position were mycelia and other indicators were detected during microscopy. DNA extractions were performed with a kit according to the manufacturer's instructions (DNeasy Plant Mini Kit, QIAGEN).
To estimate the quality of the DNA, 5 µL of each tube were deposited on an agarose gel (0.8% in TBE 0,5X). After a migration of 30 minutes at 250 V and a BET bath, visualization of samples was performed under UV (appendix, fig. 7 - 11). Polymerase chain reaction was then performed with the Firepol DNA Polymerase (Solis Biodyne) according to the manufacturer's instructions. The primers ITS1 or ITS1F and ITS4 were used (Gardes and Brun, 1993; White *et al*, 1991).

RESULTS AND DISCUSSION

This study focused on the investigation of the two species, beech and spruce, at the test – field at Eberswalde Forest Botanical Garden. The entire range of specimens were sorted by visually assessed attacks, which were located in the ground-air section, thus in the middle of the stakes. Additionally three references of native beech, spruce and pine sapwood were chosen for diagnostics. By applying microscopy to the entire range of samples, typical characteristic of fungi existence, such as mycelia or significant indicators, e.g. black points in cell-wall or pointed ends, revealed in each of the 24 samples. The mycelia, as visible in the radial sections of the pine sample in Figure 2 or caverns (black points) in transversal surfaces of the pine sample in Figure 3 were typical phenomena due to of soft rot.

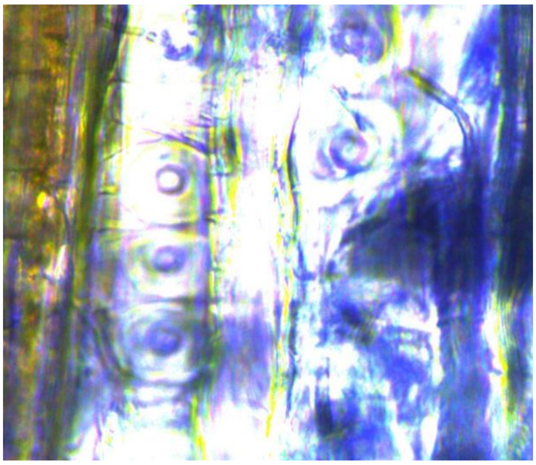

Figure 2: Pine sample untreated (radial, caverns & mycel, x 400)

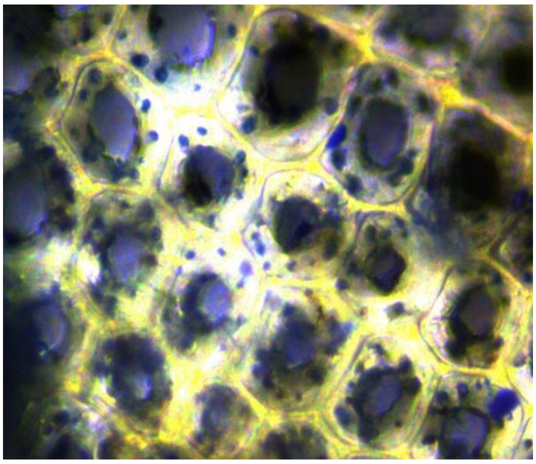

Figure 3: Pine sample untreated (transversal, caverns in cellwall, x 400)

Wood-chips were removed from the edge region and the interior areas of ground-air sections and DNA extractions were performed on the 24 samples.
Essentially no amplifications were visible for samples, except for sample 1d, 17 and 21. Sequencing was performed on the 3 amplified samples (1d, 17 and 21). But results were unsufficient as amplifications were weak and consisted of multi-bands (Figure 4).

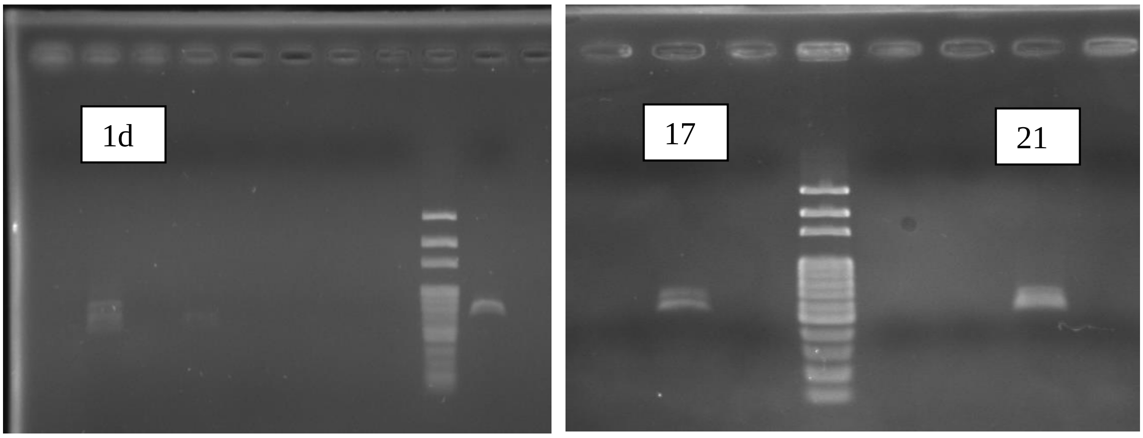

Figure 4: Agarose-gel under UV- light (DNA-extracts of sample 1d, 17, 21 diluted 1/10 variants)

Unfortunately the clear identification of soft rot fungi was as problematic, as already explained in Jacobs *et al.* (2013). Possible further reasons for uncompleted results were:

- Stakes were not degraded enough to extract enough fungal DNA compared to wood DNA.
- DNA of the stake but no DNA of the fungus – so amplifications did not work properly.
- DNA was too much degraded to allow amplification.

CONCLUSIONS

Due to the limited time of two weeks it was not possible to expand the performance of cloning procedure during the STSM. Thus, unfortunately the identification of the species, genus or group of fungi was not successful.

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Three-layer particleboards properties effected by addition of sub-dimensional particles from OSB production

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Keywords: particle boards, particle, properties, core layer

ABSTRACT

This work deals with selected physical and mechanical properties of the three layer particleboards prepared with addition of sub-dimensional particles from OSB production into core layer of particleboard in the ratio of 0, 10, 30 and 50 % to the normally used particles. The following application properties of the modified particleboards with particles from OSB production were analysed - density, thickness swelling and water absorption after 2 h and 24 h, internal bond strength, bending strength – with the aim to determine whether or not they are affirming in a positive or negative sense with the used particle. Addition of sub-dimensional particles from OSB production into core layer of particleboard had positive effect on bending strength.

INTRODUCTION

The size and shape of particles influence the mechanical properties, appearance, and machinability of particleboard (PB). Since its inception the strength-to-weight ratio of particleboard has been greatly improved through the adoption of a 3-layer structure (smooth high density surface and lower density core containing coarse particles) and advances in resin and press technology; however, low edge-screw withdrawal resistance (SWR) is still an issue for producers and users of particleboard today (Sackey *et al.* 2008). By the Sackey *et al.* 2008 efficient combinations of particles of various sizes in multilayer and 3-layer boards with the aim of efficient resin usage and mechanical property improvement have been pursued. Comparing the IB strength of two particleboard formations, Maloney (1970) constructed a 3-layer board with about 50% coarse core content comprised of particles of varied sizes and a multilayer board with a graduated core, whose center consisted of 20% of particles > 2 mm Tyler mesh-size. He found the IB strength of the 3-layer boards to be greater. The inclusion of fines and wood dust in the core of boards has been shown to increase IB (Kakaras and Papadopoulos 2004; Nemli 2003), but reduce static bending and modulus of elasticity (MOE) (Nemli 2003). The increase in IB strength has been attributed to the filling of void spaces between the larger particles with fines to produce a higher degree of interparticle contact (Nemli 2003).

Gozdecki and Wilczyński 2015 were investigated the effects wood particle size on mechanical and physical properties of wood-plastic composites. Mechanical properties increased with increasing wood particle size and composites with larger wood particles had lower water resistance.

The aim of this work was to prepare a wood particle board supplemented with sub-dimensional particles from OSB production into core layer of particleboard and to study how the amount and allocation of this particle in wood particle boards affected selected physical and mechanical properties of such modified materials.

EXPERIMENTAL

Particleboard preparation

In laboratory conditions, three layer particleboards were produced with dimensions of 400 x 300 x 16 mm and density 613-626 kg.m^{-3} in four variants with the following ratios of sub-dimensional particles from OSB production 0, 10, 30 and 50 w/w % (weight ratio of oven-dry sub-dimensional OSB particle and of oven-dry normally used particle) added in the core layer. The wood particles for PB production were a mixture of spruce and other softwoods and with a small proportion of up to 5 % on dry mass particle from beech and other hardwoods. The moisture content of surface particles was 5.2 %, in the particles in core layers 3.5 %. The weight ratio between the surface and core layers was 32:68. Urea-formaldehyde (UF) glue with 67% solid content was used. The glue proportion applied onto the surface particles represented 11 % and onto the core particles 7 %. The hardener was a 55% solution of ammonium nitrate. The PBs were also supplemented with a paraffin emulsion with 35 % solid content, applied onto the surface and core particles in a proportion of 0.85 %.

Wooden particles were firstly homogenized in a rotary mixing – blending device with UF glues, then loaded into a pre-pressing form, and finally pressed. Pressing process was performed in a laboratory press CBJ 100-11 according the standardized three stage pressing diagram at a temperature of 210 °C, a maximal specific pressure of 5.23 MPa, and a pressing factor of 12 s. Totally we produced one control type and three modified types of 3-layer particleboards. Each variant of PB was produced in 5 pieces, so altogether we prepared 20 boards.

Properties of modified PBs

From 20 laboratory pressed PBs (400 mm × 300 mm × 16 mm) were prepared samples for testing the density, moisture and strength properties. Density, moisture and strength properties of PBs were carried out in accordance with the relevant test methods as described in EN standards. Density of PBs was determined by the Standard EN 323 (1993). Thickness swelling (TS) and water absorption (WA) of PBs were determined after 2 and 24 hours by the Standard EN 317 (1993). Internal bond (IB) strength, i.e. tensile strength perpendicular to the plane of the PBs, was determined by the Standard EN 319 (1993), and bending strength (BS) of PBs was determined by the Standard EN 310 (1993) – at both tests using a universal machine TiraTest 2200.

RESULTS AND DISCUSSION

Selected physical and mechanical properties of the modified particleboards with particles from OSB production are presented in Table 1.

Table 1: Physical and mechanical properties of the modified PB with particle from OSB production

Properties of particleboard		**Sub-dimensional OSB particle (w/w in the core layer of PB) [%]**			
		0	**10**	**30**	**50**
Moisture content (MC)	[%]	8.4 (0.25)	8.2 (0.13)	8.1 (0.15)	8.2 (0.15)
Density	[kg.m^{-3}]	624 (36)	613 (42)	620 (31)	626 (31)
Thickness swelling (TS) after 2 h	[%]	4.32 (0.67)	3.37 (0.27)	3.47 (0.32)	4.04 (0.58)
Thickness swelling (TS) after 24 h	[%]	13.27 (1.47)	13.36 (2.01)	15.53 (1.49)	13.18 (1.29)
Water absorption (WA) after 2 h	[%]	15.86 (2.25)	16.81 (1.63)	16.02 (1.23)	16.44 (1.59)
Water absorption (WA) after 24 h	[%]	44.90 (3.96)	55.79 (3.78)	54.37 (9.01)	42.75 (3.45)
Internal bond (IB) strength	[N.mm^{-2}]	0.541 (0.06)	0.447 (0.09)	0.484 (0.03)	0.507 (0.05)
Bending strength (BS)	[N.mm^{-2}]	9.52 (1.06)	9.76 (0.95)	10.21 (0.88)	10.92 (0.57)

Notes:
- Mean values: of MC from 30 samples, of density from 70 samples, of TS from 20 samples, of WA from 20 samples, of IB from 20 samples and of BS from 15 samples.
- Standard deviations are in the parentheses.

The density of the modified PBs (613–626 kg.m^{-3}) was a very similar to the control PBs (624 kg.m^{-3}) – see Table 1. This result was confirmed as well by a small coefficient of determination $R^2 = 0.00$ for a linear regression analysis – see Table 2. Due to presence of sub-dimensional OSB particle in core layer in PBs, their moisture properties did not change similarly. The thickness swelling of PBs containing the highest amount of OSB particle reduced about 6.5 % after 2 hours and about 0.7 % after 24 hours and the water absorption evidently increased about 3.5 % after 2 hours and reduced about 4.8 % after 24 hours – see Table 1 and Table 2.

The presence of sub-dimensional particle from OSB production had none effect on the internal bond strength of PBs, which always was more than 0.44 MPa – see Table 1 and Table 2.

The bending strength of modified PB with sub-dimensional particle from OSB production had an increasing tendency with an increasing amount of sub-dimensional particle from OSB production in core layer of PBs ($BS = 9.54 + 0.03 \times w/w$; $R^2 = 0.24$), and maximally increased about 11.9 % – see Table 1, Table 2 and Figure 1.

Table 2: Linear correlation analysis of the sub-dimensional particle from OSB production addition in core layer three layer particleboard on the properties of modified PB

	Properties of PBs	**N**	**R**	**R^2**	**T**	**P**	**y = a + b*x**
OSB particle (% in core layer)	Moisture content	120	-0.34	0.12	-3.89	0.00	8.29 - 0.00*w/w
	Density	280	0.05	0.00	0.96	0.34	618 + 0.11*w/w
	Thickness swelling after 2 h	80	-0.04	0.00	-0.39	0.69	3.83 - 0.00*w/w
	Thickness swelling after 24 h	80	0.09	0.00	0.82	0.41	13.63 + 0.00*w/w
	Water absorption after 2 h	80	0.04	0.00	0.35	0.73	16.20 + 0.00*w/w
	Water absorption after 24 h	80	-0.20	0.04	-1.83	0.07	51.35 - 0.08*w/w
	Internal bond strength	80	–0.04	0.00	–0.31	0.76	0.50 – 0.00*w/w
	Bending strength	60	0.49	0.24	4.29	0.00	9.54 + 0.03*w/w

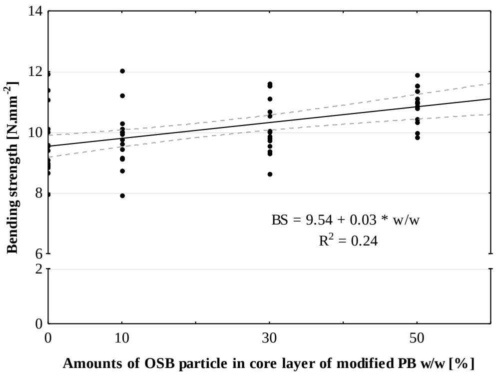

Figure 1: Bending strength (BS) of the modified PBs (core layer treated with 0 to 50% of sub-dimensional particle from OSB production)

CONCLUSIONS

The modified 3-layer PBs, due to a presence of sub-dimensional particle from OSB production added into core layer of PB in the amounts of 0, 10, 30 or 50 w/w %, had positive effect on bending strength (increased maximally about 11.9 %). Other application properties of these boards did not significantly change: density, thickness swelling, water absorption, internal bond strength.

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Performance of bio-based insulation panels

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Keywords: Bio-based building panel, earth, rice husk, physical property.

ABSTRACT

In recent years, one of the biggest issue in the construction sector is the impact of buildings materials on the health of their occupants. Indoor air quality is one of the major risk factors for human health. It has become a priority to find ways to improve it by using safe building materials with low impact and find an equilibrium between the heat and the indoor humidity improving the hygrothermal performance of buildings (Laborel-Préneron *et al*., 2016, Minke 2006, McGregor *et al.*, 2014).

Further to this concern, the interest in bio-based materials has grown due to their ability to adsorb and desorb indoor moisture (Jones and Brischke 2017), and earth as a construction material with high hygroscopic behaviour (Minke 2006, McGregor *et al.*, 2014) become an ideal agglomerate to these products. Nevertheless, earth has weaknesses like its poor ductility and water resistance. Therefore, it is common the use of natural fibres and binders to reduce the negative effects and improve strength of earth composites. The addition of natural fibres may reduce the composite shrinkage and its thermal conductivity, which means that these composites may have good thermal insulation properties (Laborel-Préneron *et al*., 2016). Some studies showed that there are some treatments that can improve some of the natural fibres properties like immersion on boiling water (Fertikh *et al*., 2011), mixture with cement or lime, immersion in linseed oil (Ledhem et. al 2000) and application of acrylic coating (Segetin *et al*., 2007).

Gypsum is a binder produced at low temperatures (120-180 ºC) that has good thermal and sound insulation properties, with a low thermal conductibility. Some authors studied the addition of gypsum to earth composites and showed that the increase of gypsum content decreased the thermal conductivity of the composite and increase the compressive and tensile flexural strength (Lima *et al*., 2016, Binici *et al*., 2005).

Several authors have optimised the stabilisation of soils with binders. Millogo *et al*. (2008) studied the effect of lime addition to clayish soils to produce adobe blocks and concluded that the addition of 10% of lime maximised the compressive resistance and minimised the water absorption. Based on these concepts, this paper studies the mechanical and hygrothermal performance of bio-based insulation panels produced with an earth matrix reinforced with rice husk and stabilised with gypsum and air lime.

Based on a literature review, it was defined a percentage of 20% of gypsum and 10% of air lime (both by volume) to obtain a high-performance insulation panel. After experimental ponderation, two quantities of rice husk were used: 15% and 30% by

volume, the later to maximise the percentage of natural aggregate. The rice husk was used dried, but for the 30% panels it was also used after being boiled.
Results of mechanical and thermal properties of the insulation panels, including compressive and tensile flexural strength, abrasion test, ultra sound velocity, thermal conductivity and moisture buffer capacity (MBV), conducted for cycles of 60-90% relative humidity and a temperature of 16 °C, common in Portugal during winter on many unheated flats, will be presented and discussed.

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Modelling of colour change as a function of climatic exposure

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Keywords: wood weathering, field test, colour change, BIM

ABSTRACT

Aesthetical changes of the wooden surface are predominately caused by the action of climatic agents known as weathering. Weathering is a general term used to define slow degradation of materials exposed to various environmental agents such as solar radiation, cyclic wetting, atmospheric temperature and relative humidity changes, environmental pollutants and certain microorganisms and results in chemical, physical and anatomical changes. The weathering of wooden surfaces is affected by the exposure condition and the prevailing climate at the micro location during the service life period**.** The goal of the present study was to develop a mathematical model for description of colour change for the different wood-based materials.

INTRODUCTION

Throughout the service life, both abiotic and biotic factors in various ways negatively influence the functional and aesthetical performance of building materials, in particular, decking and cladding – two commodities where wood and wood-based materials are abundantly used. From an engineering point of view, decay and biological degradation in general are only part of the overall performance of wooden structures. A comprehensive engineering model can therefore be dominated by the effect of crack formation, ageing, annual fluctuations in UV degradation, corrosion of fasteners, or building physical phenomena (Brischke and Thelandersson 2014).

Wood degradation under the influence of abiotic factors is a major cause of both the limitation of applicability and reduction of lifespan for wood products (Mazela *et al.* 2015). Among abiotic factors, the action of climatic agents – known as weathering – especially ultraviolet (UV) portion of the solar spectrum, rain, and moisture, slowly degrade the materials' surface. Weathering of wood results in chemical, physical and anatomical changes (Williams 2005; Jankowska 2015; Gonzalez de Cademartori *et al.* 2015; Griebeler and Iglesias Rodriguez 2015; Thiis *et al.* 2015; Burud *et al.* 2016). Loss of lightness, discolouration, cracking, checking and roughening of the surface are some undesirable characteristics of the wood after outdoor exposure (Dosdall *et al.* 2015). All these damages on wood surface are related to chemical changes in the hemicelluloses, cellulose and lignin chemical structures. Weathering deterioration is unavoidable, resulting in significant changes to the wood surface characteristics (Gonzalez de Cademartori *et al.* 2015).

Outdoor weathering make the surface more susceptible to blue stain and mould fungi attack and results in greying of the wood surface (Derbyshire and Miller 1981; Ayadi *et al.* 2003). Greying is caused by a combination of photo-bleaching and colonisation of the bleached wood surface by staining fungi. The most prominent fungi on weathered wood surfaces are *Aureobasidium pullulans* (de Bary & Löwenthal) G. Arnaud and *Sclerophoma pithyophila* (Corda) Höhn. which are blue stain fungi. These ascomycetous fungi are not able to decay the wood cell wall but feed on photo-degraded cell-wall products (Ghosh *et al.* 2009; Schoeman and Dickinson 1997). Surface mould growth affects the aesthetic service life of outdoor exposed wood and may often be the first visual sign of an ongoing degradation of the wood surface (Gobakken *et al.* 2010; Gobakken and Vestøl 2012a; Gobakken and Vestøl 2012b). For colonisation and growth of staining and mould fungi on the wooden surface, moisture content in the material and the relative humidity and temperature in the ambient air are considered as the critical factors (Häglund *et al.* 2010; Hukka and Viitanen 1999; Vereecken and Roels 2012).

The house owners and other end-users demand cladding material with long maintenance intervals and long service life; and the long-time performance of wooden and wood-based claddings will depend on the quality and the type of material, its surface properties, building design and climatic factors. Building Information Modelling (BIM), as emerging technology, bears promise to support processes integration thus enabling life-cycle management of buildings. BIM model serves as a joint knowledge database, where data transfer between various models such as sustainability analysis, structural analysis, thermal simulation, daylight simulation, construction management, cost estimation and planning, fire protection, safety on construction site, facility management etc. is possible. Therefore, the development of functioning and open interfaces is one of the major tasks in the advancement and successful adoption of BIM technology in the industry (Ghaffarianhoseini *et al.* 2017; Yalcinkaya and Singh 2015; Gourlis and Kovačič 2017).

A possible model to implement into BIM could be aesthetic service life simulation based on colour change due to selected abiotic and biotic factors. The approach is to determine the climate exposure, local exposure conditions such as shading, sheltering and design of details.

EXPERIMENTAL

The field trial is based on the testing of façade and the decking of the wooden model house unit at the Department of Wood Science and Technology in Ljubljana, Slovenia (Figure 1). The model house was finished in October 2013. The materials listed in Table 1 were exposed on the façade and decking applications. Cross-section of the elements was 2.5 × 5.0 cm. Preparation of all the materials is described by Kržišnik *et al.* (2017).

Figure1: Wooden model house unit in October 2016, after 3 years of exposure.

Table 2: Twenty-two wood-based materials used in research.

	Wood species										Treatment			
Abbreviation	**Norway spruce (*Picea abies*)**	**European larch (*Larix decidua*)**	**European beech (*Fagus sylvatica*)**	**English oak (*Quercus* sp.)**	**Sweet chestnut (*Castanea sativa*)**	**Scots pine (*Pinus sylvestris*)**	**Linden (*Tilia* sp.)**	**European Ash (*Fraxinus* sp.)**	**sapwood**	**heartwood**	**thermal modification**	**suspension of natural wax**	**copper-ethanolamine**	**acrylic surface coating**
PA	×													
PA-NW	×											×		
PA-AC	×													×
PA-CE	×												×	
PA-CE-NW	×											×	×	
PA-TM	×										×			
PA-TM-NW	×										×	×		
PA-TM-AC	×										×			×
PA-TM-CE	×										×		×	
LD		×												
LD-TM		×									×			
FS			×											
FS-TM			×								×			
FS-TM-NW			×								×	×		
Q				×						×				
C					×					×				
PS-SW						×			×					
PS-HW						×				×				
T							×							
T-TM							×				×			
FE								×						
FE-TM								×			×			

At the house, a variety of continuous and non-continuous measurement techniques was performed. For moisture measurements, resistance sensors were applied on 150 positions and linked to Material Moisture Gigamodule Universal Sensor (Scanntronik Mugrauer GmbH, Germany) that enabled wood MC measurements between 6% and 60%. In order to transform electrical resistance determined by Material Moisture Gigamodule to moisture content, the methodology described by Brischke and Lampen (2014) was used. For colour measurements, several times a year portable measuring device Colour Measuring Device EasyCo 566 (Erichsen, Germany) was used. Values of measured colours were expressed according to the CIE Lab system (Figure 2), method created by the Commission International de l'Eclairage. The CIE Lab system is characterized by three parameters, L*, a* and b*. L* axis represents the lightness, it varies from hundred (white) to zero (black), a* and b* are the chromaticity coordinates. In the diagram CIE Lab, +a* is the red direction, -a* is green, +b* is yellow, -b* is blue.

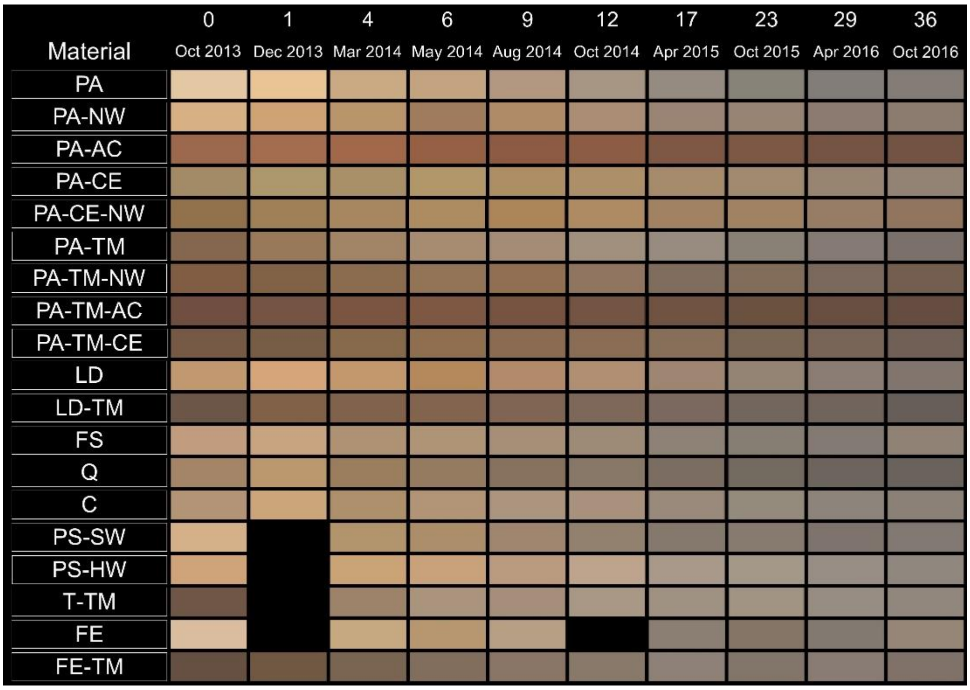

Figure 2: Representation of averaged colour changes from east and west façade on wooden model house unit over 3 year period.

The geometry of a building and local shading on a wall is important when determining the radiation on the cladding. DIVA-for-Rhino with software tool RADIANCE was used to simulate the radiation and to calculate the climate-specific irradiation at nodes located on the façade and terrace of a 3D digital building model. Using a simulation grid with one node every 10 × 10 cm gave the possibility to simulate the shading effects of features like window-sills and roof eaves. The software calculated the hourly solar radiation in every node for one whole year given the climate and the geographic position of the building (Figure 3).

Local weather records from a Davis weather station (UL, BF, Oddelek za lesarstvo / UL, BF, Department for Wood Science and Technology) were collected and sorted including sun radiation, temperature and relative humidity (RH). Based on calculated irradiation simulation, separate files for every used material with the temperature of the surface of the façade or decking, moisture content of the wood 0.2 mm under the surface, relative humidity of the air, incident and absorbed radiation, for every direction of exposure (decking, north, south, east and west façade) were prepared and mould dose (D) (Thelandersson and Isaksson 2013) and radiation dose (Dr) were calculated and summed (Figure 4 and Figure 5). MATLAB (MathWorks) was used as software platform for multivariate data analysis. (Burud *et al.* 2016; Thiis *et al.* 2015; Thiis *et al.* 2016).

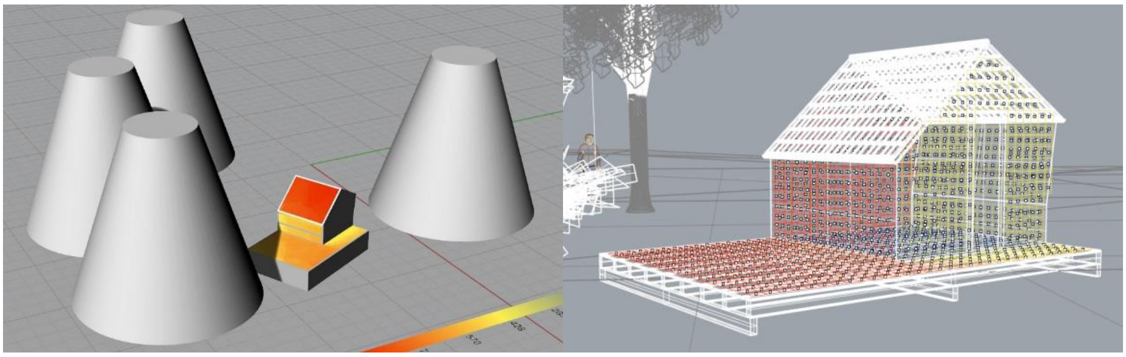

Figure 3: Simulation of the solar radiation. First model (left) with truncated cones as the representation of the tree and more detailed second model (right).

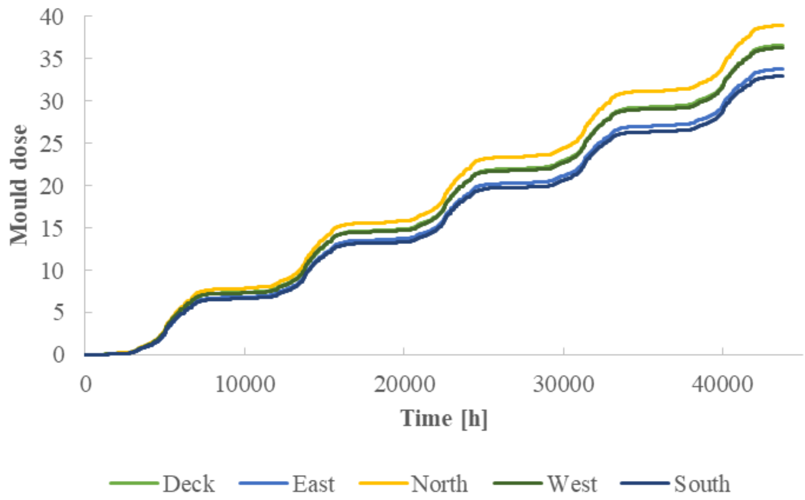

Figure 4: Cumulative mould dose (D) for all directions of exposure for Norway spruce (PA) over 5 year period.

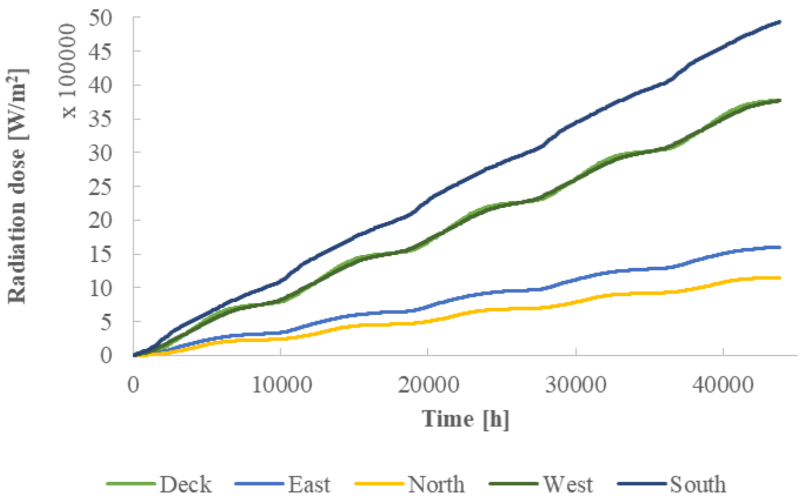

Figure 5: Cumulative radiation dose (D_r) for all directions of exposure for Norway spruce (PA) over 5 year period.

RESULTS AND DISCUSSION

15 mathematical models (9 for non-treated materials: PA, LD, FS, Q, C, PS-SW, PS-HW, T and FE and 6 for thermally modified and/or copper impregnated materials: PA-TM, LD-TM, T-TM, FE-TM, PA-CE and PA-TM-CE) out of 22 used materials were developed. One of such model with the colour representation for Norway spruce exposed on deck is shown in Figure 6 and Figure 7.

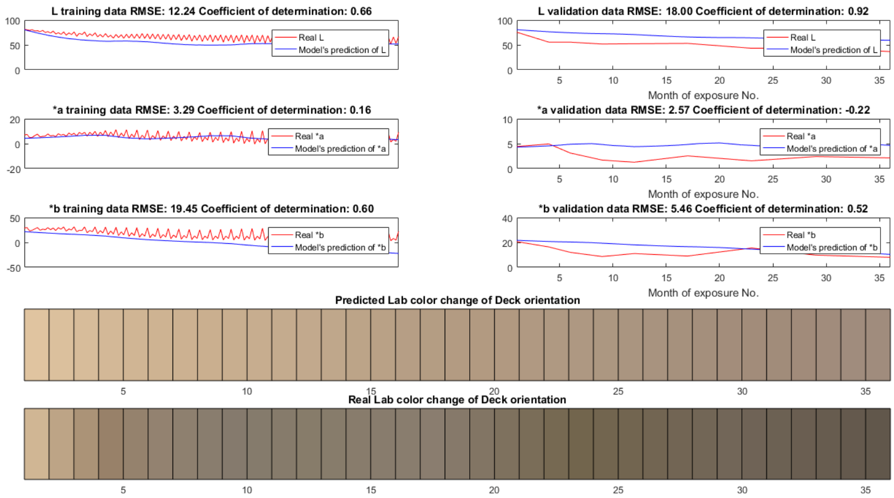

Figure 6: Model for Norway spruce (PA) exposed on deck.

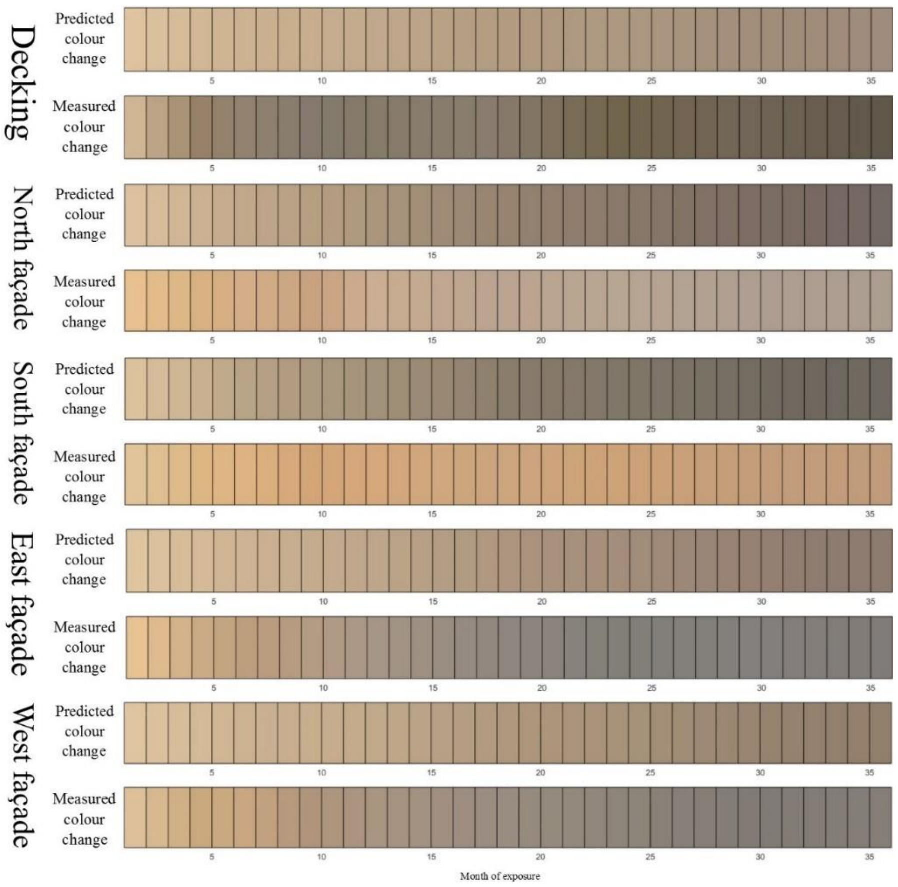

Figure 7: Modelled (predicted) and measured (real) colours for all directions of exposures for Norway spruce (PA).

CONCLUSIONS

The appearance of the exposed wood-based materials changes over time because of natural weathering and discoloration due to blue stain and mould fungi. The degradation due to abiotic and biotic factors was successfully modelled for fifteen out of twenty two used materials using weather data and measured colour changes. Based on weather data mould and radiation dose were calculated and used for making the sufficiently generic and robust mathematical models predicting the colour changes of different wood-based materials within the measurement error and differences due to the variability of the wood. Such models could be used for predicting the aesthetical performance of wooden façades element in BIM.

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Knowledge exchange and transfer from academia to industry in the field of wood protection research – Activities of the IRG-WP Communications Committee

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Keywords: Durability data base, field test sites, International Conference on Wood Protection, social media, test methods

ABSTRACT

The International Research Group on Wood Protection (IRG) was founded in 1969 as a structured group of like-minded scientists and technologists focused on generating knowledge of the science of wood deterioration, and novel solutions to provide sustainably and environmentally responsible products for the protection of wood-based materials. The primary function of the IRG is to provide opportunities for the exchange of ideas and information in an informal atmosphere, unencumbered by refereeing of papers or other pre-conditions.

While the primary vehicle is the annual meeting usually held in the second quarter of each year with global locations chosen as providing optimal opportunities for interactions between attendees and in settings that are both interesting and economically viable for our diverse attendance from around the world, the changing nature of the inputs into wood protection research over the past five decades, as well as the ever shifting environmental, global and economic influences have led to a desire to provide additional communications vehicles for the IRG members and sponsors, as well as to provide relevant information to the global audience with an interest in wood products protection and the associated research and technologies. This paper addresses the various ways that the IRG

Communications Committee has been developing to provide diverse and on-going communications throughout each year.

INTRODUCTION

The Communications Committee (CC) of the International Research Group on Wood Protection (IRG or IRGWP) was established to coordinate the electronic communications activities of the research group. While it has evolved and grown over the years, its primary functions remain the same. The CC currently has nine members who each serve for three year terms. The CC has a Chair, and the CC reports through the Chair directly to the IRG Executive Council (EC). While each membership term is for three years, this may be extended depending on the wishes of the member and the decisions of the Executive Council. The CC Chair is an ex officio member of the EC and also serves on the President's Consultative Panel (PCP). Those positions that the Chair of the CC serves on underline the importance of the CC to the functions of and working of the IRG in providing on-going communications with and for the members and sponsors throughout the year.

Figure 1: Logo of the International Research Group on Wood Protection (IRGWP).

The activities of the IRG Communications committee are currently centred around three broad initiatives, namely the IRG website, the IRG Social media activities namely Facebook and LinkedIn, and the bi-monthly IRG newsletter. Each of these is discussed in detail below.

THE IRG-WP COMMUNICATIONS COMMITTEE

IRG WEBSITE

The IRG website (http://www.irg-wp.com/) serves as the primary information provider on the overall activities of the IRG.

The homepage provides a general overview of the aims and activities of the IRG while the "About" section web pages provide details of the general organizational structure of the Group, the committee structure and current membership of the various committees. Other pages within the About section detail various procedures and forms, while others describe the Sponsors and assorted links within the sphere of wood products protection globally.

The Image gallery page is sub-divided into five separate interest pages namely, applications, test methods, basic science, research activities and social aspects within the IRG. It is fair to say, however, that the value of these image pages, and the ability to update them on a regular basis, has over the past few years been subjugated and/or subsumed by the increasing use of social media, and especially the increasing role that the IRG Facebook page has assumed in that regard.

The News and History group of web pages within the IRG provide up to date information on coming IRG meetings, including links to the next IRG meeting website, in the present case that of IRG49 in Johannesburg, South Africa in 2018, as well as other meetings in closely related fields to wood protection. A further page and interactive map shows the locations and images of all past and assigned future IRG annuals meeting, that is the IRG Scientific Conferences (Figure 1). The drop down menu group under News and History also includes the archive of all of the IRG newsletters, and also a compendium of the member bios included in the IRG newsletters since 2015. There is a web page on the History of the IRG, as well as pages on and about all the Awards within the IRG including all awardees since the inception of the IRG in 1969. A further page, including images, details all 15 IRG Past Presidents over the history of the IRG.

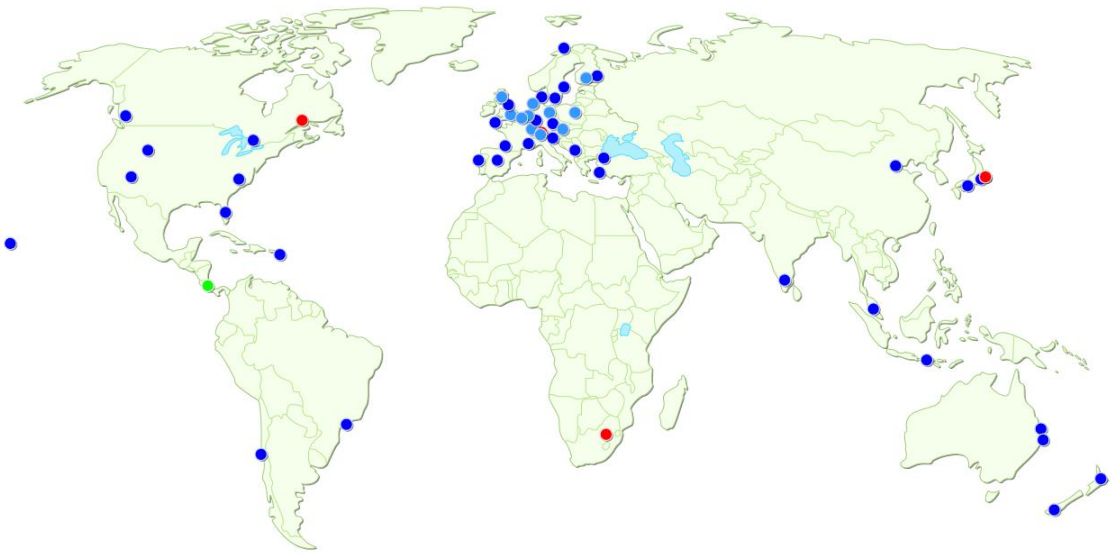


Figure 1: IRG Scientific Conference Locations 1969 - 2019.

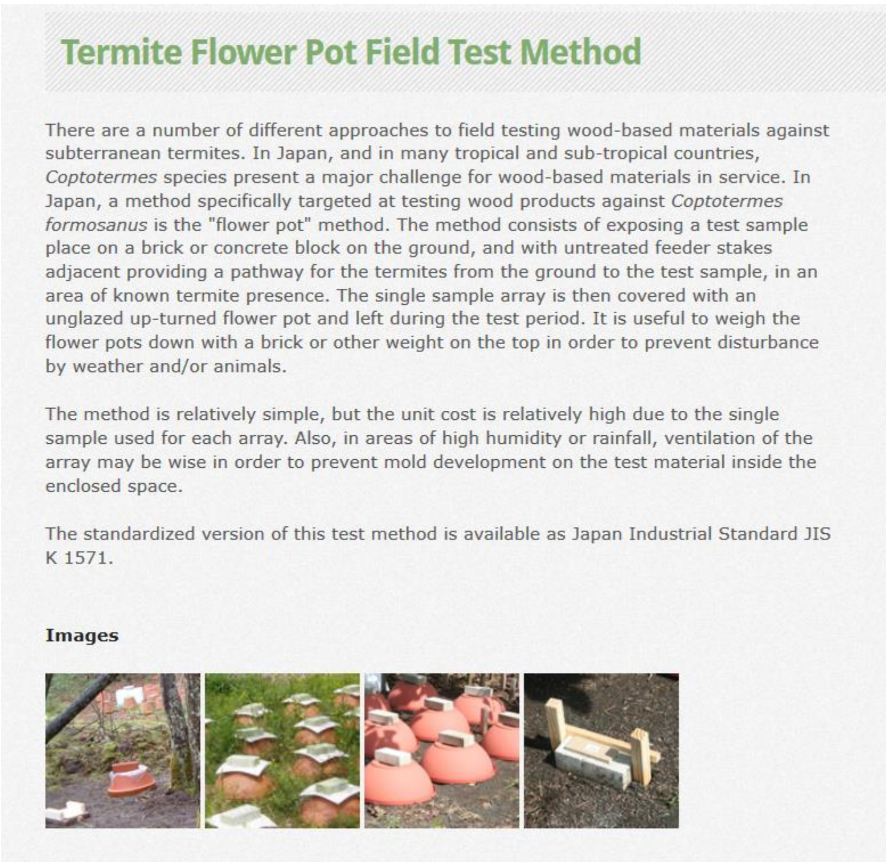
Research Section of the IRG website

As part of the Communication Committee's initiative to provide timely and useful scientific information to the members and sponsors of the IRG, as well as to others interested in wood products protection technology, we have developed and are expanding the "Research" area of the IRG website.

The initial component of the area was the IRG Documents compendium database and document retrieval system. This is an open access searchable database, with free full-text document retrieval for all IRG members and sponsors, and for-fee retrieval for others. The compendium consists of PDF versions of all IRG documents since the inception of the IRG in 1969, with over 5000 documents altogether.

A second component in the Research section of the website is the Durability Database. The aim of the IRG durability database is the allocation of wood durability test results for comparative studies and re-analyses (Brischke et al. 2012). The database serves as pool for service life prediction and modelling in order to contribute to an enhanced understanding of wood durability. It is an open web-based platform for scientific exchange in the field of wood durability and wood protection. The database contains raw data only; no statistical evaluation is included. It is the responsibility of users to interpret the test results published in the database. For each data set, the full range of information about the test method, the test material, and other relevant parameters, is included to guarantee reliability of the data. For this reason, every data set submitted is reviewed and checked for completeness of all relevant data. The database allows submission of assessment data from all kinds of standardized and non-standardized wood durability tests.

The third and fourth components of the Research area of website relates to Section 2 of the IRG, Test Methods. The first of these is the section on Test Methods, which describes in a series of individual web pages various Laboratory and Field test methods used in Wood Protection technology. Currently some 26 different test methods are included, each on separate web pages which include a description of each method, viewable image files of the method, and where available, scientific references to the method (Figure 3). It is our intention to expand the number methods and the quality of the information provided as time and resources permit.


Termite Flower Pot Field Test Method

There are a number of different approaches to field testing wood-based materials against subterranean termites. In Japan, and in many tropical and sub-tropical countries, *Coptotermes* species present a major challenge for wood-based materials in service. In Japan, a method specifically targeted at testing wood products against *Coptotermes formosanus* is the "flower pot" method. The method consists of exposing a test sample place on a brick or concrete block on the ground, and with untreated feeder stakes adjacent providing a pathway for the termites from the ground to the test sample, in an area of known termite presence. The single sample array is then covered with an unglazed up-turned flower pot and left during the test period. It is useful to weigh the flower pots down with a brick or other weight on the top in order to prevent disturbance by weather and/or animals.

The method is relatively simple, but the unit cost is relatively high due to the single sample used for each array. Also, in areas of high humidity or rainfall, ventilation of the array may be wise in order to prevent mold development on the test material inside the enclosed space.

The standardized version of this test method is available as Japan Industrial Standard JIS K 1571.

Images

Figure 3: Example of a test method description in the Research section of the IRG website.

The second area in the Test Methods section is the interactive Global Field Test Sites map (Figure 4). The map is divided into nominal continental groups of countries and each known test site is located by a hover button which is clickable. Clicking on the information hover button brings up a large scalable vector graphic SVG image of the test site. When this image is clicked, a web page appears with extensive details of the test site as well as further images from the test site. The map is and will always be a work-in-progress and we welcome further participation from anyone with information and images of test sites that are not currently included in the Map.

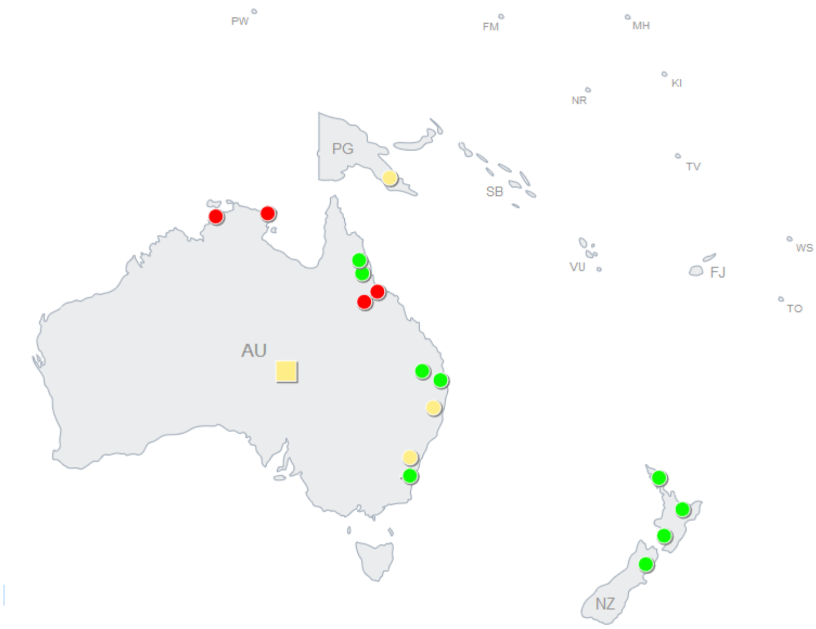


Figure 4: Test field map of Oceania.

The next area under development for the Research Section of the IRG website relates to the activities of IRG Section 1 – Biology. In this area we are developing new web pages on Wood Degrading Vectors, including microorganisms, insects and physical or other wood degrading causes. It is our intent to have at least some of these pages completed during the next 12 months, again as time and resources permit.

SOCIAL MEDIA WITH THE IRG

In common with many organizations, in recent years, communications within the IRG have been changed with the advent continued growth of the IRG Facebook page and the IRG LinkedIn page (https://www.facebook.com/International-Research-Group-on-Wood-Protection-142224589156224/, https://www.linkedin.com/groups/4161596).

These pages were initially developed, and are maintained, by the IRG Communications Committee member Dr Lina Nunes but have developed into a co-operative work between several other members.

The Facebook page provides an open and ready access for information, photos and comments and continues to grow in popularity with an audience that goes well above the normal IRGWP membership. At the IRG48 meeting in Ghent in June, members of the Communications Committee took the initiative and made a series of short video interviews with the Ron Cockcroft Award (RCA, an IRG travel grant for young researchers) winners and these were posted on the IRG Facebook page. This has been quite successful and the relatively short length of each video makes them an attractive communications tool (Figure 5).

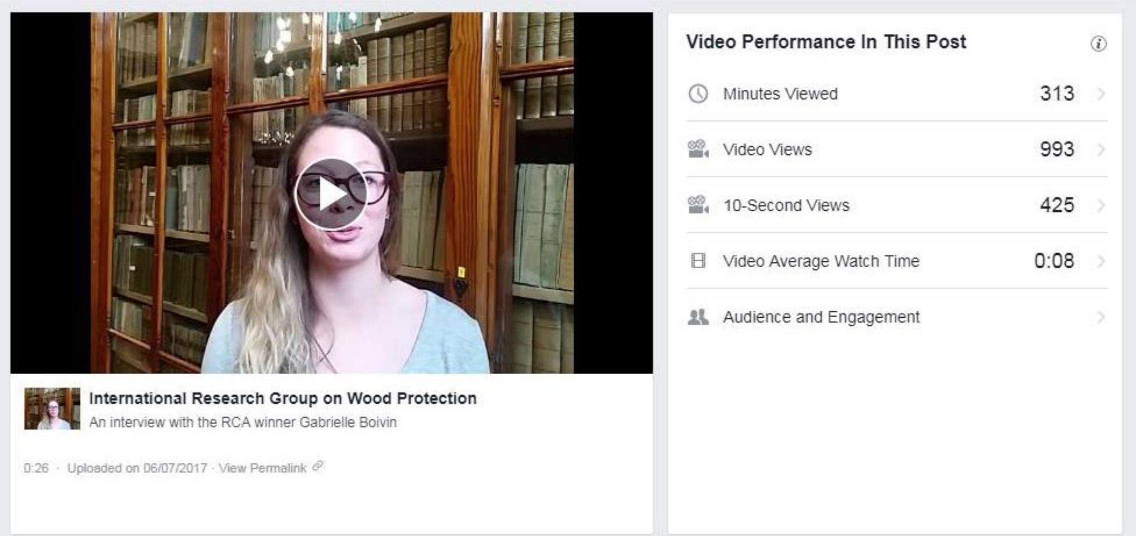


Figure 5: Example of IRG48 video audience

Similarly, the LinkedIn page continues its growth, albeit with a different role and participation.

It is important for the IRG Communications Committee to continue to adapt our communications platforms to meet the needs of our ever-changing membership makeup. As has been the case for many years, the in-coming growth in IRG membership is from a decidedly younger age group than that of the existing membership. New members these days are much more adept at and adapted to the use of Social Media as a primary communications tool. That reality lends increasing credence to our need to adapt to this changing reality.

One aspect of the IRG Communications Committee's aims that has not developed to any degree relates to the issue of providing Webcast presentations live online during the IRG annual scientific conference meetings. A key issue is that the IRG membership is geographically very diverse, and time zones present large challenges to the likely benefits of such webcasts versus the time and effort required of local organizing committees to make such productions with parallel sessions, etc. The committee continues to try and address this issue and assess the value of providing such a service. A similar initiative under consideration is the development of specific Webinars relating to Wood Protection technology. Currently these remain an unfulfilled goal as the voluntary nature of the IRG, as well as the decline in discretionary time and resources available to much of the IRG membership, present serious obstacles to fulfilling this goal.

IRG NEWSLETTER

The other communications vehicle within the IRG Communications Committees aegis is the IRG Newsletter. This is currently issued bi-monthly and at present this is sent out via an email service known as iContact. There are currently around 470 recipients of the IRG Newsletter.

The primary function of the Newsletter is to provide up to date information to our members, sponsors, and diaspora, through an active email contact process, as compared with requiring the membership to seek such information via the website or social media. While tracking information can be somewhat unreliable, it appears that most recipients of the IRG Newsletter actually open the email and read, or at least skim it. The Newsletter provides information on any extraordinary business within the IRG, important updates on the up-coming IRG Annual Scientific Conference meeting, as well as any personal news that may be of interest to the readership, and similar any Industry or organizational news that is received. An important ancillary function is to provide news of up-coming non-IRG meetings that our readership might be interested in as well as links to various relevant updated information on the IRG website or Facebook pages.

Over the last two years, the IRG Communications Committee has published one or two member bios in each IRG Newsletter. These are usually the most read items in any given Newsletter. Our intent is to provide two separate member or sponsor bios in each Newsletter going forward. The bios are usually two or three pages long with embedded clickable thumbnails of images leading to full size images viewable through the IRG website. The bios are now archived on the Member Bios webpage on the IRG website.

All the Newsletters dating back to when we commenced using the iContact email service are archived and accessible through the Newsletters Archive webpage of the IRG website, including the most recent Newsletter in direct form on the webpage.

CONCLUSIONS

The IRG Communications Committee is a group of volunteers who give their time and energy in trying to provide multi-faceted communications of wood protection research and technology to the membership and sponsors of the IRG as well as to others who may have an interest in the people and science in this field.
We believe that a multi-facetted strategy is needed to transport all relevant information from the research group to the outside world and within the group, since both are heterogeneous with respect to business interests, education, affinity to modern communication media and many other factors more. However, the overall aim of the CC activities remains the transport of knowledge and information from research and academia to different target groups such as industry, planners, builders, approval bodies, and simply the users of timber products.

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An overview of the knowledge transfer through STSMs

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Keywords: knowledge transfer, short term scientific mission

ABSTRACT

This paper presents an overview on the knowledge transfer achieved in the COST Action FP1303 through the Short Term Scientific Missions (STSM's) which had as purpose to support working visits to laboratories and institutions of COST Action FP1303 member countries.

Introduction

The COST Actions are science and technology networks which are open to academia and industry for distribution and application of knowledge. Each action achieves the objectives through different networking tools, such as: conferences, workshops, focus meetings, training schools, short term scientific missions (STSMs) and other dissemination activities (http://www.cost.eu/COST_Actions/networking).

Among other knowledge transfer tools the "Short-term scientific missions (STSM) are exchange visits between researchers involved in a COST Action, allowing scientists to visit an institution or laboratory in another COST country to foster collaboration, to learn a new technique or to take measurements using instruments and/or methods not available in their own institution/laboratory. STSM are intended especially for young researchers." (http://www.cost.eu/COST_Actions/networking).

Statistics

In the framework of the COST Action FP1303, an important role was played by networking and knowledge transfer through the STSMs. In this context the Action participants from nineteen COST countries (Austria, Czech Republic, Croatia, Estonia, Finland, France, Germany, Greece, Italy, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and Ukraine) expressed their interest to visit laboratories/ institutions from fifteen COST countries (Austria, Denmark, Finland, France, Germany, Italy, Latvia, Norway, Poland, Romania, Slovakia, Slovenia, Sweden, Switzerland, and United Kingdom). The accepted and finalized STSMs according to each grant period are represented graphic in Figure 1.

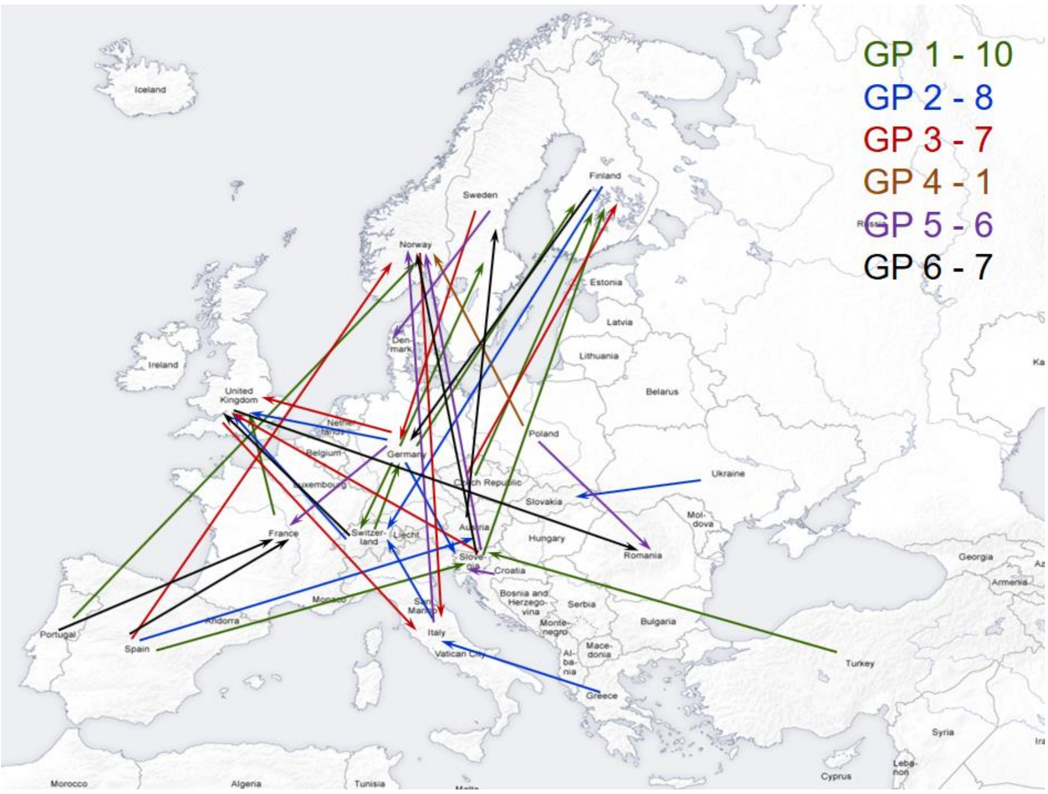

Figure 1. Performed STSM's in the framework of COST Action 1303 according to each grant period

As can be seen from the figure, it is a well dispersed spread of the applicants and host countries. From the nineteen applicant countries, eight of them are inclusiveness target countries (ITC) (Czech Republic, Croatia, Estonia, Greece, Poland, Portugal, Slovenia, and Turkey) and one is near neighbour country (Ukraine).

The percent of the STSM's according to the application country is presented in Figure 2. On the top of the list it is Germany with seven STSM's applications, followed by Slovenia and Spain with 4 application each. At the other side 7 countries (Turkey, France, Ukraine, Greece, Norway, Hungary and Austria) are on the same position with only one application each.

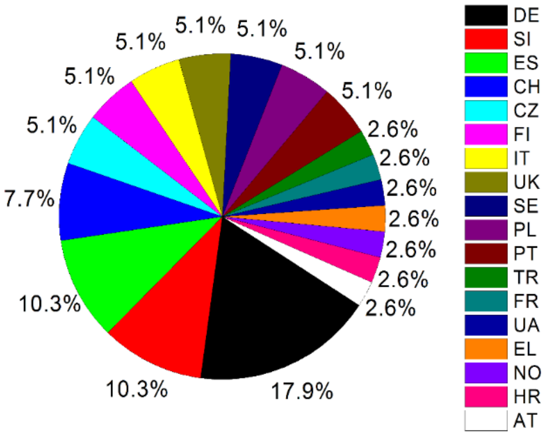

Figure 2. The percent of the number of STSM's for applicant country

At the same time, the host countries include a number of five ITC countries (Latvia, Poland, Romania, Slovakia, and Slovenia) from a total of fifteen. The number of the countries which hosted STSM's as well as the percent of applications are represented Figure 3. At this time on top of the list it is UK and Norway with 6 hosting STSM's each, followed by the Slovenia and Finland with 4 hosting STSM's each. At the other side of the list are Austria, Slovakia and Denmark with only one hosting STSM.

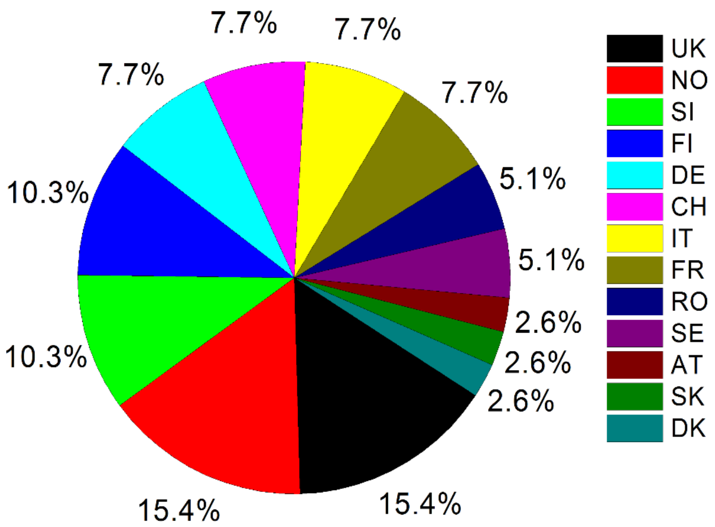

Figure 3. The percent of the number of STSM's for host countries

Another important aspect, which worth to be mentioned, is the number of applicants of persons with PhD and without and also the genders. In Figure 4 is represented graphic the total number of applicants divided in persons with or without PhD and also according to their gender.

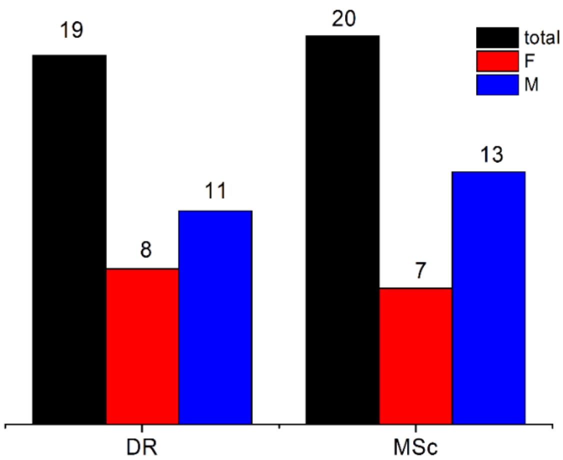

Figure 4. The total number of applicants divided according to their gender and PhD

Once again, it can be seen that from the total number of 39 STSM's performed in the framework of the COST Action FP1303, 19 persons had their PhD, while 20 persons were PhD students. At the same time, from 19 STSM's performed by persons with PhD, 8 were female. On the other side, from 20 PhD students only 7 applicants were female.

STSM's and MoU

From the beginning, the action aimed

- to improve the knowledge on the performance of bio-based materials used as building products and the assessment of factors influencing these,

- to understand the interlinked relationships between durability, product aesthetics, fibre-moisture relationships, decay hazards,
- to achieve a better understanding of the biology and mechanisms influencing the growth of fungi and other degrading organisms,
- to evaluate the efficacy of impregnation, chemical modification and surface treatments of the materials against fungal growth, and
- to develop a more scientific approach to determining service life and ultimately the performance of a material as a building component

According to the above mentioned goals, the performed STSM's represent a good indication of the achievements fulfilled during this period. In Tabel 1 are listed all performed STSM's according to different main research area of interest – survey on naturalness, life cycle assessment, modelling, adhesives, moisture, fungi, moulds, termites and marine borer, morphology, structure, mechanical testing, density mapping, modification, composites, VOC's and interactions.

Table 1. Performed STSM's in the framework of the COST Action 1303 listed according to different areas of interest

Applicant	Host	Period
Survey		
Mr Michael Burnard (SI)	Dr. Mark Hughes (FI)	10-20.02.2014
STSM title: *Investigating Views of Naturalness Across Europe* - assessment of how individuals across Europe perceive building materials according to their naturalness - understanding the cultural differences in the perception of naturalness across Europe		
Life cycle assessment (LCA)		
Dr Serkan Ozdemir (TR)	Dr. Andreja Kutnar (SI)	11-22.08.2014
STSM title: *Wood densification treatments of veneer specimens and environmental impact assessment* - densification methods - the methods and tools for environmental impact assessment of processes and products (LCA, EPD)		
Dr. Christelle Ganne-Chédeville (CH)	Dr. Johannes Welling (DE)	24-28.03.2014
STSM title: *LCA of Bio-Based Ultralight Particleboard* - life cycle assessment (LCA) of ultralight particle boards with a bio-based core layer, identify weaknesses, and improve the approaches in order to get a consistent model for the forecasting the environmental impact		
Mr Jinbo Hu (FR)	Dr. Graham Ormondroyd (UK)	01-30.06.2014
STSM title: *The life cycle assessment of novel timber treatments* - life cycle environmental impacts related to tannin-boron-treated raised lumber floor and uses LCA to quantify such impacts		
Dr. Petr Cermák (CZ)	Dr. Lauri Rautkari (FI)	15-26.02.2016
STSM title: *Performance of post-manufacture thermally modified linear welded birch wood (Betula pendula Roth): shape stability, mechanical properties and environmental effects* - mechanical performance, i.e. tensile shear strength, internal bonding, delamination tests - LCA calculation		

Dr. Andreja Pirc Barcic (HR)	Dr. Andreja Kutnar (SI)	19-25.03.2017
STSM title: *Boostering knowledge and information about the importance of the LCA analysis in environmental impact assessment of wooden products* - life cycle inventory – development of the system boundaries and data collection process for the LCA analysis		
Modelling		
Dr. Jakub Sandak (IT)	Dr. Ingunn Burud (NO)	11-17.12.2016
STSM title: *Development of a numerical model for computation of the weather dose in natural weathering of biomaterials* - development of a novel numerical model for computation of the weather dose on the base of meteorological data and other geo databases		
Mr Davor Kržišnik (SI)	Dr. Thomas Thiis (NO)	23.01-13.02.2017
STSM title: *Statistical modelling of colour change of wooden model house unit as a function of climatic exposure* - applying monitored conditions to the model to simulate the microclimate for a wooden façade and decking and further to simulate weather degradation and mould growth on the surface		
Adhesives		
Mr Alireza Bastani (DE)	Dr. Anti Rohumaa (FI)	11-18.05.2014
STSM title: *Investigation on bonding properties of modified birch veneers using ABES machine* - bonding properties of modified birch veneers (furfurylated, heat treated and melamine treated) with PF adhesive		
Dr Pavlo Bekhta (UA)	Dr. Jan Sedliacik (SK)	01-30.06.2015
STSM title: *Properties of plywood panels manufactured from thermally compressed veneer* - effect of thermo-mechanical treatment of veneer on the properties of plywood panels made using non densified and densified veneer and commercial phenol-formaldehyde glue resin		
Mr David Zerbst (DE)	Dr. Peter Niemz (CH)	15.09-06.10.2014
STSM title: *Analysis of the behaviour of bonded wood under cyclic stress* - comparison of the most important adhesive groups for timber construction (polyurethane, melamine-formaldehyde resin and phenolic resorcinol-formaldehyde resin) focusing on the behaviour of the bondline during alternating shear tension		
Dr Eduard Correal Mòdol (ES)	Dr. Stefanie Wieland (NO)	17.10-01.11.2015
STSM title: *Performance of adhesives on glulam made with European chestnut timber* - production of prototypes of glulam with the different adhesive formulations among Dynea's formulations and testing of the performance of the adhesives		
Moisture		
Dr. Petr Cermák (CZ)	Dr. Lauri Rautkari (FI)	20.10-07.11.2014
STSM title: *Influence of dry-soak cycles on dim. stability and OH-group's accessibility of thermally mod. Wood* - evaluation of the moisture behaviour of thermally modified wood - dimensional stability after certain drying, sorption behaviour and OH-group´s accessibility by means of DVS		
Ms Susanna Källbom (SE)	Dr. Holger Militz (DE)	09-18.03.2016

STSM title: *Influence of high humidity exposure on sorption properties and morphology of wood particles after thermal modification* - studying the influence of earlier high humidity exposure on the sorption properties and wood particle morphology/size of unmodified wood particles before and after thermal modification		
Dr. Sanne Johansson (SE)	Dr. Emil Engelund Thybring (DK)	24-28.04.2017
STSM title: *Wood-water interactions in brown-rot decayed wood characterized by low-field NMR* - analysis of water-saturated samples (both degraded material and controls) low-field NMR to differentiate between LFNMR signals from water in different physicochemical environments		
Fungi, moulds, termites and marine borer		
Ms Linda Meyer (DE)	Dr. Pia Larsson Brelid (SE)	30.06-04.07.2014
STSM title: *Isolation of decay fungi from in-ground and above ground durability field tests* - sampling fungal isolates from field test specimens to identify them and their reproduction under laboratory conditions		
Mr. Lothar Clauder (DE)	Dr. Magdalena Kutnik (FR)	28.08-10.09.2016
STSM title: *Analysis of fungi in TMT samples* - genomic DNA extraction, quantification and identification of genotypes of different fungi on TMT wood		
Ms. Carola Hesse (DE)	Dr. Miha Humar (SI)	23.03-01.04.2015
STSM title: *Studies on the material resistance & moisture performance of four european wood species* - evaluation of the durability aspects and the resistance against soft, white and brown rot of Common juniper, Black cherry, Yew and Rowan		
Ms. Mariana Palumbo (ES)	Dr. Miha Humar (SI)	20-25.10.2014
STSM title: *Mould and fire resistance of biobased insulation boards* - planning of an experimental setup on the development of natural insulation boards based on vegetal pith and natural binder		
Ms Sónia Duarte (PT)	Dr. Carl Gunnar Fossdal (NO)	18-29.08.2014
STSM title: *Assessment of subterranean termite symbiotic fauna under different diets* - analysis of subterranean termites (captured and tested in Portugal) for their symbiotic fauna in terms of their morphological characteristics and for their lignocellulolytic capacities		
Mr Malte Janus (DE)	Dr. Simon Cragg (UK)	06.03-04.04.2016
STSM title: *Laboratory screening of thermo-mechanically densified and thermally modified timbers for resistance to the marine borer Limnoria quadripunctata* - testing the resistance of wood against *Limnoria quadripunctata*		
Dr Lina Nunes (PT)	Dr. Magdalena Kutnik (FR)	27.09-04.10.2017
STSM title: *Test methods to evaluate termite susceptibility of insulation materials* - elaboration of a draft laboratory test procedure for susceptibility of insulation materials to subterranean termites - application to six different insulation materials using *Reticulitermes flavipes* - the definition of insulation categories according to its bio-susceptibility		
Mr. David Lorenzo (ES)	Dr. Magdalena Kutnik (FR)	
STSM title: *Advanced understanding of the design in the performance, degradation and service life prediction of wood species in use class 3 field test devices*		

- analyzing the performance and degradation of wood species in the use class 3 field test devices in France and comparing the data with the ones recorded in Spain and understanding of conditions influencing in the performance and determining the parameters to be taken into account in the "Performance-durability-by-design"		
Morphology and structure		
Dr. Anna Sandak (IT)	Dr. Marion Noël (CH)	22-28.03.2015
STSM title: *Microscopic evaluation of morphological changes to spruce wood after short term natural weathering* - investigating the kinetic of the degradation rate of wooden samples exposed for the short term weathering conditions through optical, scanning and atomic force microscopes		
Dr. Lauri Rautkari (FI)	Dr. Emil Thybring Engelund (CH)	09-20.02.2015
STSM title: *Raman imaging of naturally and artificially decay resistant wood* - Raman imaging to map pinosylvins in the cell walls of pine heartwood		
Dr Charalampos Lykidis (EL)	Dr. Jakub Sandak (IT)	14-24.09.2015
STSM title: *The use of NIR spectroscopy as a quality marker of hydrothermally treated wood* - analysis of the hydrothermally treated with saturated steam wood by NIR spectroscopy		
Dr Athanasios Dimitriou (UK)	Dr. Jakub Sandak (IT)	29.02-29.04.2016
STSM title: *Surface charachterisasion fo spruce after natural weathering* - determination of the colour change, and structural evaluation by VIS, NIR, MIR spectroscopy, determination of glossiness, XRF analysis, determination of roughness		
Dr Magdalena Broda (PL)	Dr. Maria-Cristina Popescu (RO)	23-29.04.2017
STSM title: *The reactivity of organosilicon compounds with wood - FT-IR study* - evaluation of the reactivity of various organosilicons with wood by using the infrared spectroscopy methods, and assessing their influence on the performance of treated wood		
Dr. Dennis Jones (UK)	Dr. Maria-Cristina Popescu (RO)	16-28.08.2017
STSM title: *Determination of the effectiveness of a combined thermal/chemical wood modification by the use of spectroscopic methods* - analysis of the combined thermal/chemical treated samples by infrared (FT-IR) and near infrared (NIR) spectroscopy to better understand chemical changes and interactions in the samples		
Ms. Carolina Gomes de Oliveira Griebeler (ES)	Dr. Gianluca Tondi (AT)	09.02-08.05.2015
STSM title: *Effect of thermal modification on the colorimetric parameters and physical properties of Eucalyptus* - analysis of the heat treated wood on the esthetical properties, as well as mass loss, shrinkage, equilibrium moisture content, volumetric swelling and fiber saturation point		
DMTA/DMA		
Dr Marion Noel (CH)	Dr. Graham Ormondroyd (UK)	10-20.05.2015
STSM title: *DMTA analysis of modified and weathered wood samples* - evaluation of the roughness of a set of samples exposed for short term to weathering conditions		

- analyzing the behaviours of the chemically modified wood samples with polybutylene succinate by DMTA		
Dr Magdalena Broda (PL)	Dr. Erik Larnøy (NO)	29.05-28.06.2016
STSM title: *Using DMA device to characterise physicomechanical properties of archaeological oak wood treated with silanes* - evaluation of the reactivity of various organosilicons with wood by using the infrared spectroscopy methods, and assessing their influence on the performance of treated wood		
Ms. Charlotte Grosse (CH)	Dr. Merwenna Spear (UK)	02-17.08.2017
STSM title: *Wood modification with bio-polyesters. Analysis of performance with DVS and DMTA* - analyzing the physico-mechanical properties of modified wood with bio-polyesters by DMTA under varying humidity - analyzing the sorption behavior of oligomers used for impregnation of solid wood - analyzing the influence of treatment parameters (temperature, relative humidity and duration) on properties of wood modified with bio-polyesters, by DVS		
Density mapping		
Mr Petter Stefansson (NO)	Dr. Jakub Sandak (IT)	14-25.03.2016
STSM title: *X-ray density mapping of weathered wood samples* - investigating the kinetic of the degradation rate of wooden samples exposed for the short term weathering conditions by X-ray for detailed mapping of wood density		
Modification		
Dr Matthew Schwarzkopf (SI)	Dr. Viacheslav Tverezovskiy (UK)	01-15.04.2016
STSM title: *Utilization and modification of the Istrska belica olive as a wood preservation treatment* - identifying the feasible oil modifications and preparing modified oil to be used in further wood impregnation studies		
Mr Davor Kržišnik (SI)	Dr. Lone Ross Gobakken	12-20.10.2017
STSM title: *Artificially accelerated greying of the wood surface* - testing different concentrations of iron (II) sulfate on different wood species and finding out the optimal recipes for different combinations		
Composites		
Mr. Albert Hernandez Estrada (FI)	Dr. Jörg Müssig (DE)	1.07-13.08.2017
STSM title: *Investigation of the impact of dislocations in hemp fibres at the composite level* - studying the impact of dislocations at the end product level, at the composite level (using for composites fibres extracted manually from the plant without any further processing and fibres that followed processing and epoxy resin)		
VOC's		
Mr. Lothar Clauder (DE)	Dr. Graham Ormondroyd (UK)	29.03-18.04.2015
STSM title: *Emissions from bio-based building materials* - evaluation of the emission absorbance and identification of the emission by Gas Chromathography - Mass Spectroscopy and Ion Chromatography (IC) with impact on impregnating solution and its anti-corrosive effect and the influence of the temperature and moisture on aldehydes		
Interactions		

Mr Jérôme Colson (AT)	Dr. Torbjörn Pettersson (SE)	31.07-15.10.2017
STSM title: *Characterization of fundamental wood polymer to synthetic polymer interaction by means of colloidal probe technique* - assessing the compatibility between regenerated lignocellulosic model fibres and various polymers on a nanometer scale		

As mentioned above, all STSM's reflect the fulfilment of the objectives proposed from the beginning of the Action FP1303. Moreover, the big number of applications covering most of the countries which signed the MoU indicate the interest of the researchers on the subject and their involvement in the achievement of the proposed objectives. Moreover, the action helped the researchers to form a good network for future collaborations.

Figure 5. Some of the applicants "having fun" during their STSM's

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I (Carmen-Mihaela Popescu) would like to thank COST Association for approving this Action, Dennis Jones (Chair of the Action) which nominated me as STSM manager and all applicants and hosts researchers.

Strengthening the confidence in bio-based building materials – BIO4ever project approach

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Keywords: bio-based materials, multi-sensor characterisation, service life modelling, end of life strategies, simulation software

ABSTRACT

Recent advances in building materials have delivered several solutions for the construction sector. However, while considering bio-based materials dedicated for buildings, the operational durability is still a limiting factor in many applications and environments. Biomaterials, defined here as materials derived from organic sources, have become recognized as an attractive alternative to several traditional building solutions, often called "building materials of the 21st Century". These can efficiently sequester carbon, balancing emissions from other materials. However, compared with traditional building materials possess some properties that are less understood and/or remain difficult to control.

The BIO4ever project promotes usage of innovative façade biomaterials with minimal environmental impact, but also substantially improve sustainability of biomaterials by controlling their transformation at the end of use. The experimental data are used for development of the numerical models simulating the material deterioration in a function of time and exposition. Accurate service life prediction, service life costing and aesthetical performance models of recently evaluated bio-based building materials are foreseen as the most important deliverables. Dedicated algorithms simulating material modifications by taking into account original material characteristics and degrading process parameters are developed at the micro, mezzo and macro scale. Software visualizing bio-materials' performance will be dedicated for investors, architects, construction engineers, professional builders, suppliers and other relevant parties, including also final customers. The appropriate numerical tools, able to capture the multi-scale evolution of damage are recently tested under realistic conditions within field trials and surveys on structures in service.

INTRODUCTION

The trend for rapid deployment of innovative material solutions at reduced-costs through predictive design of materials and innovative production technologies is observed nowadays. Such materials are optimized for specified applications, assuring at the same time expected properties and functionality at elongated life, minimizing the environmental impact and reducing risk of product failure. As a consequence, higher numbers of well performing (also in severe environments) construction materials are available on the market. It is extremely important for the bio-materials production sector to follow this trend and to continuously improve its offer.

The expansion of bio-based products availability and its wide utilization in modern buildings is a derivative of the Europe 2020 strategies. It is foreseen that bio-materials will play an increasingly important role in the future, in order to assure the full sustainability of the construction sector.
The development of really innovative and advanced bio-products relies on the deep understanding of the material properties, structure, assembly, formulation and its performance along the service life. Today's bio-based building materials, even if well characterized from the technical point of view, are often lacking of reliable models describing their performance during service life. Another aspect, often underestimated (but critical for the sustainable use of bio-based building materials), is related to the transformations of building materials after their service-life. The advantage of the elevated resistance for degradation can become a restraining factor in recycling, reuse or depose/landfill.
The overall goal of BIO4ever project is to contribute to public awareness, by demonstrating the environmental benefits to be gained from the knowledgeable use of bio-based materials in buildings. A dedicated software simulating bio-materials performance, degradation and end-of-life in severe operating environments is under development. It will serve as a tool for demonstrating advantages of using bio-based materials when compared to other traditional resources. The tool is dedicated for investors, architects, construction engineers, professional builders, suppliers and other relevant parties, including also final customers.

INVESTIGATED MATERIALS

New developments in the field of wood modification offer innovative products with enhanced properties of natural timbers. These include novel bio-based composite materials, as well as more effective and environmental-friendly protective treatments, e.g. thermal treatment, densification and chemical modifications. Similar revolutionary progress is observed with surface treatments including innovative coatings, impregnations or integration of nanotechnology developments in wood protection.
The samples investigated within the project represent all the above-mentioned groups. Performance of 120 selected façade materials provided by over 30 industrial and academic partners is recently evaluated. The experimental samples include different wood species from various provenances, thermally and chemically modified wood, composite panels, samples finished with silicone and silicate based coatings, nanocoatings, innovative paints and waxes, melamine treated wood, copper treated wood, bamboo cladding, reconstituted slate made with bio-resin and samples prepared according to traditional Japanese technique: shou-sugi-ban.

MULTI-SENSOR CHARACTERIZATION

A multi-sensor measurement chain, including both laboratory and on-site techniques, for the acquisition of properties at different scales (molecular, microscopic, macroscopic) is established at CNR-IVALSA. Routine material characterization includes:

- Photogrammetry
- VIS, near and mid infrared spectroscopies and hyperspectral imaging
- IR thermography
- Surface characterization (color, gloss, wettability, roughness)

Investigated bio-materials are characterized before, during and after degradation by biotic and a-biotic agents in order to provide experimental data to be used for better understanding the bio-materials performance/degradation as a function of time. Obtained data are currently utilized for development of numerical models.

WEATHERING TESTS

Weathering is the general term used to define the degradation of materials exposed to the weather condition. The rate of weathering varies within tree species, function of product, technical/design solution, finishing technology applied but most of all on the specific climatic conditions. Three different approaches are used for controlled samples degradation:

Natural weathering of bio-materials on the vertical stands

Dedicated stands were installed at CNR-IVALSA (San Michele All'Adige, ITALY). Experimental samples were exposed to four cardinal directions for different weathering doses/periods and characterized with laboratory instruments. Weathering stands simulating façade installation are presented in Figure 1. A sequence of images corresponding to the monthly changes of samples appearance is shown in Figure 2.

Figure 1: Facades materials exposed to natural weathering

Natural weathering on the robotized stand

The stand, recently under development, will assure optimal exposure to South by varying inclination from 23° to 70° following the sun position. All samples were automatically characterized weekly with a multi sensor scanner installed on the stand. The robotized stand hosted a digital camera, VIS and NIR spectrometers as well as a gloss meter. Moisture and temperature on the back (unexposed) side of samples were continuously monitored. Three replicates per bio-material were installed in order to assure statistical reliability of results.

Figure 2: Facades materials at the beginning of weathering test, and their appearance with the progress of weathering (up to 5 months).

Artificial weathering tests with SUN-test and QUV

Weathering campaign by using state-of-the-art artificial weathering instruments was conducted in order to compare performance of investigated materials. In addition, samples prepared from Norway spruce wood (*Picea abies* L. Karst.) within a Round Robin test (COST FP1006) served as supplementary set to validate obtained results. In that case, 21 sets of twin samples were exposed for the duration of 12 months, facing the South in 17 locations in Europe. Samples were collected monthly, characterized afterward in the laboratory with multi-sensor approach.

END-OF-LIFE OF INVESTIGATED MATERIALS

The best solution from the environmental point of view will be identified for all investigated bio-materials. Suitability of the state-of-the-art methods currently used (such as combustion, pelletizing, digestion, land filling, and fermentation) are investigated for every material (Figure 3).

Figure 3: Facades materials during degradation in soil – simulation of landfilling

An additional set of intensive experimental trials was performed in order to develop alternative methods. It included exposition of the bio-materials to selected rot fungi and insects. A special focus was directed toward recycling systems for converting organic (bio-materials) wastes into high protein content feed supplements. This approach follows directly demands of FAO. Efficiency of selected insects for biomass transformation of wasted biomaterials is therefore investigated (Figure 4).

Figure 4: Facades materials after 3 months of degradation with termites in laboratory tests rated according to 5 point scale EN 252 (adapted) (left: grade 2 – moderate attack, right – grade 4 –failure)

MULTISCALE MODELLING

The approach of materials/buildings monitoring by using multiple sensors simultaneously has become more frequent due to better representation of the real-life scenarios. In this case, fusion of different sources of information is a fundamental, but also challenging task. This is due to the complexity of the optimal sensor selection, measurement strategy, signal processing and interpretations of results (Sandak *et al.* 2016). The following aspects are explored within the project:

- selection and evaluation of the most suitable signal pre- and post-processing techniques/algorithms aimed to the extraction of most useful information from the raw data sets
- elaboration of "Data Fusion" procedures for the integration of the data obtained from different analytical techniques/sensors and from different degradation stages
- multivariate classification/grading of the investigated materials quality/functionality, with a special focus on aesthetical aspect
- development of numerical models simulating changes of bio-materials' properties as a function of the weathering doses and construction details
- design of a visualization software simulating aesthetical changes of the bio-materials due to natural weathering progress
- creation of the numerical tool for computation of the bio-materials' service life period, including maintenance/renovation scheduling.

DEVELOPMENT OF DEMONSTRATION TOOLS FOR ARCHITECTS/ENGINEERS/INVESTORS

The new knowledge and numerical models would become useless without confrontation with the target group of future users. Unfortunately, very few architects and civil engineers are correctly trained in the aspects of using wood/bio-materials in structures. Therefore, an intensive campaign for promoting wood and bio-materials is conducted in the frame of BIO4ever project. Dedicated software simulating bio-materials performance, degradation and end-of-life in severe operating environments is foreseen as a most important deliverable of the project. The concept for the software simulating changes of bio-materials (related to both functional performance and aesthetics) for the whole duration of their service life is presented in Figure 5.

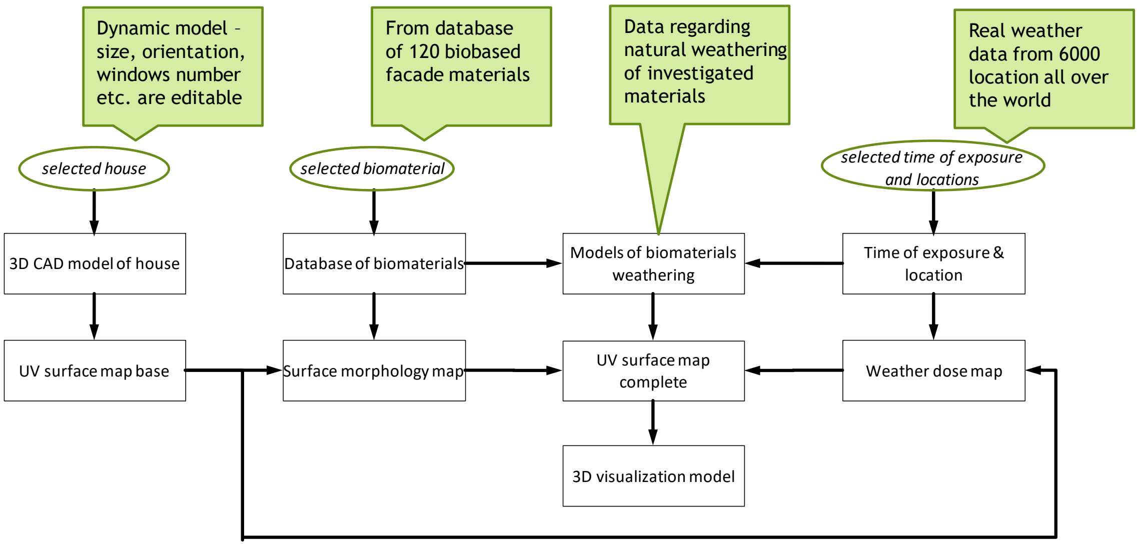

Figure 5: Flowchart of the data for 3D visualization of the building exposed to natural weathering

Time series of pictures were acquired during exposure of tested materials. These were subsequently used for interactive simulation of facades appearance. Customers will be able to choose a material from the database and simulate the building outlook at the brand new stage. In addition, numerical simulation will allow visualization of changes the appearance depending on the time of service, exposure direction, geographical location and with consideration of architectonical details of the structure. The print screen of the software prototype is presented in Figure 6.

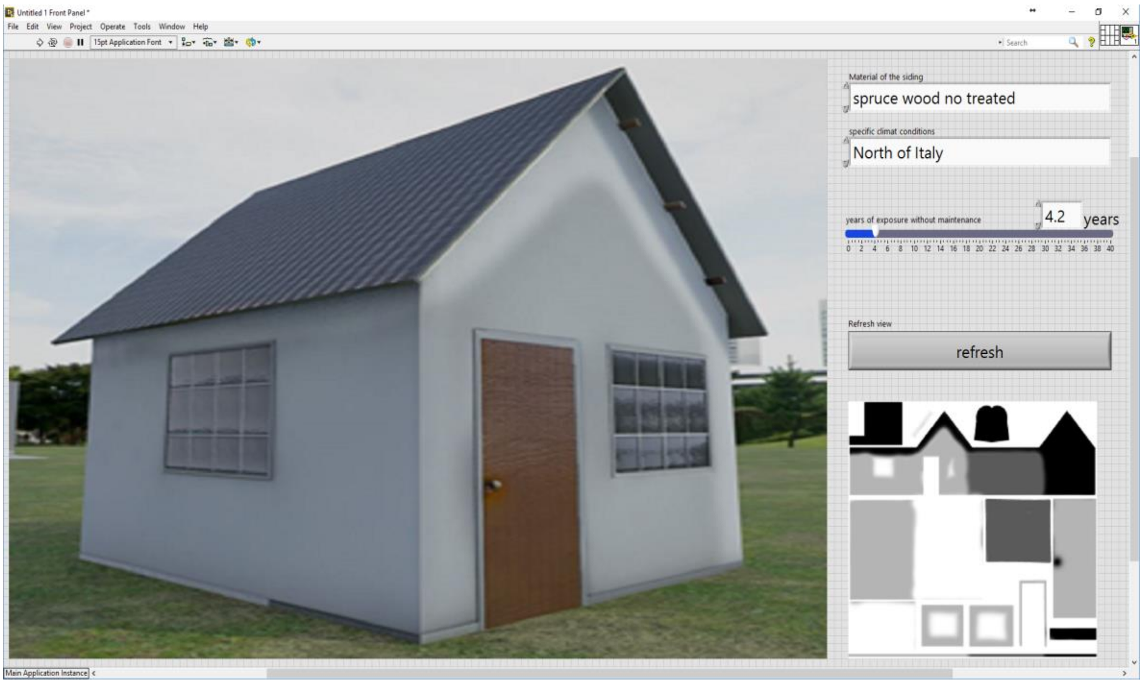

Figure 6: Print screen of demo software

CONCLUSIONS

The trend for rapid deployment of novel/advanced material solutions at reduced-costs through predictive design of materials and innovative production technologies is observed nowadays. It is extremely important for the bio-materials production sector to follow this trend and to continuously improve its offer. The development of really innovative and advanced products relies on the deep understanding of the material properties, structure, assembly, formulation and its performance along the service life. Comprehensive understanding of the physical/chemical properties and their connection with the material's structure will be obtained as a result of a combination of analytical/experimental methods and numerical modelling. Results of the BIO4ever project provide technical and scientific knowledge but also contribute to the public awareness, by demonstrating the environmental benefits to be gained from the knowledgeable use of bio-based materials in buildings.

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Multidisciplinary teaching helps students to understand the context of building with bio-based materials

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Keywords: multidisciplinary teaching, wood material technology, wood architecture, wood construction

ABSTRACT

Adjusting to the various aspects of building with bio-based materials and to the learning of students is a challenge, but also an opportunity to truly foster the sustainable, energy-efficient development of the built environment. Encouraging students from different fields to co-operate brings new energy and ideas to both research and teaching. Co-operation between the departments of Forest Products Technology, Civil Engineering and Architecture in the field of teaching and research started more than twenty years ago at Helsinki University of Technology (Vahtikari et al. 2006). At the beginning the network carried the name PRA deriving from the first alphabets of the Finnish terms for wood (puu), construction (rakentaminen) and architecture (arkkitehtuuri). Currently the network is known as Aalto Wood. Joint teaching has consisted of lecture-based courses exploring the properties and use of wood material from various perspectives and larger project courses in which students from various disciplines were asked to bring the expertise from their own field to the given/defined/chosen assignment and to learn from others by working with them in a research-design-and-build project team. From the very beginning, students were asked to suggest own research ideas within the project themes, which may lead to research questions that would otherwise remain unexplored. This paper presents how some of the courses in the Aalto Wood teaching network have grasped the topic of building with bio-based materials. In addition, some results from students' research-design-and-build projects are described.

INTRODUCTION

Aalto University is making an effort to encourage students from different fields to co-operate during their studies. The idea behind multidisciplinarity is to widen the perspectives of teachers and students, and help them understand viewpoints and arguments from other disciplines and fields. One of the initiatives aims to foster the sustainable, energy-efficient development of our built environment. Co-operation between the departments of Forest Products Technology, Civil Engineering and Architecture in the fields of teaching and research started already more than twenty years ago at the former Helsinki University of Technology TKK (Vahtikari et al. 2006). In the beginning, the network carried the name PRA deriving from the first alphabets of the Finnish terms for wood (puu), construction (rakentaminen) and architecture (arkkitehtuuri). Currently it is known as Aalto Wood.

Co-operation has brought new energy and ideas to both research and teaching. Recent examples of research co-operation within Aalto Wood include the multidisciplinary projects *Competitive wood-based interior materials and systems for modern wood construction,* Wood2New, and *Energy-efficient living spaces through the use of wooden interior elements,* Wood Life. In addition to Aalto University, the international WoodWisdom-NET funded Wood2New project, included research partners from Sweden (University of Linköping), Norway (Norsk Treteknisk Institutt), United Kingdom (BRE) and Austria (Holzforschung Austria, Technisches Büro für Chemie Karl Dobianer), as well as several industry partners. (Wood2New) Wood Life was part of the *Aalto Energy Efficiency Research Programme* at Aalto University. (Aalto Energy Efficiency Research Programme) Both projects focused on the interior use of wood material and involved experts from the various fields of the Aalto Wood network - architecture, wood material technology, civil engineering - but also from other fields related to the built environment, like environmental psychologists and microbiologists, and acknowledged scientists specialized on interior air quality and toxicology.

Joint teaching within the Aalto Wood network has consisted of lecture-based courses exploring the properties and use of wood material from various perspectives and larger project courses, in which both teachers and students from various disciplines were asked to bring the expertise from their own field to the course assignment and to learn from others by working with them in a research-design-and-build project team. One of the major benefits of project-based learning in multidisciplinary teams is how it encourages students to be active participants and develops their working life skills (Vahtikari et al. 2013). Teaching practices vary among different disciplines, schools and departments at the Aalto University, which makes also the running of the course more challenging and enforces teachers and students to adapt and adjust to different working methods, viewpoints and teams. Versatile perspectives are also a benefit: questions and remarks "out of the box" challenge way of thinking and demand new solutions for the given project assignments, as well as for organizing the course and evaluating the results.

MULTIDISCIPLINARY STUDENT PROJECTS

Project course *Integrated Interior Wooden Surfaces* was originally designed to be part of a 20 ECTS study package called Wood Construction. It was the only course focusing entirely on the interior use of wood. Other courses had a wider perspective on wood architecture and construction emphasizing for example the requirements of and reasons for developing building with wood into an industrial process. The *Integrated Interior Wooden Surfaces* course consisted of lectures and a research-design-and-build assignment. Students were divided into groups of three to five students with the aim to have at least one student from every Aalto Wood disciplines in each group. The course was not only multidisciplinary, but also multicultural, since the majority of participants were students participating in the one-year Wood Programme (Wood Program), tailored for international students from various engineering and architectural Master's programmes Students learned from each other, not only engineers from architects and vice versa, but also from students of different background and countries, since there is a big global variation among domestic and imported wood species, climates, building and architectural traditions, as well as the use of interior and structural materials.

Utilizing the functional properties of wood has been the core of the *Integrated Interior Wooden Surfaces* course from the very beginning. The duration of the course has varied from six to twelve weeks, as well as the level of freedom in defining the project task. Some years students were themselves given the possibility to specify the end-use application in which functional properties of wood were to be used, and some years the assignment was more specific, defining e.g. where their design was supposed to fit and the purpose, like enhancing the user comfort in a real, existing office or finding a way to bring wood in to a wet space, like a bathroom.

Wood can make an office space more comfortable and user-friendly

The focal point of the office space assignment was on improving the interior comfort of a generic and small meeting room in the Department of Architecture. The task had a high profile as the room was used by the Dean. The final design was to be assembled on the wall.

Presented ideas show a vast diversity, with the focal point on lighting, acoustics, warmth or interior air quality of the space. Figure 1 shows two prototypes: one for an acoustic panel and one for a moisture buffering panel. Other designs included an interior panel made of naturally curved birch veneers, a shading device for the window, and a flexible wall panel allowing for a thermally and ergonomically comfortable standing or seated position (Figure 2).

Figure 1: A prototype for an acoustic panel (left) designed to improve the sound properties of speech in the meeting room by reflecting, diffusing and absorbing sound. Group: Tinfte, Kofler, Bie Malde. To the right: a prototype for a moisture buffering panel from group Brazi, Stanier. Images by Katja Vahtikari and Anne Kinnunen.

In addition to research, design and build, the students were asked to prove their claim regarding the functional properties of their choice of wood, design and the performance of their product. The group focusing on acoustics reviewed the requirements and standards for room acoustics in offices and measured reverberation times of the room with and without the acoustic panels. The group focusing on the humidity of interior air tested the moisture buffering capacity of various panels and modelled the effect of increased surface area of exposed wood in the office space. The flexible panel group wanted to employ the haptic properties of wood, and the warm touch to the wooden surface. In this case, the tests focused on techniques making the wooden wall panel flexible and adjustable.

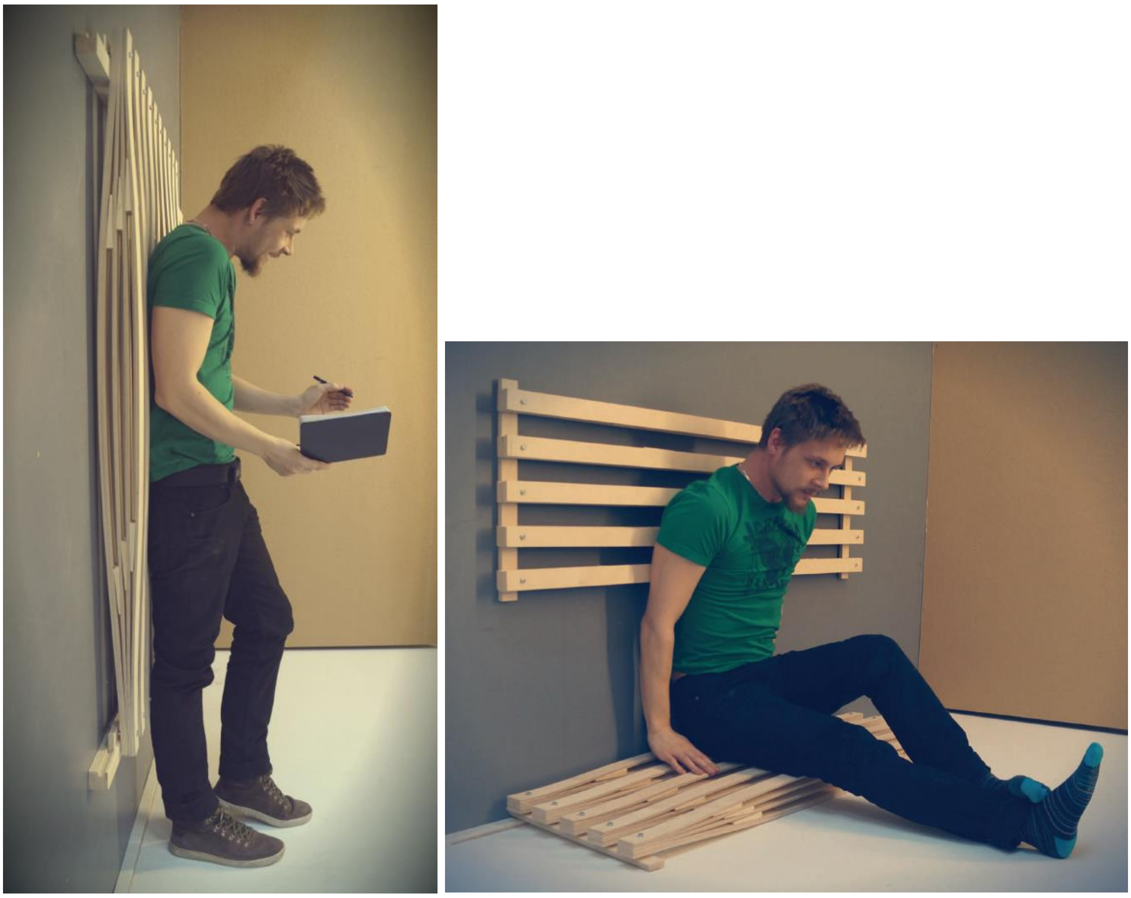

Figure 2: A prototype for a flexible wall panel (group Meri, Mera). Images by Javier Mera and Niko Meri.

Wood in wet spaces

In spring 2016, *Integrated Interior Wooden Surfaces* course work was linked to research projects Wood2New and Wood Life, and students were asked to study and design solutions for functional wooden surfaces in a wet space, like bathrooms. A similar task was also given to students of two furniture design courses, the wood studio of autumn 2015 and spring 2016, at the Aalto School of Arts, Design and Architecture. All final projects are presented in the book *Functional Wood* (Cronhjort et al. 2016).

In the course *Integrated Interior Wooden Surfaces,* five multidisciplinary master student groups took the initiative to develop their ideas for functional wooden surfaces in wet spaces. Final projects included a wall panel design of thermally treated shingles, a modern sauna bench, shower corner, bathtub and sink. All completely in wood. In addition to technical design, the students looked in to the suitability of species, surface treatments and functionality of the proposed object for the demanding space. The solutions showcased the impact of diverse backgrounds, for example the shingle wall solution (Figure 3) took its inspiration from traditional external roofing on vernacular Finnish timber log houses and the bathtub from Japanese Ofuro baths.

In addition to research and laboratory testing, all projects also included empirical testing in real environments. For example, samples of various shingle wall solutions were tested in the shower of a large family, whereas engineering students of the same group focused on contact angle measurements, optimizing the thermal treatment of the selected species, spruce, and the dimensioning of single shingles.

Figure 3: A prototype for shingle shower wall of thermally treated split spruce. Group: Traver, Hakola, Koskinen, Kuçuku, Konse. Image by Katja Vahtikari.

DISCUSSION AND CONCLUSIONS

Course evaluation has provided feedback for the course development throughout the years. The core concept, bringing different disciplines together to work on a common project, was perceived positively. For the majority of the engineering students the design aspect of the assignment was new. Visual aspects are often excluded from typical engineering courses whereas the material research aspect and laboratory testing was new for many architecture students. Some of the project groups made user studies, which helped them to better understand the end-use environment and user perspective. Important and beneficial for bio-based product development in general would be to monitor the performance of the finished product in real use. The yearly course schedule was too tight to allow such monitoring, but in an ideal case it could have been embedded in some follow-up course focusing for example, on developing surface coating and modification methods.

ACKNOWLEDGEMENTS

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Knowledge transfer using termites as an educational model

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Keywords: Education, knowledge transfer, science communication, termites

ABSTRACT

Along with scientific and technical activities, research institutes and universities should also play a significant role on the transfer of the accumulated knowledge to the society.

Deterioration of wood in sevice by wood borers, and particularly by termites, is an area of research that fits perfectly on this condition. With special relevance on southern European countries, a typical end user will either assume that “wood rots” and is eaten by borers as a sort of fate and will therefore be easily tempted by alternative solutions, will have a tendency to overreact to the problem, seeking to kill all the insects or will be looking for some “magical” solution that will not deteriorate. Raising the awareness of the public to the correct use of wood to avoid or control insects, and at the same time explain the importance of the deterioration agents in the ecosystems is a difficult but fulfilling task. The present paper describes some of the outreach activities conducted on the last few years at LNEC or with LNEC’s collaboration, using termites as the preferred educational model (Figure 1).

Children are naturally curious and have a high capacity to transfer their acquired knowledge to their parents. Over the last years, several organised visits of children between 4 and 6 years old to LNEC’s insect laboratories or from the researchers to the kindergartens have provided an important feedback on the success of this approach. Particularly, termites seem to be a perfect model to make children understand complex concepts as ecosystem functioning or carbon cycle, as well as learning the basic concepts of how to recognise an insect and the social organisation of a termite colony.

In terms of secondary schools, termites have also been an excellent model to explain the symbiosis and symbiogenesis theories. Within this, a transversal project about symbiosis was submitted, with advices from LNEC research team, focusing in the flagellate protists which live inside termite hindgut and play an important role on lignocellulose digestion. For wider public audiences, the participation in a scientific transfer of knowledge action promoted at national level (NEI2014 – European Night of Researchers), certainly contributed to the public dissemination of the scientific work on this subject.

The involvement of business and stakeholders in the knowledge transfer activities should also be pursued, as both it may promote a closer perception on the needs of industry, as well as industry and stakeholders may perceive that the solution they are looking for might

be already developed or under development. As an example of an action on this field, a two-day termite course was organised recently, with massive participation from the pest control industry.

Also, the scientific community may benefit from knowledge transfer, not only to foster collaborations among different researchers/research teams, but also to broaden the field of application of the present research.

Figure 1: Several examples of outreach activities where termites played the most relevant role.

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Popular wood products - discrepancies between selling points and user expectations from a Norwegian perspective

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Keywords: Decking, cladding, modified wood, marketing, customer expectation

ABSTRACT

The use of wood in exterior applications such as decking and cladding is a part of the Norwegian culture. During the last years, a number of modified wood products have been introduced to the Norwegian market. Modified wood is rather expensive compared to traditional wood products, and is thus marketed as an exclusive product. Marketing activities often include lighthouse projects and cooperation with architects to emphasise the products' potential. Additionally, selling points such as high natural durability, dimensional stability, freedom from maintenance and environmental friendliness are stressed. But, not only modified wood is advertised as contemporary and sustainable material. Often Siberian larch and Scots pine wood with high heartwood percentage are marketed as extraordinary durable material for cladding and decking. Many end users in Norway spare no expense and choose one of the materials mentioned above, expecting a superior product free from issues like discolouration, cracking and decay. In some cases, however, these products show signs of discolouration and cracking already after a rather short period of use. This leaves the customer dissatisfied because the material did not perform according to the expectations conveyed by the marketing material. This paper illustrates the area of conflict between selling points, customer expectations and actual product properties of popular wooden materials for cladding and decking in Norway.

INTRODUCTION

Domestic wood has been the dominant building material in Norway for centuries and the entire range of utilization of wood, from wood fuel to wooden floors, panelling, decking and cladding can be considered a part of the Norwegian culture. Especially wooden cladding and decking and their maintenance are popular topics during early summer. A couple of weeks ago, the newspaper with widest circulation in Norway, Aftenposten, elected the "king of decking". This enthusiastic handyman had recently extended his decking to 110 m^2 and was interviewed about advantages of his decking, and advice for proper dimensioning of a decking. Shortly after the article was published online, several observant fellow-countrymen had contacted Aftenposten and notified the editors about a bigger decking. Within two hours after publishing, the new "king of decking" was identified, having 300 m^2 of decking at his disposal. The same alertness applies to new decking materials, fasteners or surface treatments. Paired with a certain wealth, new trends are quickly picked up and put into action. One of these trends are environmentally accepted materials such as modified wood or wood from sustainably managed forests with properties suitable as material for cladding (use class 3.1) or decking (use class 3.2). These products are often more expensive than their regular competitors, resulting in diligent observation by the owner, and, in case of discontent, customer complaints. Treteknisk is the leading Norwegian institute when it comes to such complaints, and the current paper is based on experiences from some customer complaints.

MATERIALS

Treated materials

Thermally modified wood
In Norway, mostly thermally modified Scots pine and ash are sold for cladding and decking. Thermal modification of wood can be applied for purely optical reasons or to improve the technical properties of the wood. Processes which aim for the latter improve the dimensional stability of the wood and its durability against wood destroying fungi, mainly by thermal degradation of hemicelluloses. This leads to reduced water uptake of the material. Additionally, the colour of the wood is changed to dark brown. Thermally modified wood is marketed as most environmentally friendly modified wood because the treatment, compared to other modifications, does not require any additional agents to obtain the desired improvement of the wood. Other selling points for thermally modified wood are low maintenance requirements, little checking and classy greying.

Royal treated wood
This treatment combines regular wood preservation and hydrophobation by an oil treatment. The first treatment step is the impregnation of the boards with water based wood preservatives, improving the durability of the boards' sapwood portion against decay by wood destroying fungi. In the second step of the treatment, the wet boards are dried by storage in a solution based on linseed oil heated to about 80 ºC in vacuum, creating a hydrophobic surface of the boards. Pigments can be added to the linseed oil solution colouring the wood surface in for example red or black. The Royal treatment is applied to cladding and decking boards, which are sold as material with improved dimensional stability and freedom from maintenance, unless fading of the actual colour shall be avoided.

Untreated materials

Scots pine with high heartwood percentage
Many European countries have a tradition for the use of highly durable tropical timber as consequence of early access to this material through colonized land or trade relations with colonial empires. Such traditions are absent in Norway, and Scots pine timber with high percentage of heartwood, so called malmfuru, has for centuries been the most durable timber available. In the light of the long tradition of using Scots pine heartwood and the uncritical desire for environmentally friendly materials, malmfuru has again become a very popular material for cladding and decking. It is marketed as low-maintenance material of local origin, impregnated by nature and thus equipped with unique durability.

Siberian larch
Larch belongs to the group of trees that form heartwood which is clearly distinguishable from the sapwood by its brown colour. Compared to Scots pine, however, the percentage of heartwood is higher. The two dominant larch species on the European market are European larch (*Larix decidua*) and Siberian larch (*Larix sibirica*). For most tree species, slow growth is said to yield higher quality timber than fast growth. The same applies for larch, and the main selling point for Siberian larch is its presumed high density, strength and durability as consequence of slow growth under the harsh climate conditions in Siberia. Siberian larch is marketed as material for cladding and decking of superior

durability against wood destroying fungi. A major actor on the Norwegian marked even promotes Siberian larch as alternative to timber impregnated with copper-based preservatives.

ISSUES AND DISCUSSION

Based on the material information summarized above, customers take the decision to use one of these contemporary materials. After a relatively short time in service, however, the performance of the materials often deviates from the customers' expectations, and complaints are filed. The reasons for complaints can be divided into aesthetic issues and durability issues.

Aesthetic issues

Cracking of wood often is a consequence of dimensional changes of wood. Following the selling point of significantly reduced likelihood of cracking, customers complain about prominent cracking of thermally modified ash used as decking boards after 2-3 years in service (Figure 1). Cracks of up to 4 mm in width were observed in spring - despite improved dimensional stability. The improvement of dimensional stability is usually measured as anti-swell- efficiency (ASE), an indicator which is mainly controlled by the modification temperature. The latter varies between 160 and 240 ºC, depending on the modification process and the intended use of the modified wood. The average ASE of commercially available thermally modified wood is estimated to 40 %, compared to 60-70 % in case of other modifications. As a consequence, describing the crack performance of thermally modified wood as significantly improved falls short in comparison to other types of modified wood. Additionally, thermal modification increases the brittleness of the wood, thus making it more prone to cracking. And, last but not least, square meter prices that are five to 16 times higher than those for copper impregnated decking boards reduce the readiness to tolerate cracks in the boards. Apparently, the mismatch between the selling point dimensional stability and the perceived cracking performance has led to a change in marketing practice: A major supplier of thermally modified wood in Norway by now recommends to keep some spare boards in case replacement of single boards should become necessary. Another selling point for thermally modified wood is the classy greying of the material as consequence of weathering. In case of uneven weathering due to driven rain (Figure 2) or roof overhang, surface greying appears patchy and thus does not resemble the teak-like patina customers hope for. This circumstance applies to all solid wood products and should therefore be clarified during sales talks and in marketing material.

As a peculiarity of dark coloured Royal treated wood, warming of the material due to sunlight and potential resin bleeding from knots as consequence should be mentioned. This feature is not mentioned in the marketing material, despite the fact that it is a natural process and subject to a number of customer complaints.

Figure 1: Cracks in decking board of thermally modified ash after two years in service (Hundhausen 2012)

Figure 2: Colour change on cladding of thermally modified Scots pine cladding.

Durability issues

Recently, Treteknisk received samples from a cladding made of a material purchased as Scots pine heartwood. The material had been in service as cladding on a house in Stavanger (West Coast) for five years, and showed severe fungal degradation of heart- and sapwood (Figure 3). Analysis of the undegraded cross-sections showed a heartwood percentage between 5 and 75 %. In another case, Treteknisk was contacted regarding a decking of Siberian larch. The decking was installed in Oslo six years ago, and showed degradation of the sapwood areas of some boards (Figure 4).
A look at the durability classification of Scots pine and larch explains one issue of the above situations: Scots pine heartwood is classified as moderately to slightly durable against fungal attack (EN 350, 2016), the same applies for heartwood of both European and Siberian larch. Sapwood of both species, however, is classified as not durable. This implies that a delivery of Scots pine heartwood and larch with consistently moderate to slight natural durability requires accurate grading at the sawmill. Knowing the peculiarities of heartwood formation and grading processes in modern sawmills, reliable producers thus indicate margins of tolerance of at least 5 % for boards with less than 100 % heartwood. Given this information during sales talks, customers would be aware of the risk for decay and potentially buy spare material to replace boards that do not contain 100 % heartwood.
Another issue of the situation is marketing larch as substitute for impregnated wood. Referring to impregnated wood implies a minimum durability of the material equivalent to that of the heartwood of larch. This is because the heartwood is impermeable for the impregnation solution, and thus the least durable part of impregnated wood. Sapwood impregnated with current impregnation agents, in turn, is classified as very durable, and is therefore more durable than heartwood. Consequently, the minimum durability within a larch board can be expected to be durability class 5 – not durable, compared to durability class 3 – moderately durable - in an impregnated Scots pine board. Thus, larch is by no means a substitute for impregnated Scots pine! To be fair, the service situation of the materials in the two cases named above needs to be commented: The cladding was mounted on a house in Stavanger on the west coast of Norway, with an average monthly precipitation of 125 mm during the last year. Due to the coastal location, most of this precipitation occurs as driving rain, resulting in an extraordinary exposure of wood in outdoor application. The decking was mounted with little distance to a concrete surface, allowing for standing water and high relative humidity under the decking. These examples illustrate that both the selection of suitable materials, but also measures of physical wood protection are crucial for the optimum performance of wooden building materials.

Treteknisk has so far not been involved in customer claims regarding the durability of thermally modified wood, although the increased durability of this material is frequently used as a selling point. The durability rating of thermally modified wood based on laboratory results ranges from very durable to not durable. Westin et al. (2017) evaluated several above-ground field tests to compare the durability of thermally modified wood intended for application in use class 2 and 3 with that of samples treated with other preservatives. The results from the 10-year round-robin test showed poorer performance of the thermally modified wood compared to the samples treated with metal-free organic preservatives according to use class 3 requirements. These results suggest a restriction of thermally modified wood to application in use class 3.1.

Figure 3: Two ends of a sample from Ore-pine cladding. Heartwood coloured with heartwood reagent, estimated heartwood percentage 15 % (left) and decay of sap- and heartwood (right).

Figure 4: Decay in sapwood region of decking boards of Siberian larch after 6 years in service (Flæte 2016).

CONCLUSION

This article points out the conflict between selling points for, customer expectations about and actual properties of popular wood products for cladding or decking in Norway. One aspect, however, has not been touched so far: Do customers tend to have realistic expectations? The frank answer to this question is: Certainly not! Especially in the light of above-average material prices they expect low maintenance and premium performance. These expectations are met by the images conveyed by the marketing material. In many cases, however, the actual products fall short of both consumer expectations and marketing efforts. The message of this article is to encourage the wood industry and retailers to conduct more realistic and honest marketing and consulting. This is essential to secure and extend the standing that wood has as material for many applications. The hint at potential cracking of thermally modified wood, and the following advice to keep spare boards for eventual repairs, is a good example for sustainable marketing.

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Knowledge Transfer Partnership. Adding value to UK grown timber in construction

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Keywords: Wood drying, CLT, Heat and moisture transfer, Knowledge transfer

ABSTRACT

The Knowledge Transfer Partnership (KTP) is a programme that encourages collaborations between business and academia in order to increase competitiveness and innovation in industry. The main benefits of KTPs are to provide industries with increasing profitability as a result of the quality improvement by production method optimisation and new product development that can create access to new markets. This project is held between Clifford Jones Timber Ltd and the BioComposites Centre of Bangor University in order to add value to, so far undervalued UK grown softwood timber. In the UK's building materials market, sawn timber is the third most imported material (National Statistics 2017). Sitka spruce, Scots pine and larch are the most common timber resources in UK, with spruce accounting for 62% of the overall resources (Forestry Commission 2011). Softwood grown in the UK is fast grown, which can cause major defects such as bowing and warping when dried to 12% MC or lower (Crawford et al. 2015). Several studies suggest a solution to drying UK grown timber to 12%, is to introduce medium-high heat and steam during the drying process. The high temperature and steam enables the relaxation of lignin and aids in restraining the massive twists, which are observed with conventional drying methods (Riepen et al. 2004, Cooper and Cornwell 2005). Cross laminated timber (CLT), which is not yet produced in the UK, seems a suitable alternative product that can utilise timber not currently considered for structural purposes. Crawford et al. (2013) had proved that it is possible to produce CLT made of Sitka spruce with very promising results. This projects aims to the development of a CLT product made by UK grown timber and transfer the academic knowledge to the industry through the process.

INTRODUCTION

Knowledge Transfer Partnerships (KTP) is a UK funded programme that helps businesses to grow through innovative solutions. KTP scheme was established at 2005 as a replacement of the former similar scheme Teaching Company Scheme (TCS), which had been formed in 1975. Since then, the idea of the knowledge transfer has delivered increasing profitability for industries as a result of the quality and operational improvement, increasing sales and openings to new markets by the development of innovative products. The aim of the KTP scheme is to translate the academic knowledge to direct commercial improvement of business. The KTP is consisted by three partners, a business, an academic institution with an associate who acts as the project manager. The associate is employed by the academic institution and works for the company whilst being supported both the academic institute and the company. The role of the associate is to introduce new skills and knowledge to the industry that can be translated to increase profitability by innovation.

This particular KTP project partners are the Clifford Jones Timber Ltd (CJT) and the BioComposites Centre (BC) of Bangor University and the aim is to add value to UK grown softwood timber by introducing them into the building market as a construction material. UK grown softwoods are mainly used for fuel in the form of pellets or briquettes and in wood panel and paper production as they are considered unsuitable for construction timber. The reason for this is that UK grown softwoods are very fast grown, and the very wide growth rings. This can cause major defects such as bowing and warping when dried to 12% MC or lower which is the requirement for construction timber (Crawford et al. 2015). Defecting material is rejected from graded timber and cannot be used in construction. Therefore, to reduce the quantity of rejected material, UK sawmills produce UK grown sawn timber dried to a minimum MC of 20%. However, these timbers are only suitable for outdoor products such as fencing poles.

CJT currently produces fence poles and laminated beams for outdoor constructions such as in playgrounds. The timber used for the laminate products, is imported pine, which, if it can be replaced by a local grown softwoods, can significantly increase the profitability of the company. This will also open up a completely new market for the undervalued UK timber.

A method to dry UK grown spruce down to 12% is the use of medium-high heat and steam drying process which has been evaluated by several studies. The hypothesis behind this method is that the high temperature and steam will lead to the relaxation of lignin and will aid in restraining the massive twists observed with conventional drying methods (Riepen et al. 2004, Cooper and Cornwell 2005). However, the large scale optimisation of this process still needs to be investigated and improved. During the drying process there are three major complex interactive mechanisms that must be considered; the heat and moisture transfer, the phase change of the free and combined water and the glass transition temperature of lignin. The interaction of these complex mechanisms will ultimately affect the final timber product. However, if these mechanisms can be simulated as a multiphysic equation through finite element analysis it is possible to predict the drying outcome and aid in optimisation of the drying schedule for the best possible product.

During this KTP project heat and moisture transfer within the wood during the drying process are monitored in order to predict the behaviour of UK grown timber, dried to a moisture content below 20%. The collected data will be used to create a simulation that can be used to model and optimise the drying procedure for achieving an economically viable method of drying local grown timber for the production of construction timber. As UK softwoods are fast grown species, the best end product candidate seems to be the cross laminated timber (CLT) as it is not yet being produced in the UK. The most common softwood forest resources in UK are Sitka spruce, Scots pine and larch, with spruce accounting for 62% of the overall resources (Forestry Commission 2011). Crawford et al. (2013) had proved that it is possible to produce CLT made of Sitka spruce with very promising results. However, they used 12% MC dry wood for their study, which was dried using small-scale laboratory equipment and specific methods that are challenging when applied to a bigger scale. Therefore, development of an economically viable drying method for UK grown softwoods is essential to add significant value to UK grown softwoods.

The overall project aim is designed, not only to provide the development of a new product to the UK market but also, and most importantly, is to provide the deep scientific knowledge to the company in order to better understand wood as a material and improve the quality and productivity by the optimisation of the production procedures.

EXPERIMENTAL

In order to evaluate the appropriateness of the local grown timber as a candidate for CLT production, the mechanical properties and the shear strength of the lap joints were investigated. The first stage of the project was to select three species from the log yard of the company. The species selected were locally grown Sitka spruce and larch, and imported Scandinavian pine which was used as control, as these are the main available timber species.

From each of the species 6 samples were collected randomly from different segment of the same log to represent any variability across the timber. All samples were conditioned in a conditioning room until weight stabilisation. The sample dimensions were 25x25x350 mm. The support span was 280 mm and the speed strain was adjusted to 12 mm min-1 in order for the specimen failure to occur within 60±30 seconds from the start of the load application. The load was applied tangential to the timber's growth rings. The modulus of rapture (MOR) and modulus of elasticity (MOE) was calculated according to equations Eqn. 1 and Eqn. 2 respectively.

$$MOR = (3 \times Fmax \times l)/(2 \times b \times t^2) \quad (1)$$

$$MOE = (l^3 \times (F2 - F1))/(4 \times b \times t^3 \times (a2 - a1)) \quad (2)$$

l: support span
b: specimen width at the bending point
t: specimen thickness at the bending point
Fmax: maximum load
F1: 10% of maximum load
F2: 40% of maximum load
a1: strain extension at 10% of maximum load
a2: strain extension at 40% of maximum load

For the adhesion shear strength, from each of the timber species two planed layers were collected randomly from different sections of the same log to represent any variability across the timber. All samples were conditioned in a conditioning room until weight stabilisation. The sample dimensions were 600x70x5 mm. The layers were glued together with the currently used MUF adhesive for laminate products provided by CJT. The layers had a grain orientation of approximately 45^{o} degrees and laminated with opposite orientation (Figure 1a). The samples were clamped together for 48 hours to ensure proper adhesive curing. Then the samples were cut into smaller samples with dimensions of 100x20x10 mm and cut halfway to the glue line in both sides to expose a glue line area of 20x10 mm Figure 1b. Then the samples were placed into the condition room until weight stabilisation. The samples were subjected to shear strength with a strain speed of 50mm min^{-1}. The adhesion shear strength was calculated according to Eqn. 3.

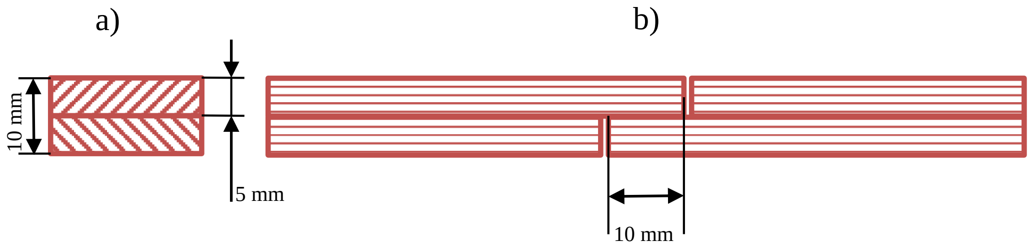

Figure 1: Schematic presentation of adhesion test sample. a) Cross section b) side section

Shear strength = Fmax/(b x t) (3)

b: Glue area width
t: Glue area length
Fmax: maximum load

Small scale prototype CLT have been made by conditioned spruce for demonstration and presented to the company in order to visualise the product perspective (Figure 5). Along with the mechanical testing, kiln drying trails on local grown spruce are currently undertaking place and the heat and moisture transfer is recorded. The kiln trials are set up to 70ºC and in the presence of steam to achieve relaxation of lignin in order suppress the stresses which lead to twist and bow of the planks. The collected data will be used for the understanding the moisture and heat transfer and will be used for the validation of a multi-physics model simulation. Currently this stage of the project is ongoing and the results will be presented in a future paper. Other UK grown species like lLarch and Scots pine will also undergo the same procedure for the development similar multi-physics simulation.

RESULTS AND DISCUSSION

Results

The MOE and MOR values are presented in Table 1 and the in Figure 2a and b. According to Figure 1a the highest MOE as expected was observed in pine samples. The timber with the second highest MOE was the spruce and the lowest was the larch. The larch was the species with clearly the lower MOE, were spruce and pine samples had around the same values and because of the SD there was not any clear difference observed.
Similar results were obtained in MOR values (Figure 2b). However, even the MOR SD of the pine and the spruce samples are overlapping it appears that spruce samples has lower values as the highest points of the spruce SD is significantly lower than the pine. The larch MOR values showed the highest SD which is again significantly overlapping spruce values.

Table 1: MOE and MOR average values. Values in brackets represent the standard deviation (SD)

	Pine	Spruce	Larch
MOE (MPa)	6946.61 (506.82)	7146.91 (995.93)	5882.52 (1853.13)
MOR (MPa)	63.59 (5.03)	61.85 (6.63)	65.24 (12.77)

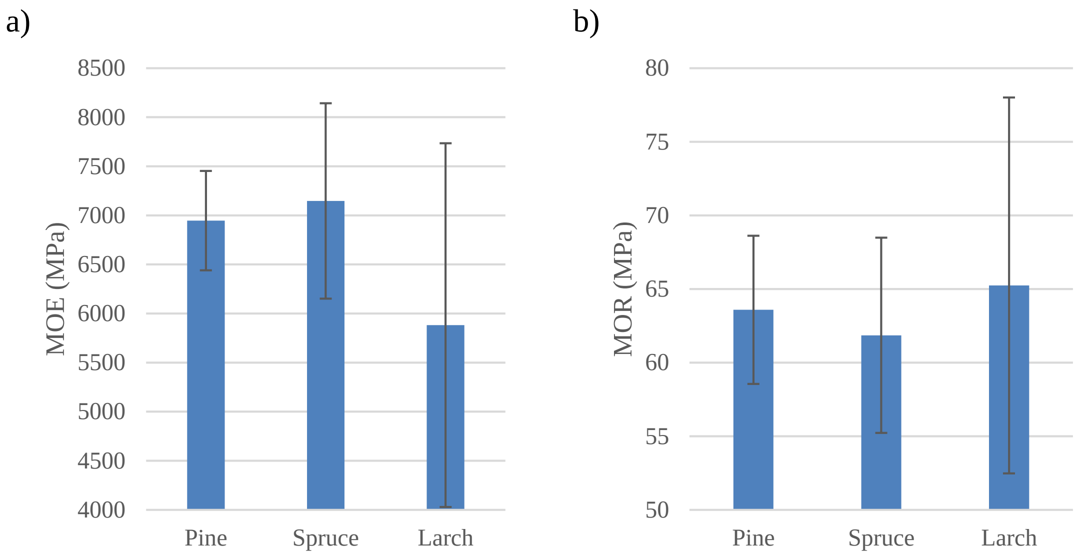

Figure 2: a) MOE and b) MOR in MPa. Error bars representing the standard deviation (SD)

In order to identify the possible similarities between timber species the MOE and MOR raw values were plotted in Figure 3. It seems that there is no significant difference between pine samples and the spruce samples, as they are forming a cluster on the up left corner of the graph. The larch samples on the other hand are clearly forming a different spread cluster that is below the spruce and the pine.

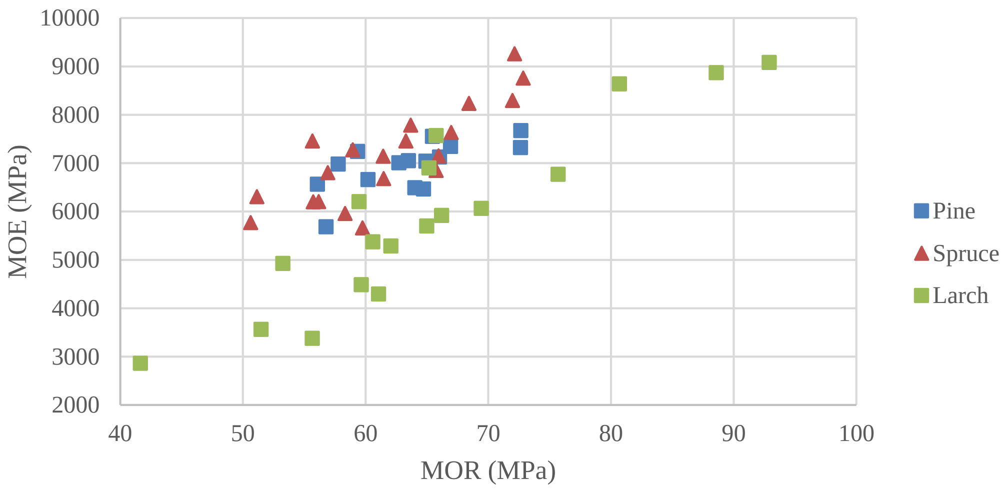

Figure 3: Scatter graph of MOE against MOR

The lap joint adhesion strength values are presented in Table 2 and Figure 4. According to Figure 4, the highest adhesion strength was observed in spruce samples. The timber with the second highest adhesion strength was the pine and the lowest was the lLarch. The larch was clearly the specie with the lowest values whereas spruce and pine samples had around the same values and because of the SD, there was not any clear difference observed between these two species. However, it was observed that the pine samples had gaps in glue line as a result of poor preparation, resulting to high deviation. Additionally, the pine samples with the highest observed values did not show any significant material failure. Whereas the spruce and especially the larch samples showed that the failure mainly occurred on the material surface rather than the glue line.

Table 2: Adhesion shear strength

	Pine	Spruce	Larch
Shear strength (MPa)	4.25	5.80	3.04
SD	2.23	2.13	0.99

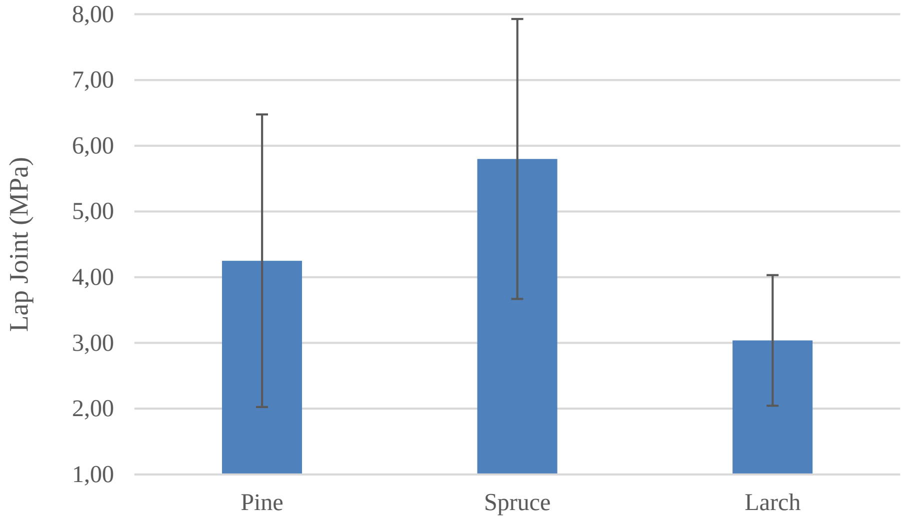

Figure 4: Adhesion strength in MPa. Error bars representing the standard deviation (SD)

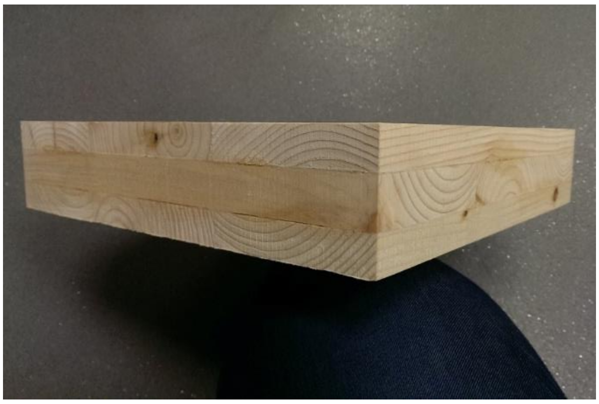

Figure 5: Demonstrating CLT made by local grown Spruce

Discussion

By the analysis of the MOE and MOR data, it seems that the Sitka spruce does not significantly differ from the pine samples whereas larch had clearly lower values. However, as was expected, spruce showed higher SD because, UK grown spruce has significantly wider annual growth rings compared to Scandinavian pine. The small tight annual growth rings in Scandinavian pine resulting to a more homogenized material in contrast to wide growth rings of spruce, which is affecting the mechanical behaviour when subjected to load stresses due to larger areas of variation in the material.
The analysis of the adhesion strength data suggests that the Sitka spruce does not significantly differ from the pine samples whereas larch had clearly lower values. However, spruce appeared to fail on the surface rather on the glue line which means that

the adhesion strength exceeds the material strength properties. Therefore, pine could provide stronger bonds but because of the poor sample preparation it was not observed. It is essential to repeat the lap joint test for the pine samples in order to estimate more accurately the adhesion strength.

CONCLUSIONS

The mechanical properties investigation showed that spruce does not significantly differs from the imported pine and therefore could be used as source material for CLT production. The larch showed lower values than spruce, however it could still be considered for CLT production as it is possible to be graded as construction timber. The kiln trials will be evaluated and the decision for the most appropriate species will be made according to the most economically viable process that takes into account the cost of production, material accessibility and additional investment costs.
The production of an accurate drying simulation model is expected by the end of this project. Furthermore, during this project the company will be benefit not only by the introduction of a new product but also by the knowledge transfer on wood science and the procedures that lead into a successful research and development project.

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Straw bale building performance and design diversity

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Keywords: straw bale, building, advantages, drawbacks, design

ABSTRACT

The importance of biobased materials is increasing. Building with straw is a distinctive example of green building principles. It has the potential to become a major promoter of biodiversity conservation within the built environment.

Straw is recognized and used worldwide in architecture and it is important in the context of architectural heritage as a roof cover, a binder or recently in a shape of a bale.

Several research studies proved that building with straw, especially building with straw bales, has potential and is an appropriate building material for the needs of the contemporary user. Nowadays, Straw Bale Building (SBB) is the most recognizable form of building with straw. Generally speaking, SBBs are mostly built by owners and investors as a result of their desire for natural and environmentally friendly buildings. Recently, SBBs have branched out from residential use and have been built for the commercial sector with specific for public use. Since the construction of the first such building in the 19th century (Nebraska, USA), several SBB building techniques have been developed and successfully implemented in many different climate zones.

The intention of this contribution is to present SBB performance characteristics and its design diversity. The key benefits of SBB are low impact on the environment, good thermal and acoustic properties, material availability, etc. Meanwhile, there are drawbacks concerning fire resistance, structural stability and moisture issues which have been already proven by many tests to be unjustified when design and erection of a building are carefully delivered. Many countries around the globe recognize straw bales as an appropriate building material but mostly only as an infill where other standardize materials are used as construction system that it is established. "Examples of good practice" are the best promotion for new materials. In this paper, two study cases of a good practice are presented which also confirm the diversity of SBB design.

INTRODUCTION

Straw is an annually assured agricultural by-product and it makes up about half of the yield of cereal crops. Straw is usually gathered in a form of a bale for easier removal from the field and also for its easier storage. Often it is also left on the field and burned which is very problematic from the environmental perspective.

In architecture, straw has been used in combination with a variety of building materials and methods to provide safe and comfortable housing as long as human beings have been building shelters. Several techniques concerning straw were developed and successfully implemented in many climate zones as a roof cover, a binder or in a shape of a bale. Building with straw bales is currently the most interesting form of building with straw and it is recognized worldwide. The first "true" straw bale-based walling systems originated in the sand hills of Nebraska (USA) at the turn of the 19th century, not long after the use of the first baling machines (King 2006). In Europe, Feuillette's house (2017)

is the first house made of straw and the first one built with a wooden frame filled with straw in 1921.
Current interest in straw bale building (SBB) is greater than ever since the environment awareness has increased and many environment management directions have been set. If reasons differ as to why many pioneers chose to build with straw bales nowadays the primary interest in building with straw bales is a low impact on the environment. Also, the investors and building dwellers themselves are mostly emphasising organic nature of straw bales as a key value of building with straw (Brojan 2014).

GENERAL PERFORMANCE PROPERTIES

The general idea of building with straw is stacking bales as an infill in a timber frame structure or as load bearing structure where bales are carrying the entire load. Normal sized (approx. 38 × 45 × 90 cm) straw bale fits manual work. General guidelines (Morrison 2012) advice to use bales that are quadrilateral shaped, tied up tightly and dry – moisture content should not exceed 15 % (wet weight basis). Bale density should be more than 85 kg/m^3 and more than 105 kg/m^3 when building a load bearing structure.
The straw bale building process can be regarded as learning by doing. It means that working process is less demanding and building technique to handle straw bales can be quickly mastered. Many builders are first timers with no or little experience and their work is based on theoretical knowledge obtained mostly from straw bale building guides or by participation on one of straw bale workshops. However, for a sufficient dwelling environment, well-delivered details are a crucial segment of design and building, therefore, comprehending a help from an experienced straw bale builder is reasonable. Recently, SBBs have also branched out from residential use and have been built for the commercial sector with specific for public use.

Benefits

Energy efficiency (insulation properties), sustainability, affordability, environmental benefits, and beauty and comfort are the most often highlighted benefits of SBB by many researchers.

<u>Sustainability</u>

Analysis of the statistical data clearly showed that the amount of available straw on an annual basis is sufficient for straw bale building purposes worldwide, which is presently also the most promising form of use of straw in its elementary shape (Jones 2009). Straw bales for a building purpose are easily produced, mostly in the field during the harvest process. In the UK at least 450 000 houses of 150 m^2 in size could be built with a surplus of straw (Jones 2009). A similar calculation revealed that in Germany approx. 350 000 (Minke and Mahlke 2005) and in Slovenia approx. 17 000 (Brojan 2014) straw bale houses could be built with annually produced straw.

<u>Environmental benefits</u>

Environmental aspect is many times the main reason to build with straw bales. Several research papers confirmed that SBB has a low impact on the environment and that SBB can actually cause a net decrease in greenhouse gas emissions (D'Alessandro et al. 2017, Brojan 2013, Jones 2009).

Insulation properties

Besides the obvious organic nature of straw bale as a building material, straw bale buildings also have many attributes that offer great living conditions to the dwellers who emphasized thermal and acoustic comfort as a great advantage of SBB (Brojan, 2014). In regards to thermal insulation, it was confirmed by many research experiments (FASBA 2014, Ashour 2003, McCabe 1993) that the thermal conductivity of a straw bale ranges between 0.33 and 0.675 W/mK which can be compared to values of insulating materials used nowadays. Calculations and performed in-situ measurements show (D'Alessandro et al. 2017, Brojan 2013) that the thermal resistance (U) of plastered straw bale wall meets the standard of building regulations which requiers $U_{max} = 0.28$ W/m^{2}K) (TSG – 1 – 004: 2010). Therefore, neither heating nor cooling of straw bale building is demanding, assuming that the floor plan design is well planned (position and size of openings/windows) and details are correctly designed and build. In the case of the straw bale (45 cm) acoustic insulation values range between 43 and 55 dB (Minke in Mahlke, 2005). The technical requirement of acoustic insulation R'w (Weighted Apparent Sound Reduction Index) is 52 dB (TSG – 1 – 005: 2012).

Drawbacks - disadvantages

The most common highlighted concerns of SBB are related to fire safety, moisture, pests, lack of building codes and insurance plans, and structural stability.
In the past few decades, most researchers were focused on three issues which are the most threatening to dwellers' safety. Several studies have been reported on fire safety, high moister content in the walls, structural stability and, mechanical response and behaviour of straw bales (Maraldi et al. 2017, Brojan and Clouston 2014, Wihan 2007, King 2006). Most researchers came to the conclusion that the use of straw bales is safe and problems that related to fire, moisture or structural safety can be avoided by following certain rules.

Fire safety

Field and laboratory experience show plastered bale walls to be highly resistant to fire damage, flame spread and combustion (Theis 2003). Based on the reports straw bale buildings are fire safe and meet e. g. REI90 criteria given in standard SIST EN 13501-2 (Lampret 2011). However, to prevent fire hazards a clean building site is needed. During the bale raising, the straw on the ground must be removed continuously until the walls are plastered.

Moisture

Avoiding the moisture problems is one of the most important segments of straw bale building to prevent mould in the wall (Straube 2006). It was confirmed that appropriate plaster affects the moister content in the wall (Wihan 2007). Plaster type is selected based on the climate of the building's location. In general, it is recommended to use high moisture permeable materials (clay, soil, lime) in colder and more humid environments. Meanwhile in dry and warm climate also less moisture permeable materials can be used (e. g. cement).

Structural stability

There are several construction systems that can be used in straw bale building. The riskiest, but yet interesting and with a great potential, is straw bale load-bearing construction. The potential of such a construction can be confirmed with an interesting example of a load bearing straw bale house built in Switzerland (Europe). Werner Schmidt (2017) took a challenge and designed an interesting house in the mountains (1300 m above the sea level) where the snow loads are over 620 kg/m^2.
Since 2013 in the USA suggested straw bale construction building code was approved by the International Code Council's (ICC). In 2015 the "Appendix R" on straw bale construction was successfully implemented in International Residential Code (IRC) for one- and two-family dwellings, meaning that straw bale code is valid for almost every jurisdiction in the United States (Morrison 2017).

CASE STUDIES

Design approach

The intention of this contribution is to present the variety of straw bale building design. In general, building design primary depends on building location and legislation demands (size and building shape, roof pitch) and secondary on investor's needs and desires. The design of a floor plan needs no special handling; there are many possibilities especially when straw bales are used as an infill in timber frame structure (a.k.a. post and beam) which is the most common structural systems in SBB (Brojan 2014). Straw bales are discreetly inserted into wall composite since the layer of plaster which protects the straw from external impacts such as moisture is unavoidable.

Study case 1 – Single family house in Radomlje (Slovenia)

Straw bale house in Radomlje (Slovenia) is a typical case of straw bale building, see Figure 1. The owners' environmental consciousness and way of living found SBB to be an acceptable and appropriate building method. They were actively involved in all stages of the building process, including the house design which is also typical of SBB.

Figure 1: Straw bale house in Radomlje, Slovenia (photo: Blaz Babnik).

The building permit was obtained in 2012. Construction started in March 2012 and was completed in September 2013; the duration of construction was 18 months. The house has a simple two-story rectangular floor plan with a useable area of approx. 120 m², no basement, and pitched roof. The straw bale house is a timber frame structure (see Figure 1) where the straw bales are non-structural and used only as infill. House has a concrete pier foundation with timber floor grid which is also filled with straw bales. In total, approx. 850 straw bales were used.

Figure 2: Timber frame structure.

A specific property of the house is a raised ground floor which was built to avoid the layer of tar. Straw bales are plastered with two layers of clay on the inside and on the outside, clay for the first layer and lime for the second layer. The clay was obtained from the house's construction site. Building envelope reflexes softly and curvedly shaped interior.

Study case 2 - Gateway Building

Gateway building is one of the largest straw bale buildings in the UK built between 2008 and 2011. It has been awarded for Sustainability Achievement Award in 2012. Gateway building accommodates various university Departments (School of Biosciences and the School of Veterinary and Medical Sciences) and offers a wide range of functions – offices, laboratories, seminar and computer rooms.

Figure 3: Gateway Building in Nottingham (United Kingdom).

The facade of Gateway Building is formed from prefabricated modular straw bale panels, locally produced using straw harvested from the University's own farmland. Straw has been applied as an external curtain wall system, with each panel spanning all four floors of the building in one prefabricated piece. This cost-effective and environmentally friendly system was quick and easy to construct. Panels are 14 m long and consist of a cross-laminated timber frame filled with compressed straw and finished externally with render to provide a vapour permeable coating that prevents decay and protects the straw from the external environment. These panels were prefabricated in an off-site ‘flying factory’ using local labour and delivered ready to be put in place. In the main entrance atrium a series of ‘truth windows’ (see Figure 4) form an interesting feature; some of the plyboard panels have been taken out and replaced with clear perspex to allow visitors to see the straw bales, which would otherwise be concealed from view (Make architects 2017, ModCell 2017).

Figure 4: Truth windows in Gateway Building atrium.

DISCUSSION

In recent years, environmental strategies require sustainable solutions also in the building sector which is responsible for a greater part of the global energy consumption and greenhouse gas emissions. One of the solutions would be using natural materials such as straw. Many research studies and building analyses confirm the emphasized attributes of using straw; low impact on the environment, building technique simplicity, and thermal and acoustic comfort.

Experiencing architecture generates various perceptions and responses. Straw bale houses in many cases mirror the various aspects of owners’ lives. Therefore, the comprehension of a space and building depends on personal preference and desires. Self-builders implement through creativity their space comprehension experiences into the design of their dwelling. Emphasizing the natural quality of a building material by exposing the softness of the material through the surface treatment informs the observers about the possibility of its variety use. On the other hand, a more sophisticated design approach is also possible and clean lines can be obtained. In a case of Gateway Building, straw bales are sandwiched between cement boards. Based on the characteristic of two case studies of straw bale building which represent extreme in the design of SBB (see Table 1), it is evident that such a building offers many design possibilities.

Table 1: General straw bale building properties of case studies

	Gateway Building	house in Radomlje
floor area (m^2)	3100	120
number of floors	4	2
foundation	concrete slab	concrete pier foundation
structure type	timber panel	timber frame
external layer	cement board	clay, lime render
function	classroom, office	dwelling
design	Make architects	Blaz Babnik

location	Nottingham, UK	Radomlje, Slovenia

CONCLUSIONS

This contribution is an attempt to introduce the straw bale building potential to the wider audience who is directly involved in building and to the one who is tending to design and build environment-friendly. The anxieties are mainly attributed to the poor knowledge of straw bale building techniques and its details among planners, builders and also potential investors and users. The current flaws can be addressed more as future research opportunities to improve existing models and systems of straw bale use.

Straw bale building design needs to be thought-out well to achieve optimum functionality but at the same time, creativity is almost limitless. It can meet the criteria of modern design and it also illustrates the comprehension of an individual. There are no specific design guides for straw bale building. However, well-delivered details are crucial to assure appropriate dwelling conditions and meet set criteria. Presented straw bale building study cases demonstrate a wide range of diversity in shape, size, and its functional use, yet meet building code demands concerning structural stability, thermal performance etc.

Straw bale building has progressed drastically in the past decade in regards to building design, building location (climate zone), and building techniques etc. If straw bales were firstly used by self-build enthusiasts, nowadays can be applied even to more sophisticated architectural projects. Furthermore, there are still open questions demanding new scientific proves and conclusions to support further use of straw in the future.

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Developing novel applications of mycelium based bio-composite materials for design and architecture

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Keywords: Bio-composite, Mycelium, Material, Design, Architecture

ABSTRACT

The growing need of the industry for alternative materials and products that are biodegradable and derived from renewable resources has recently led researchers from varied fields to search for more sustainable alternatives, and develop natural bio-composites to replace varied petroleum-based products in order to reduce the intolerable stress on the planet environment. In this research, the natural ability of saprophytic fungi to bind and digest lingo-cellulose, is utilized to develop natural bio-composite materials for novel applications in design and architecture.

Previous research has shown a potential to develop products such as packaging, building and insulation materials, leather-like, textile and transparent edible films. However, no research has been found in which all the significant variables were systematically tested. In this work, several fungi species were grown on varied local agricultural-growth wastes to evaluate which pair of fungi-plant material features the most suitable combination for future applications. The fungi; *Pleurotus pulmonarius, Pleurotus ostreatus, Pleurotus salmoneostramineus and Aaegerita agrocibe* where grown on woodchips of Eucalyptus, Oak, Pine, Apple and vine. The samples were tested for selected properties, including chemical changes in organic matter (pH, electric conductivity, water, carbon and nitrogen contents), mycelium growth rate, density and quality impression. By examining these fundamental materials characteristics, we aim to achieve a thorough understanding of the structural and aesthetic opportunities that this novel bio-material should offer. The current stage of the research shows that the most efficient integrations where the samples of *P. ostreatus* grown on Apple or Vine woodchips. Future work will focus on using suitable analytical methods for further understanding of the changes in mycelium and plant structures during the digestion process, and locating essential variable parameters of previous and post processing, to achieve desired material properties and introduce innovative characteristics and functions over existing industrial products and applications.

INTRODUCTION

Utilizing fungi ability to digest varied lingo-cellulose wastes

Recent advances in technological, biological and digital computation abilities, alongside the need for more sustainable manufacturing methods, assist to develop alternative materials and fabrication processes, using multidisciplinary tools. In a world characterized by rapid population growth, intensified agriculture and industrialization, where fast, low-cost manufacturing process encourages a constant growth of production and consumption, leading to an accumulation of waste, environmental pollution, and depletion of natural resources, there is a growing need for alternative materials and products, particularly in the mass industry, that are biodegradable and derived from renewable resources.

A complex enzymatic process enables the white rot fungi with a unique ability to digest highly stable molecules such as the structural polysaccharides of plants (Danai et al. 2012). This process plays a significant role in natural ecosystems and is already widely used for varied agricultural and food applications (Levanon et al. 1988). However, the fungal ability to bind and digest lignin and cellulose fibres of plants can also provide an inherent bonding, forming a natural, lightweight bio-composite, in which the fungal mycelium functions as the matrix and holds the plant substrate pieces together, without the use of any synthetic adhesives (**Figure7**). The resulting material can therefore be applied as a biodegradable alternative for a wide range of industrial materials, products and applications.

In this paper, the novel concept of utilizing this integration of fungal mycelium with the plant fibres, will be introduced. The paper starts with a general review of current design works done with mycelium. It then presents a preliminary experiment we conducted, to scan for a suitable fungi-plant set, as well as understand whether some analytical methods can assist with the characterization of the final bio-composite material. It concludes that there is a clear connection between the quantitative and qualitative parameters we have tested so far. In future work, we wish to test more analytical methods to better characterize the structural changes during mycelium development and its effect on the final material.

Using mycelium-plant material as a bio-composite in design and architecture

A bio-composite consisting of mycelium-plant material can be applied as a biodegradable alternative for a wide range of industrial materials. At the end of its use, the mycelium product can decompose to be available as a recourse for the development of other organisms in the environment. Previous research has shown a potential to develop products such as packaging (Holt et al. 2012 (Ziegler et al. 2016)), building (Jiang et al. 2016, 2013; Jiang et al. 2017; Travaglini et al. 2014), thermal and acoustic insulation materials (Yang et al. 2014; Pelletier et al. 2013; Pelletier et al. 2017), decorative house products (Mycoplast), leather (Mycoworks), textile (Hoitink) and transparent edible films (Kumar 2000). In recent years, some workshops and exhibitions (such as Fungal Futures 2016) of international artists and designers who investigate and develop materials using mycelium are taking place. However, most of the current research focus on evaluating the mechanical properties of the raw material on a macro level, using a set of physical tests, such as compressive and tensile strength, stiffness, elasticity, density, dimensional stability, aging, water absorption, thermal and acoustic insulation (Mendez et al. 2016; Lelivelt 2015). Yet, in order to detect and control the final material properties, a bottom up approach is required, in which structural changes within the plant and fungal components should first be identified. Using such approach could contribute and advance the possible applications using mycelium based bio-composites as novel materials.

Characterization of mycelium-plant bio-composite materials properties

The objective of this experiment is to locate the most suitable fungi-substrate combination for further exploration and development of potential materials, products and applications in the field of architecture and industrial design. In this work, four fungi species; *Pleurotus salmoneo-stramineus (P. salmoneo), Pleurotus ostreatus (P. ostreatus), Pleurotus pulmonarius (P. pulmunarius), Aaegerita agrocibe (A. agrocibe)*; where grown on five types of woodchips substrates; *Eucalyptus ecamaldulensis* (Eucalyptus); *Quercus calliprinos*; (oak), *Pinus halepensis* (pine); *Vitis vinifera* (Vine- Cabernet Sauvignon);

Malus domestica (apple- Golden Delicious). Each substrate was tested for selected properties before and after the mycelium growth, including chemical changes in organic matter (water, pH, electrical conductivity, ash, nitrogen content and organic matter digestion); mycelium development was evaluated by rate, density and quality factors.
The water content was measured at the beginning of the experiment to test whether the substrate contains a sufficient amount of water (about 65% is essential for fungal growth and development); And at the end of the experiment, where it is expected to rise or remain stable, due to the release of metabolic water during enzymatic digestion process.
The pH level of the substrate is expected to drop where fungal mycelium have developed. A relatively high initial pH level (around 8) can donate to the selectivity of a substrate, since *Pleurotus* mushrooms can manage to grow on higher pH levels than other, unwanted fungi types. Furthermore, the digestion process of the fungi lowers the pH level of the substrate to about 5), thus it might assist to indicate the amount of mycelium development on the substrate.
The optimum nitrogen content range for *Pleurotus* mushroom growth is about 0.6-1%. The organic matter composing wood contains about 50% carbon and around 1% nitrogen. During its growth process, the mushroom digests mostly carbon from the substrate, without consuming nitrogen. Thus, the relative amount of nitrogen in the final material (substrate with mycelium) is expected to be higher compared with the control (only substrate). The change in nitrogen content during mycelium development is therefore another parameter to consider while evaluating mycelium development.
The amount of organic matter is determined by calculating the relative part of ash (non-organic components) from the total mass of the initial substrate material, compared with its amount on the final material (substrate with mycelium). Since the fungi digest organic matter, the relative part of the ash will therefore increase, thus indicate the amount of organic matter digested by the fungi. Hence, the loss of organic matter (ΔOM) indicates the amount of mycelium growth.
By accomplishing this experiment, we aim to understand which fungi-plant set is most suitable to work with for design and architecture applications. Further experiments will include a systematic testing for variations of substrate composition and characteristics, while exploring advanced production methods to fully utilize the possibilities and properties of this material. In future work, mycelium development could be evaluated using quantitative visual inspections such as fluorescence chitin assay (Ayliffe et al. 2013). The unique fungal digestion mechanism could be utilized to manipulate and enhance the mechanical properties of the plant fibres (Dresbøll and Magid 2006) to feature integrated performances of the fungal mycelium that is bound within the plant matter. As demonstrated in previous research (Avni et al. 2017), substrate composition can also affect the structural components of fungal cell wall, therefore assist to manipulate the final material properties.

EXPERIMENTAL

Mycelium cultivation

The mycelium cultivation process was done in the mushroom research lab of MIGAL, northern R&D, Israel. The woodchips substrate for this experiment is pruning sourced from local forest trees and agricultural crops in the Galilee area, Israel. The average particle size is 5X15 mm. The substrate was thoroughly mixed with (50% w/v) water, then placed in a ⌀14cm glass petri dish (150gr wet substrate in each plate) and sterilized in an autoclave (1hr, 121°C). Each plate was inoculated with a disk of ⌀7mm mycelium grown on agar, then incubated at 25°C for 4-5 weeks. Five replicas for each variation of substrate type and fungi specie were used. Two plates of each substrate type (not inoculated with mycelium) where used as control. Mycelium growth rate was calculated by measuring its diameter every 2-3 days. Visual inspection was used to determine mycelium quality and density, ranged from 1-Thin, almost transparent; to 5- thick and firm, white (Figure 1). Mushroom growth parameters were multiply (growth rate mm/day X mycelium density 1-5) and compared with organic matter loss to evaluate their relation.

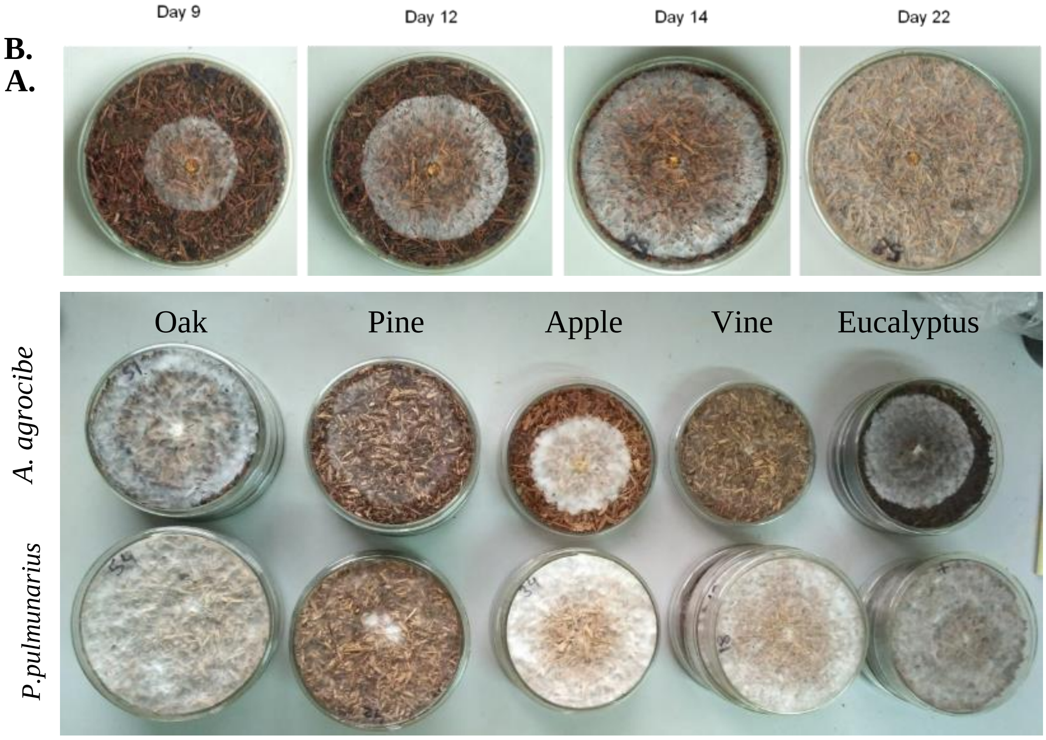

Figure 1: [A] Development of P. pulmonarius mycelium on oak for 16 days (from left to right). [B] Day 28, growth of A. agrocibe (top row) and P.pulmunarius (bottom row) on oak, pine, apple, vine and eucalyptus substrates. mycelium density and growth rate were measured during the experiment.

Chemical parameters:

All chemical properties where tested before and after mycelium growth. Two repeats where measured for each test. pH and conductivity where measured using a sample of substrate soaked in distilled water (1:10 w/w). Water content was determined by oven-drying (48 hours at 105°C). Samples where then milled using a 2mm sieve for carbon and nitrogen tests. Nitrogen content determined according to Kjeldahl, using a Buchi K-435 digestion and B-324 distillation units. For ash content measurement, milled samples were placed in crucible and burned in a Bifatherm multistage MS8 kiln (5 hours at 600°C).

Figure 2: Chemical parameters tests (from left to right); pH and electric conductivity, water, nitrogen and ash contents.

RESULTS AND DISCUSSION

Water capacity

As shown in Figure 3, the initial water content of all selected substrates was 52-54%. During the experiment, the control samples (without fungi) have lost significant amount of water compared with mycelium containing samples. The *P. pulmunarius* samples retained the highest water content during the experiment, followed by the *P. ostreatus*, *P. salmoneo* and *A. agrocibe (in this order).* The growth of *P. salmoneo and A. agrocibe* on vine and apple substrates did not develop or had a little growth and their water content dropped similarly to the control. All types of fungi that were grown on the pine substrate contained less water content compared with its control.

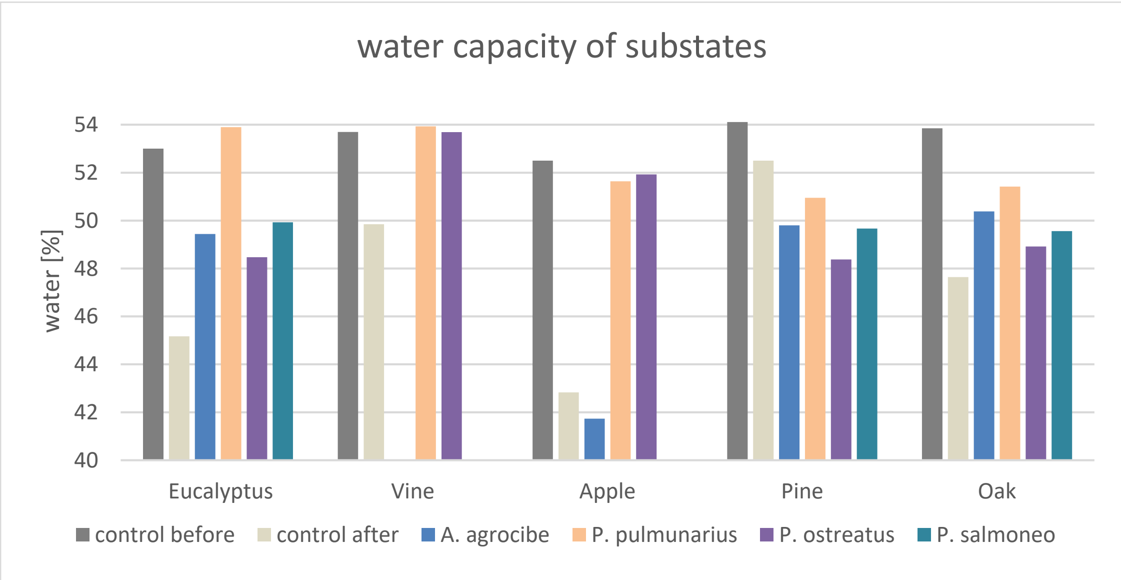

Figure 3: The changes in water content of selected lignocellulosic substrates during growth of several mushroom types. The mycelium retains higher water content compared with the control (before and after the experiment).

The lack of current substrates to hold enough water seems to challenge the growth of some fungi and demonstrates the effect of mycelium development on retaining the water content in the substrate. The control was drier in comparison to samples where mycelium has developed, except for the samples containing pine substrate, which were all drier than its control. This might be related to the very low density of mycelium on these samples (Figure 1). Furthermore, though the initial water content of the apple substrate was the lowest, its combination with *P. ostreatus* and *P. pulmunarius* retained its initial humidity and produced thick, dense mycelium. Considering these results, it seems that changes in water content can point on the level of mycelium development but does not necessarily indicate mycelium density.

pH level

As indicated in Figure 4, the *P.ostreatus* and *P.salmoneo* samples show a significant decrease in pH level, yet all other results do not show a coherent correlation between pH change and mycelium development. The initial pH level of all selected substrates was around 5-5.5. Such pH level is not optimal for woodchips based substrates. This might have influenced mycelium development.

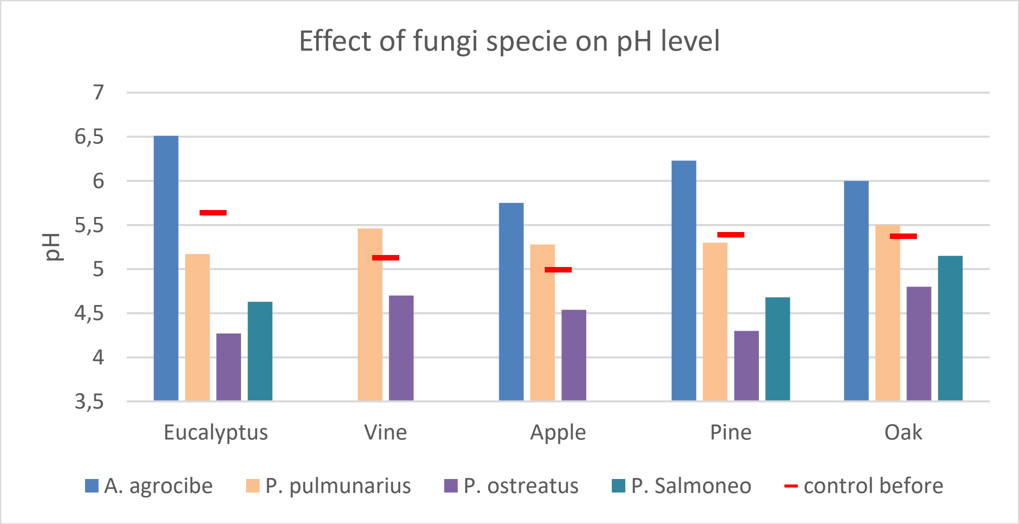

Figure 4: Changes in pH level of selected lignocellulosic substrates during growth of several mushroom types. Due to enzymatic digestion process, the pH level is expected to drop in comparison with the control where fungal mycelium has developed.

Nitrogen content

Figure 5 indicates that in all sets, accept the *A. agrocibe* on oak, the nitrogen level increased during mycelium development. The most significant increase is seen on the eucalyptus substrate that had a lower initial nitrogen content (0.6%) and increased during the growth of *P. ostreatus* by 0.5%. On all other substrates, the change is smaller (about 2%). The oak substrate had a relatively high initial nitrogen content of (about 0.7%), yet, the final values after the growth of varied fungi did not rise significantly (about 0.1%).

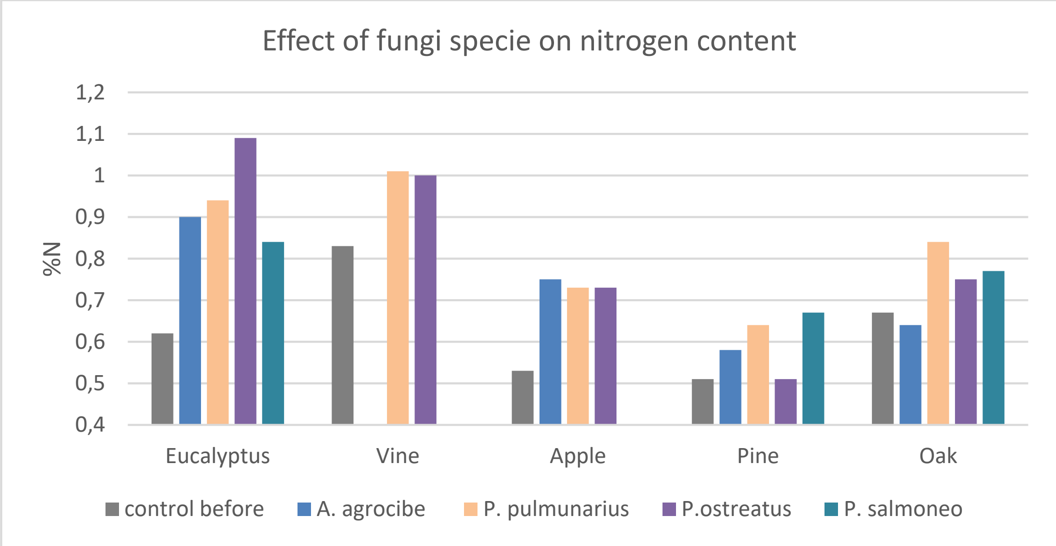

Figure 5: Changes in nitrogen content of selected lignocellulosic substrates during growth of several mushroom types. Due to enzymatic digestion process, the relative nitrogen content is expected to increase in comparison with the control.

Organic matter digestion

As can be seen in Figure 6, the samples of *P.ostreatus* grown on Vine and Apple substrates and the *P.pulmunarius* on oak, have shown the highest loss of organic matter during mycelium development (about 21gr). The smallest change is seen on the pine substrate. The high correlation between the change in organic matter content and mycelium development (Figure7) indicate that this test is a reliable quantitative index to evaluate mycelium quality.

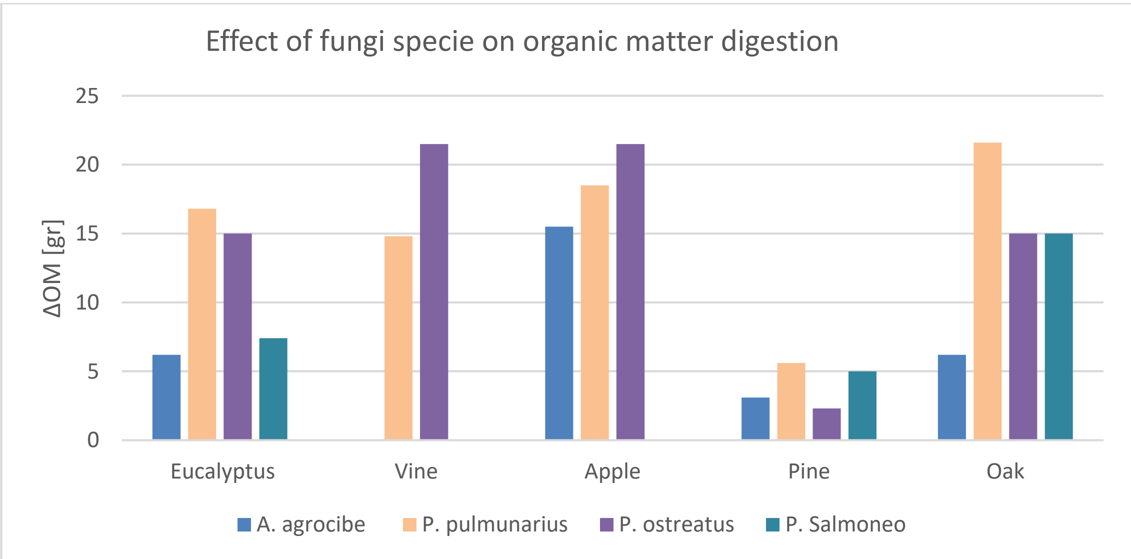

Figure 6: Changes in organic matter content of selected lignocellulosic substrates during growth of several mushroom types. Due to enzymatic digestion process, the relative organic matter content is expected to decrease in comparison with the control. The largest change in organic matter is expected where fungal growth is most developed.

Figure7 : P. ostreatus grown in ⌀14cm petri dishes with Apple (left) or Vine (right) woodchips.

Mushroom growth

To evaluate the mycelium quality and suitability for further work, mushroom growth parameters were multiply (growth rate mm/day X mycelium density 1-5) and compared with the amount of organic matter loss (Figure 8). This comparison shows high correlation between the selected parameters (R squared value is close or same to 1). According to this comparison, the mycelium growth on apple and vine substrates (Figure7), showed the most suitable qualitative and quantitative characteristics so far. According to this comparison, there is a clear correlation between the quantitative change in organic matter content during mushroom growth with the qualitative parameters of mycelium density and thickness tested (Figure 1). Therefore, this comparison is the most reliable index to evaluate mycelium development and suitability for further exploration so far.

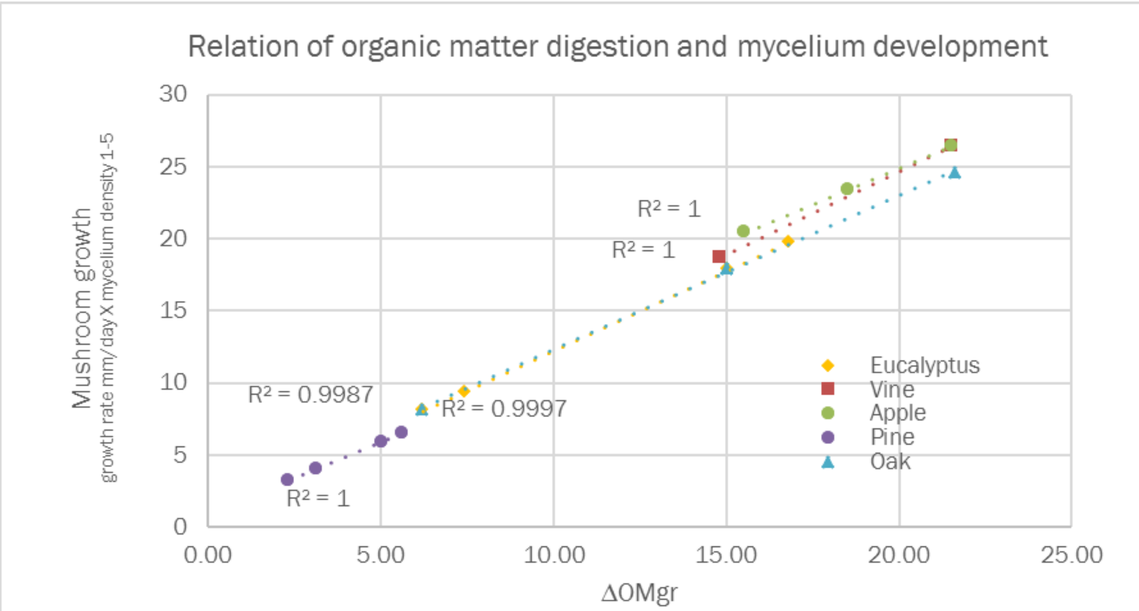

Figure 8: A comparison between the amount of organic matter loss to mushroom growth parameters (growth rate mm/day X mycelium density 1-5) shows high correlation, indicating it as reliable calculation for mycelium development.

Substrate parameters

The results generally indicate a lack of few parameters that are essential for mushroom growth and proper mycelium development. The water absorbance ability of desired substrates should be increased to around 65%; the initial pH level of the substrate should be higher, around 7-8; nitrogen content of the substrate should also start at higher levels, closer to 1%. This could be achieved by a few actions:

a. Increase the surface area of the substrate components by reducing the particle size to around Ø2mm as well as add varied amounts of sawdust (Danay et al. 2012), while maintaining aerobic conditions in the substrate.
b. A prior heat treatment to open and expand air cavities between the wood fibres, thus increase the porosity of the desired substrate.
c. Test additional materials with higher water absorbance ability, such as hemp fibres (Lelivelt 2015), coconut, soy bean meal, wheat bran, gypsum etc. (Danay et al. 2012) should be added to the selected substrate to increase its water capacity to the desired amount. The addition of such substrates can also contribute to its initial nitrogen content and to the mechanical properties (Lelivelt 2015).

CONCLUSIONS

The objective of this experiment is to locate fungi-substrate combinations that are most suitable for further exploration and development of potential materials in the field of architecture and industrial design. A set of 4 fungi species grown on 5 different agricultural plant waste substrates. The samples were tested for selected properties, including chemical changes in organic matter and qualitative evaluation of mycelium development. The high correlation between organic matter loss and mushroom growth parameters assisted to evaluate the efficiency of each substrate and fungi set. Best results are *P.ostreatus* mycelium grown on vine and on apple substrates. Therefore, variations of this fungi-plant sets could be used in further work. However, to better evaluate the suitability of each substrate-fungi set for more particular applications, additional analytical methods should be used. There is a need to develop a further set of parameters (physical, chemical and visual) of the varied substrate components to understand their relations with one another and its impact on final material properties.

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Effects of Methyl Methacrylate impregnation on durability of timber.

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Keywords: Methacrylate, wood, modification, durability, decay

ABSTRACT

Modifications such as methacrylation of wood can be used to improve both wood mechanical properties and durability characteristics. Methacrylation of wood can alter the water sorption behaviour of wood and this will have implications for the durability of methacrylate impregnated timber. In this paper, the effects of methacrylation on the durability of wood exposed to decay fungi wood were investigated. Samples of pine and spruce wood were impregnated with methyl methacrylate monomer and were exposed to brown and white rot fungi following the EN 113 standard method. Results confirmed a reduction in the moisture content of exposed modified samples and a resulting reduction in fungal attack for the majority of wood species/fungal combinations tested, with only brown rot attack on modified spruce showing ambiguous results. The modification was shown to increase durability by reducing fungal attack via reduction in water uptake, rather than by toxic or biocidal action.

INTRODUCTION

Wood can be modified via a number of thermal or chemical modifications Modifications such as methacrylation of wood can be used to improve both wood mechanical properties and durability characteristics. Methyl methacrylate has been polymerized in wood using catalysts (e.g. peroxides) and heat, or radiation, although catalyst aided polymerisation is faster than radiation aided (Ibach and Rowell, 2013). Impregnation of wood with methacrylate has been shown to improve mechanical properties such as hardness and bending strength (Hadi et al 2013, Ibach and Rowell 2013).

Methacrylate impregnation of wood will also alter the water sorption behaviour of the treated wood (Ding et al 2012). This will have implications for the durability of methacrylate impregnated timber as one of the key requirements for fungal decay of wood is the presence of sufficient water. Indeed modification methods utilising methyl methacrylate have been shown to significantly increase durability of timber (Li et al 2010, 2011). This study aims to determine the effect of methacrylation on the durability of selected timber species using standard testing methods.

EXPERIMENTAL

The wood types selected were Scots pine sapwood and Sitka spruce juvenile wood; to be treated using two formulations of methyl methacrylate hereafter referred to as treatment one (T1) and treatment two (T2).

Samples were placed in a treatment vessel with weights on them to stop them floating. A vacuum was then applied to the vessel. Once the vessel was evacuated, the treatment solution (Methyl methacrylate and azodiisobutyronitrile activator) was added without releasing the vacuum. The samples were maintained in the solution under vacuum for 15 minutes. The vacuum was then released to facilitate the uptake of the solution. The samples remained in the solution for a further 30 minutes (45 minutes was used for spruce). On removal from the treatment vessel the samples were immediately wrapped in aluminium foil and heated for a minimum of 16 hours. Following curing the methyl methacrylate content within the samples was determined. Target retentions were 40% for spruce and 45% for pine. Blocks not achieving this target were excluded from testing.

Retention was calculated using Equation 1 and Weight percent gain (WPG) from Equation 2

$$\text{Retention (\%)} = ((M_1 - M_2)/M_2) \times 100 \quad (1)$$

$$\text{WPG (\%)} = ((M_1 - M_2)/M_1) \times 100 \quad (2)$$

Where: M_1 = Untreated oven dry
M_2 = Treated oven dry weight

The samples were then placed into a conditioning room at 20°C and 65% RH until constant mass was obtained. The equilibrium moisture content (EMC) of the blocks was determined under these conditions (Eqn 3). Conditioned samples were irradiated using gamma irradiation to sterilise them. The effect of irradiation on EMC was also determined by including extra blocks in the irradiation cycle. These were then conditioned at 20°C and 65% RH until constant mass, with EMC calculated using equation 3.

$$\text{EMC (\%)} = ((M_3 - M_2)/M_2) \times 100 \quad (3)$$

Where: M_2 = Treated oven dry weight
M_3 = Wet weight at equilibrium

Once conditioned and sterilised, the blocks were tested for durability against basidiomycete decay using the methods described in the standard EN113 (CEN 1997). Test jars were inoculated with either *Trametes versicolor* CTB863A (a white rot causing fungi) or *Coniophora puteana* FPRL 11E (a brown rot causing fungus). Once the fungus was established sterile supports were placed on to the agar surface. One treated and one untreated sample were then placed into each jar, with a total of four sample pairs per fungus per treatment type. Virulence controls of solid pine for *C. puteana* and beech for *T. versicolor* were also used with two untreated sample blocks per jar. Blank, uninoculated jars, were also utilised with one treated and one untreated block per jar with three replicates.

The samples were exposed for a period of 16 weeks (as per EN113), at the end of which the samples were removed from the jars, carefully cleaned of adhering mycelium and weighed to determine post test weight. The samples were then oven dried at 103°C for 16 hours before being weighed again. The moisture content and any mass loss of the blocks at end of exposure was then calculated. Mass loss of the wood component was calculated as a percent of the original untreated mass of the blocks (Eqn 4). Durability classes were assigned according to EN350-1 (CEN 2016).

$$\text{Mass loss (\%)} = ((M_2 - M_4)/M_1) \times 100 \qquad (4)$$

Where: M_1 = Untreated oven dry
M_2 = Treated oven dry weight
M_4 = Dry weight after decay

RESULTS AND DISCUSSION

Treatment levels

The mean percentage of methacrylate and the corresponding weight percent gain (WPG) are shown in Table 1 below. The differences between treatments are significant at p=0.05 in all cases.

Table 1. Treatment parameters of samples – mean values of retention and WPG

	Pine		Spruce	
	T1	T2	T1	T2
Retention [%]	47.71	46.92	48.95	55.81
WPG [%]	96.46	88.58	98.87	128.61

Equ*ilibrium Moisture Content*

Treatment using methacrylate was found to significantly reduce the equilibrium moisture content (EMC) of the samples (Figure 1). There was a small increase in EMC following irradiation although this was still significantly lower than the untreated samples.

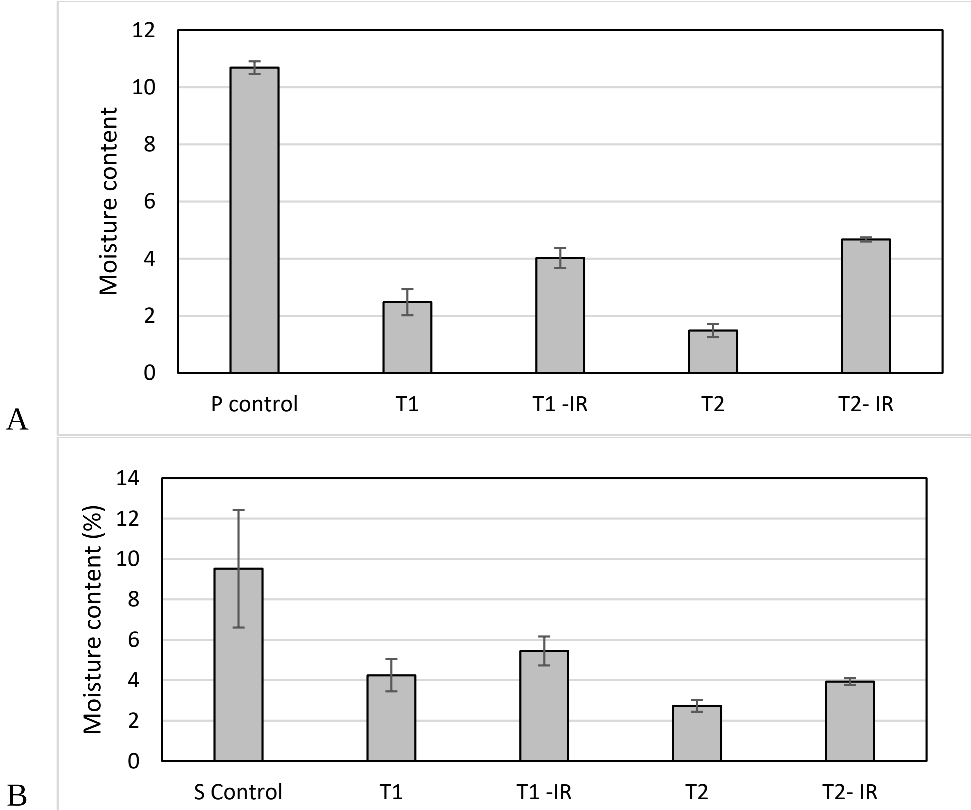


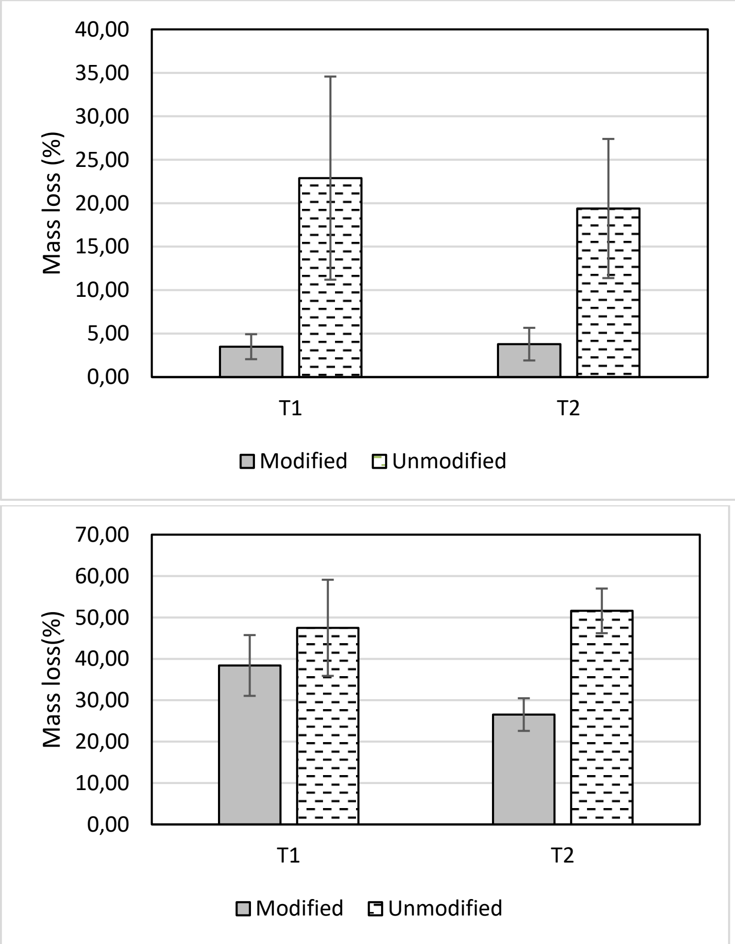
Figure 1. EMC of A) Pine and B) spruce samples at 65% RH before and after irradiation (--IR) Error bars show standard deviation

Basidiomycete decay test

At the end of the test all of the blocks for all treatments were found to be covered with mycelium, with no discernible difference between treatments or wood type. Virulence control tests showed mass losses over 20% ensuring that the test was valid.

The mass loss data for spruce is shown in Figure 2, with the percentage mass loss of the treated blocks compared to that of the untreated blocks for both fungi. The data shows a considerable and statistically significant reduction of decay of the treated samples compared to the untreated samples, with both formulations, when exposed to the white rot fungus *T. versicolor*. However, with the brown rot fungus, *C. puteana*, a statistically significant reduction in mass loss was only seen with treatment 2. It should be noted that treatment 2 in spruce resulted in significantly higher WPG values, than with treatment 1.

A



B

Figure 2. Mass loss (%) of spruce samples exposed to A) T. versicolor and B) C. puteana for 16 weeks. Error bars show standard deviation

The data of the mass loss (%) of the pine samples is shown in Figure 3. In this case, there is a statistically significant reduction in mass loss due to decay seen with both formulations for both fungi.

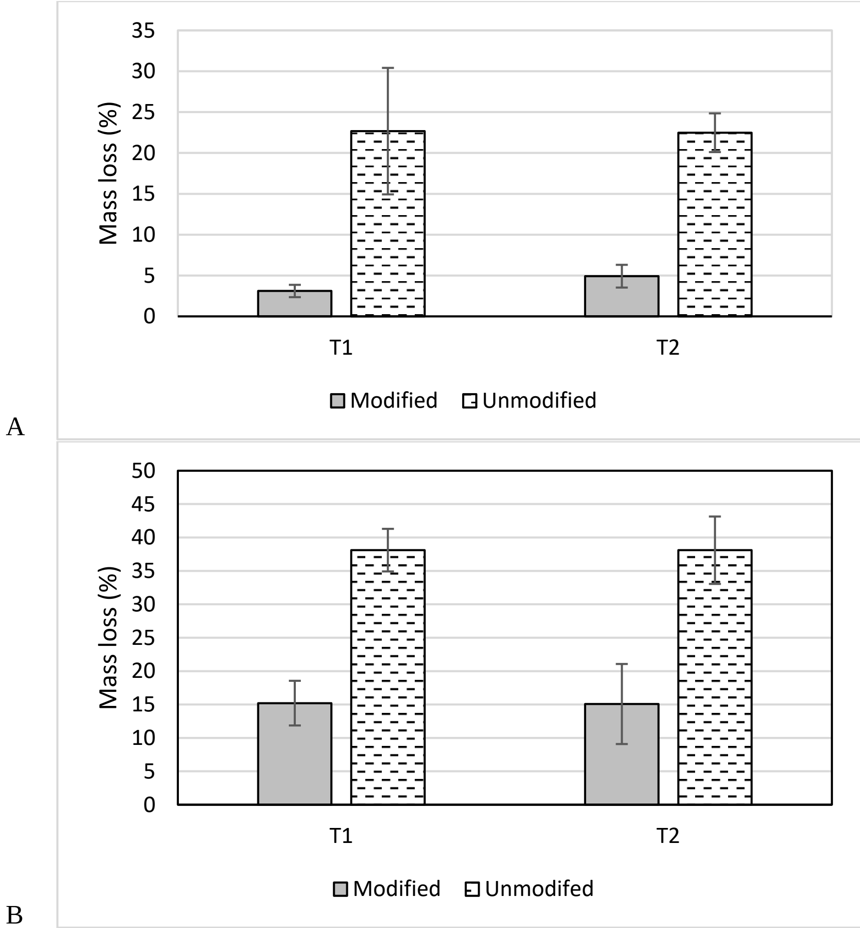


Figure 3. Mass loss (%) of pine samples exposed to A) T. versicolor and B) C. puteana for 16 weeks. Error bars show standard deviation.

The durability classes of the samples are summarised in Table 2 and illustrate an increase in durability following treatment

Table 2 Durability class of treated samples

	T1		T2	
	T. versicolor	*C. puteana*	*T. versicolor*	*C. puteana*
Pine	1	3	2	3
Spruce	1	5	3	3

CONCLUSIONS

The results show an increase in durability of both pine and spruce samples when treated with methyl methacrylate. The protection mechanism can be inferred to be a lowering of water uptake resulting in a reduction of decay; there is no evidence of any fungitoxic effects. The protection varies between wood species and fungal species and can be influenced by formulation of the treatment solution.

ACKNOWLEDGEMENTS

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Resistance of bio-based, synthetic and inorganic thermal insulations against attack by house mouse

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Keywords: wooden structure, thermal insulation, damaging, house mouse

ABSTRACT

The poster presents resistance of selected natural bio-based, inorganic and synthetized organic thermal insulations against the house mouse (*Mus musculus*). At 24 hour's tests its males and females damaged not only natural bio-based insulations, *i.e.* cellulose (Tempelan), straw, hemp (Q-Flex), cork (Expanded granulated cork) and fleece (NaturWool), but also expanded polystyrene (EPS 70 F WhiteFacade; Isover EPS GreyWall), and even insulations made from mineral substances, *i.e.* rock-wool (Nobasil FKD; Isover TF) and glass wool (Isover Multimax). On the other hand, enough resistant against the mouse-attacks were two types of synthetized organic insulations, *i.e.* polyurethane foam (Puren MV PUR-PIR) and extruded polystyrene (Austrotherm XPS TOP; Styrodur 2800 C). Damaging activity of the mouse males and females was comparable. They attacked the thermal insulations: (1/ firstly) mechanically – disrupted them with guns, and (2/ followed from bas of natural bio-based insulations) build hideouts without consuming them, or also consumed grains present in the wheat straw.

INTRODUCTION

Damaging of thermal insulations in wooden structures by mechanical, physical, chemical or biological factors leads to impair of their efficiency in a connection with energy and economy losses. Thermal insulations used in wooden buildings (vertical walls, ceilings, roofs, *etc*.) are often inserted between OSB, plywood, gypsum and other solid boards creating composite sandwiches. Bio-attack of such sandwiches by rodents (mouse or rats) is limited and only scarce. However, in some design solutions the insulations are located as separate ones, mainly in roofs, and here their accessibility for attack by rodents is a potentially higher.

Biological attacks of thermal insulations by bacteria, moulds, decaying fungi or insects are more likely at natural bio-based insulations (wooden fibres, cork, cellulose, straw, hemp, *etc*.) comparing to other types of insulations (Wasserbauer 2000, Tisoňová and Reinprecht 2013). Therefore, in practice the natural bio-based insulations should be in some cases treated with biocides – *e.g.* with boric acid (fungicide, insecticide and fire-retardant) which is added to cellulose insulations (Climatizer Plus, Tempelan, *etc*.).

However, rodents with buggies mechanically damage not only natural bio-based insulations, but also insulations made from inorganic and synthetized organic materials (Timm and Fisher 1986, Hygnstrom 1992, 1996). Rodents concurrently exclude urine and excrements (uric acid disrupts the chemical structure of some thermal insulations and surrounding materials, *e.g.* wooden elements and vapour barriers), and they can damage electrical installations and cause people-health impairments, as well (Wasserbauer 2000).

EXPERIMENTAL

For the anti-rodent resistance tests have been used 13 types of thermal insulations – bio-based (cellulose, straw, hemp, granulated cork, fleece), synthetized organic (expanded polystyrene, extruded polystyrene and polyurethane), and inorganic (rock-wool and glass wool) – listed in Table 1. Ten samples with dimensions of 100×175×410 mm (thickness × width × height; the thickness 100 mm of the bulk bio-based insulations was achieved by their pounding among two cardboards) were used from each type of thermal insulation.
Samples of the thermal insulations were inserted into glass containers 555× 545×410 mm – three samples into one container divided with two glasses on three 179 mm wide subsections – see Fig. 1A. Following, during the 24 hour‘s anti-rodent resistance tests performed at a room temperature ~18°C, the males and females of house mouse (*Mus musculus*) - var. albino laboratory (65 males and 65 females with average weight from 20 to 25 g) wanted to get from one side of samples on their other side where was present a bait food (mixture of fruits, chesses, chocolates, sausages and breeding granulated food) – see Fig. 1. These tests were evaluated on the basis of: (1) mechanical damages of thermal insulations (pang depth in insulations – max. 100 mm), and (2) counts of mouse mortality.

RESULTS AND DISCUSSION

The least resistance to house mouse activity showed all tested commercial natural bio-based insulations containing polysaccharides or also other organic compounds, *i.e*. blown cellulose (Tempelan), straw (Wheat straw), hemp (Q-Flex), cork (Expanded granulated cork), and fleece (NaturWool) – Table 1, Figure 1.

Table 1: Thermal insulations – type, name, physical characteristic and resistance to house mouse

Type of insulation	Name	Density	Thermal conductivity	Resistance to house mouse activity		
				Pang depth in insulation [mm]		Mortality
		[kg·m^{-3}]	[W·m^{-1}·K^{-1}]	$x_{min.} - x_{max}$	x_{mean}	[0−10]
Cellulose	Tempelan	65	0.038	40-100	79	1
Straw	Wheat straw	100	0.140	80-100	96	0
Hemp	Q-Flex	35	0.042	70-100	89	0
Cork	Expanded granulated cork	70	0.042	80-100	93	0
Fleece	NaturWool	15	0.038	100	100	0
Expanded polystyrene	EPS 70 F WhiteFacade	16	0.039	0-100	53	3
	Isover EPS GreyWall	15	0.032	10-100	50	1
Extruded polystyrene	Austrotherm XPS TOP	30	–	0-30	3	1
	Styrodur 2800 C	30	0.037	0-5	0.5	0
Polyurethane	Puren MV PUR-PIR	40	0.027	0	0	0
Rockwool	Nobasil FKD	60	0.039	50-100	76	5
	Isover TF	55	0.038	0-100	41	2
Glass wool	Isover Multimax	50	0.030	0-100	43	1

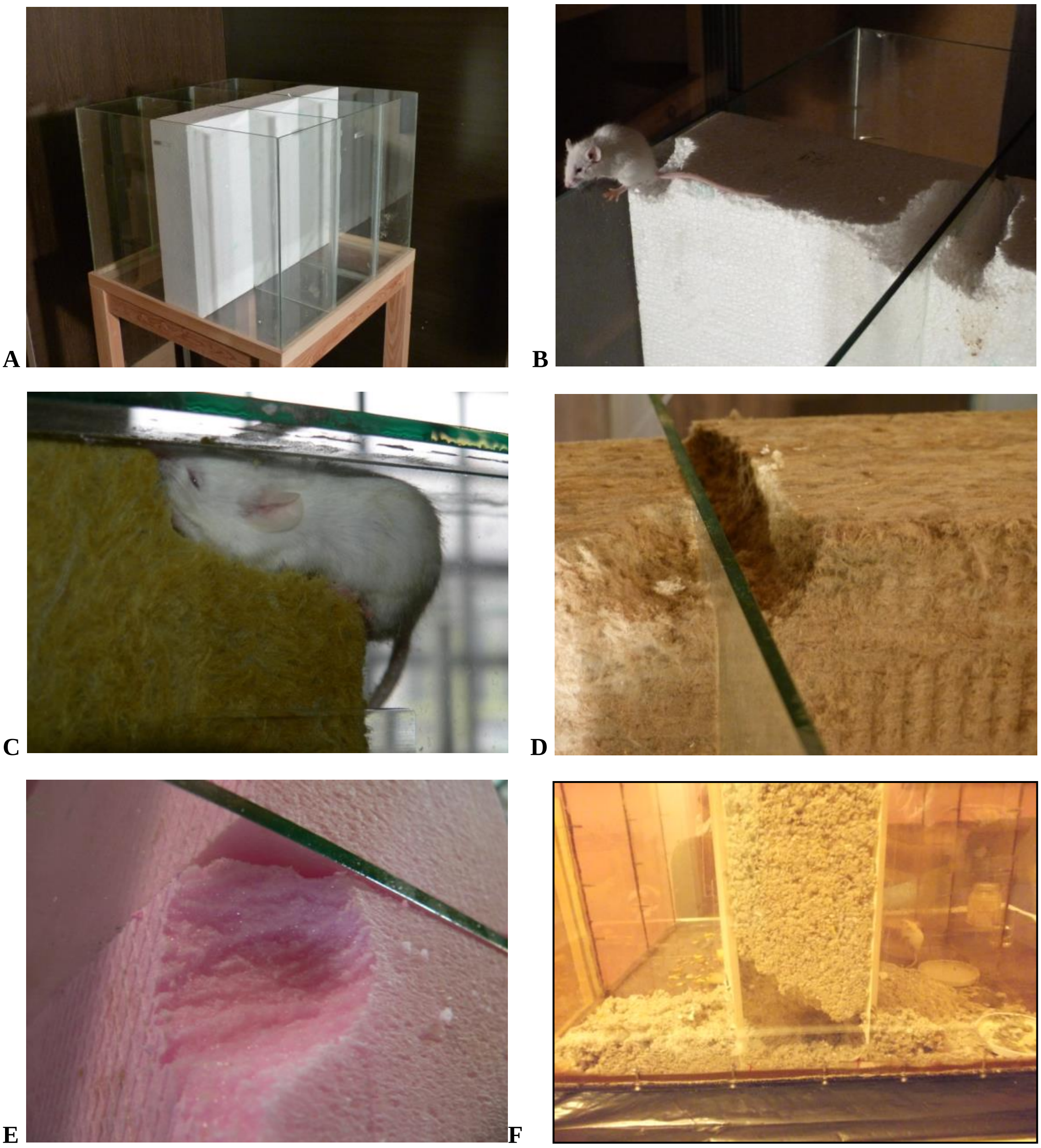

Figure: 1 Examples of the thermal insulations attacks by house mouse males and females: A – glass container divided with two glasses on three 179 mm wide subsections prepared for testing the "EPS 70 F WhiteFacade" insulation; B – attack of expanded polystyrene EPS 70 F WhiteFacade; C – attack of rock-wool Isover TF; D – attack of glass wool Isover Multimax; E –only poor attack of extruded polystyrene Austrotherm XPS TOP; F – strong attack of cellulose insulation Tempelan

A partly better anti-mouse resistance had the expanded polystyrene (EPS 70 F WhiteFacade; Isover EPS GreyWall) as well as the inorganic insulations, *i.e.* rock-wool (Nobasil FKD; Isover TF) and glass wool (Isover Multimax). Rock-wools, having fibers with diameter of 4 – 20 µm and length of 10 – 70 mm, mutually connected with phenol-formaldehyde resins and also containing hydrofobizators (silicone oils, silanes, *etc*.), were attacked in 9 or 10 tests with a local weakening of the insulation thickness by about 76 % or 41 %. A significant damage of mineral thermal insulations at ½-years long tests with the house mouse obtained also Timm and Fisher (1986) and Hygnstrom (1992) – analysing deterioration of isolations indirectly on the basis of changes in their heat transfer (*e.g.* see thermal conductivities of undamaged insulations in Table 1).

The highest anti-mouse resistance showed polyurethane foam (Puren MV PUR-PIR) and extruded polystyrene (Austrotherm XPS TOP; Styrodur 2800 C). The polyurethane was not attacked probably due to its micro-structure with closed pores, and also due to its chemical structure since in cured PUR may remain free isocyanates, or in cured PIR also polyester-polyols – both these substances with potential rodenticide efficiency. The extruded polystyrene had an evidently better anti-mouse resistance (only 1 attack in 10 tests) than the expanded polystyrene (8 or 10 attacks in 10 tests). The difference of these two types of thermal insulations having the same chemical structure to attack by mouse can be explained by their different microstructure (the extruded XPS is not formed from bead granules, its pores are more closed, and its density is double to the expanded EPS), and also by different types and amounts of chemical additives (*e.g.* Austrotherm XPS TOP contains fire retardant with a potential rodenticide effect) – Table 1, Figure 1.

CONCLUSIONS

- The anti-mouse resistance of various thermal insulations depends first of all on their microstructure. The non-fertile and non-fibrous insulations with a closed structure (PUR-PIR and XPS) were not attacked by mouse, but on contrary, those ones with a friable (cellulose, cork, EPS) or fibre (straw, hemp, fleece, rock-wool, glass wool) structure were easily attacked by mouse.
- The proposed 24-h laboratory test method in glass containers, used for determination the mouse activity in the substance of thermal insulations at searching of food on their other side, gives an important basic knowledge about a high, medium or none resistance of insulations to rodents.
- The sex of mouse did not effect on their activity in the thermal insulations.

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