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

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

Book of abstracts

Editors:
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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)

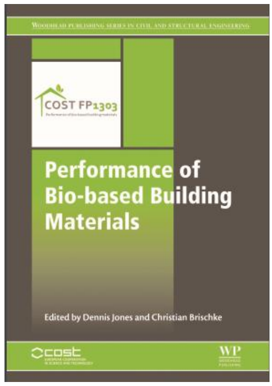
Many of the Early Career Investigators in this Action may be unaware of these previous Actions, but some of those here (myself included) have been active in several of these (indeed I recall being involved in a joint meeting between E2 and E8!). Many of you were present in the kick off meeting of our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

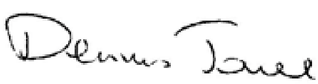
Whilst this Action started off as my rambling ideas more than 5 years ago, it would never have happened without the activity of many people within our network. However once started, I must offer my sincerest thanks to the following:

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

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

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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. 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:

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

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):

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

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:

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

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.

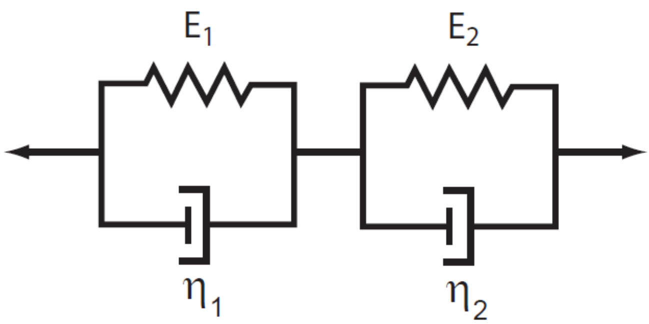

Figure 1: Two Kelvin-Voigt elements in series

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.

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 (*e.g*. Ammer 1964; Bavendamm and Reichelt 1938; Theden 1941; Stienen *et al.* 2014; Höpken 2015; Meyer and Brischke 2015; Brischke *et al.* 2017). The experimental set-ups (see examples in Fig. 1) 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.

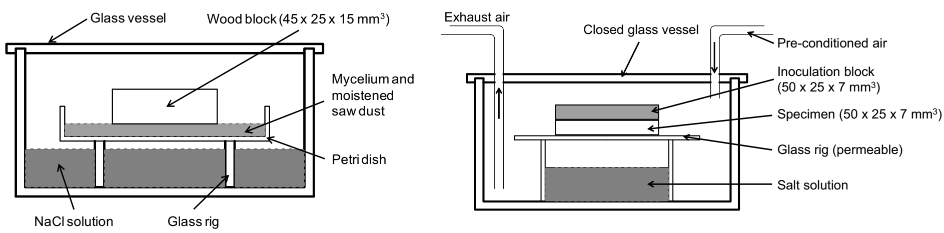

Figure 1: Experimental set up for decay tests. Left: Set up according to Bavendamm and Reichelt (1938). Right: Set up according to Theden (1941).

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 fibre 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.

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.

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Moisture monitoring in buildings in different microclimate environment

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Keywords: water, service life, degradation, buildings, wood decay fungi

ABSTRACT

Service life of wooden structures is one of the most important criteria in the decisionmaking process. The duration, during which a certain wooden structure will perform its task, depends on variety of factors (Isaksson and Thelandersson, 2013). However, service life of wood exposed outdoor is predominately affected by wood decaying fungi (brown and white rot fungi) (Van den Bulcke *et al.,* 2011). Moisture conditions and temperature are the most important factors influencing the ability of the fungi to degrade wood (Van Acker *et al.,* 2014). These two factors depend on the design of the respective construction, exposure conditions and local climate conditions. If MC and temperature are monitored, severity of respective location can be evaluated (Welzbacher *et al.,* 2009). Based on the severity of the location, additional protection by design measures can be applied. However, if this is not sufficient, material that is more durable should be selected.

One of the issues related with assessment of potential threat of certain location is related to question, what the moisture limit for fungal decay is. There are various data available in the literature. In the classical literature, moisture limits depend predominately on the fungal species. For example, Schmidt (2006) reported, that minimal MC for *A. vaillantii* and *G. trabeum* is 30%, while slightly lower (26%) minimal MC are reported for *C. puteana* and *S. lacrymans*. However, recent finding showed that moisture limits for fungal growth and decay depends on the fungal species used, and considerably differs between wood species investigated. For example, minimal moisture contents for wood decay varied between 16.3% (*G. trabeum* on Scoots pine sapwood) and 52.3% (*D. expansa* on Douglas fir) (Meyer and Brischke, 2015).

The aim of respective paper was to determine material climate as defined by Brischke and coworkers (2008) and Isaksson and Thelandersson (2013) of wooden construction of the four objects in Slovenia, namely: WW2 Partisan hospital Franja, Hay-racks in the Alpine plateau Pokljuka, Old house in northern part of Slovenia Vrba and model house made of thermally modified wood in Mozirje (Figure 1). The objects are located in different microclimate conditions in gorge (WWII hospital), on the mountain plateau (hay-rack) and on open space (old house). The severity of location results in different service life conditions.

There are two types of continuous monitoring performed on wooden objects. There are temperature and RH sensors (Scanntronik, Germany) located inside and outside the

respective objects. Conductance paste between the sensor and wood enabled accurate measurements. All data was collected hourly with Thermofox data loggers (Scanntronik, Germany). In parallel, the moisture content (MC) on eight locations was also determined, through resistance measurements at these locations. Insulated electrodes (stainless steel screws) were applied at various positions and linked to a Gigamodule logger (Scanntronik, Mugrauer GmbH, Germany). This equipment enables measurements of wood MC between 6% and 60%, with measurements logged twice per day. All the measuring and logging equipment was placed inside a steel box. In order to convert electrical resistance measured inside wood to MC, wood species-specific resistance characteristics were developed based on the methodology described by Lampen (2012).

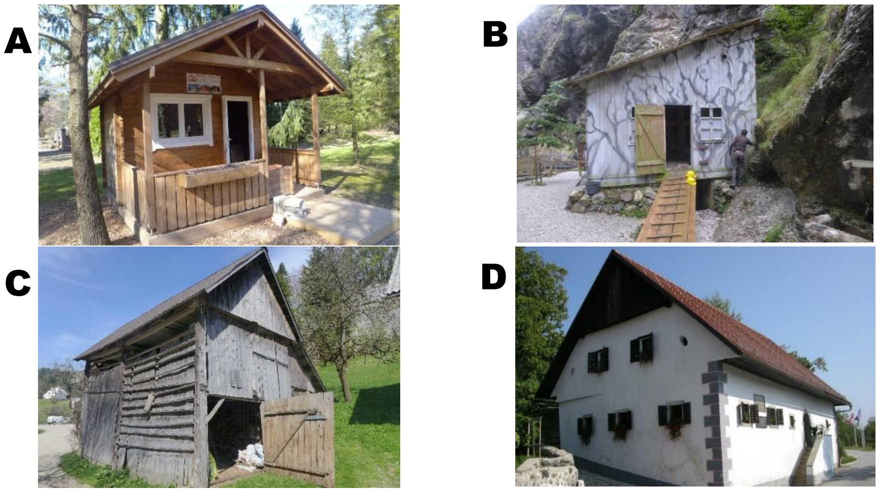

Figure 1:Model house made of thermally modified wood (a), WWII partisan hospital Franja (B); Hay-rack in Pokljuka (C) and house in the north of Slovenia in Vrba (D).

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Fungal and bacterial colonies growing on wood surfaces exposed to an Atlantic climate

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Keywords: Fungi, bacteria, oak, Douglas fir, wood weathering

ABSTRACT

The weathering of wood has been extensively studied in the use classes 4 and 5. Much less research has been conducted on wood in exterior use that is not in ground contact, *i.e.* use class 3. There is especially a lack in research concerning the influence of the presence of bacterial and fungal communities on the weathering process of wood.

The aim of the project is to identify any synergistic effects between biotic factors such as aerobic bacteria, Basidiomycota, Ascomycota and abiotic factors such as light, temperature and moisture on the weathering of wood surfaces in use class 3.

In order to study the interactions of fungi and bacteria on wood during the weathering process, the microorganisms have to be identified. With the help of a surface contact test the microorganisms were transferred to agar plates and consequently incubated so that they could grow in optimal conditions. Once the microbiological colonies had developed sufficiently they were separated by selecting sections from the colonies and replated on fresh agar. The pure cultures were subsequently identified.

The methods for isolating aerobic bacteria, Basidiomycota and Ascomycota from wood surfaces that were exposed to Atlantic climate as well as identification techniques are shown in detail.

Figure 1: From left to right: Douglas fir and oak wood samples, fungal and bacterial colonies growing on malt-agar, ESEM analysis of oak wood

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

The BIA Project 2013-42434R titled "Evaluation of the functional behavior of the wood outside the contact with the ground", tries to advance in the knowledge of the behaviour of different types of wood, exposed outside in different Spanish climates. For this purpose, seven experimental devices have been placed in different Spanish climate regions. These climate regaions are Asturias, Palencia, Valencia, Madrid, Cordoba, Huelva and Vitoria, and were selected taking into account different continental and coastal climates.

Each experimental device has seven pieces of wood, with dimensions of 750x100x20 mm. Each of these seven pieces was of a different wood species, namely *Pinus sylvestris, Pinus radiata, Pinus nigra, Castanea sativa, Picea abies, Eucaliptus globulus and thermotrated Pinus radiata*. In the device located in Madrid, in addition to the seven pieces of wood placed in each location, an eighth piece of *Pinus sylvestis* with section 750x150x150 mm was placed, to analyse the effect of the mass. Each piece of wood in each experimental device had its temperature and its moisture content measured every two hours.

In the present work the behaviour of the different species during the first two years of exposure is analysed, drawing provisional conclusions regarding their different sorption velocity and the best way to carry out the wood characterisation processes for their exterior use.

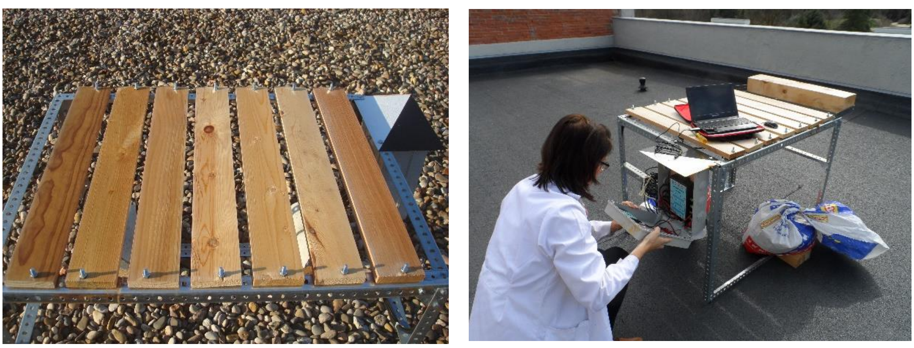

Figure 1: Experimental device.

In order to convert the electrical resistance readings (R), provided by the measuring equipment in wood moisture content (MC) values, mathematical models were used that relate both variables to each other with the aid of temperature.

The main objective of the project is to obtain national data (closely related to our specific climatic conditions, our wood species and the distribution and intensity of biotic agents at national level) as part of a European standardisation process

The term of 3 to 4 years should allow designers, producers and users not only to optimise their designs from an environmental point of view, but also to determine the best treatment, the best species or the type of product best suited to ensure the Life in service planned in project.

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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 commodities like decking and fences 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 (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. 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 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 tools have the potential to serve as instrument for design and service life prediction of timber structures.

The core of the proposed engineering tools is a performance based design approach which is similar to the approach used in *e.g.* structural engineering. The performance prediction of wooden structures is generally a three-step approach, see Fig. 1. A design solution is considered successful if the exposure dose over time stays equal or below a critical dose d_{crit} characterising the resistance of the material in use (engineering analogy: 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. To include all influencing factors, a factorisation approach is used based on dose-response relationships between wood material climate and responding fungal decay,

where onset of decay is defined as limit state. 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.

For decking and cladding, a first engineering tool was proposed in the 'WoodExter' project (Thelandersson *et al*., 2011), consisting of equations, tables and diagrams needed to determine the influencing factors (consequence class, basic exposure index for the geographical location, modifying factors to account for local climate conditions, sheltering/driving rain, distance from ground, detailed design, timber species). An updated version (from the 'WoodBuild' project) was presented in Isaksson *et al*., 2015. For timber bridges, an engineering tool was recently proposed in the 'Durable Timber Bridges' project (Pousette *et al*., 2017). The approach is comparable to the aforementioned approach for decking and cladding, however, some of the model input was updated due to more recent testing and simulations, as well as some bridge specific factors were included (*e.g*. examples of timber bridge details and their moisture trapping behaviour). The DuraTB-guideline also includes good and bad examples of detailing as well as recommendations on monitoring intervals, in order to achieve the intended service life.

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, new/future research results can be easily implemented, as well as the user be able to use own data for some of the 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.

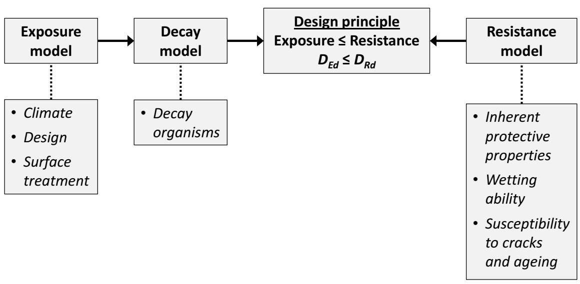

Figure 1: Performance modelling with three-step approach.

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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 (Figure 1).

Figure 1. RISE's test site in Borås, Sweden

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, 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 (Figure 2).

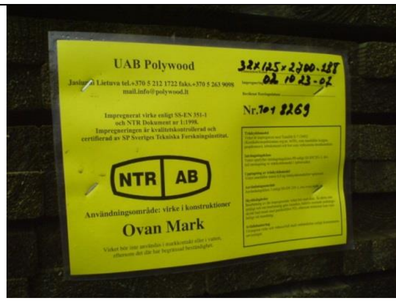
Wood protection class	Quality mark	Example of bundle marking
NTR M	NTR M	
NTR A	NTR A	
NTR A Pole	NTR A pole	
NTR AB	NTR AB	
NTR B	NTR B	
NTR GRAN (Spruce)	NTR GRAN	
NTR GW (Spruce)	NTR GW	

Figure 2. NTR-NWPC quality marks.

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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 become more 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 industrialised systems. However, the variety of raw materials, designs and construction systems, combined with some harsh climates, could have as result in some cases of pathological problems associated to wood destroying fungi, insects and aesthetics.

The wood species selected and the design details are fundamental for performance and durability of the timber houses. The wood degradation depends on firstly 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 to a high level of detail as well as ensuring 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 continue to serve their original purpose.

This house constituting a prime example of the versatility of this wood in structural and decorative wood elements. It is worth pointing out that all joints between structural components have been assembled with traditional techniques and without using metallic elements.

Figure 1: *Eucalytus globulus* house in Spain.

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Performance of wooden windows and façade elements in different natural environments

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Keywords: Norway spruce, thermal modification, wax, wooden facades, wooden windows,

ABSTRACT

Wooden products, which are a part of building envelopes (windows, doors and façades), are affected by several different parameters, *e.g*. liquid water, air humidity, UV radiation, temperature and pollution. Their performance and life-time is largely dependent on wood moisture content (MC), wood species, as well as potential wood modification and surface treatment. Windows and façade elements presented in this research were made of non-modified Norway spruce (*Picea abies* L.) (NMS) and Silvapro® thermally modified spruce (TMS). TMS elements were surface treated with naturally based Silvacera® wax (TMS-W) (Silvaprodukt d.o.o.) and synthetic coating (TMS-C) (Remmers Baustofftechnik GmbH). All elements were exposed at constantly rotating test objects at the following five locations around Europe since October 2015: Žiri and Ljubljana (Slovenia), Hannover (Germany), Skellefteå (Sweden) and Madrid (Spain). Results for a period of 12 months since the beginning of the exposure of wood MC, colour changes (ΔE) and fungal growth (mould) are presented in this paper.

The wood MC of TMS façade elements (Figure 1, left) was lower compared to NMS which was even more prominent in case of windows (Figure 1, right). Wax impregnated elements (TMS-W) exhibited lower MC due to increased hydrophobicity of wooden elements. Façade elements with synthetic coating (TMS-C) were the driest whereas in case of windows this difference was not prominent due to less severe exposure, greater thickness of elements and exposure only from outside compared to façade elements which were exposed from all six sides.

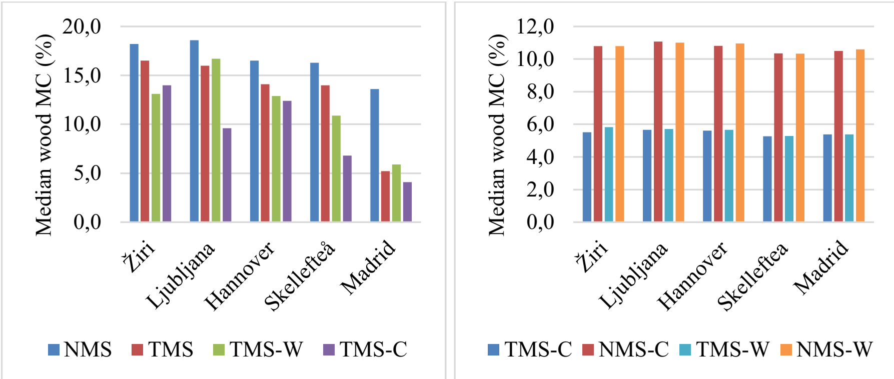

Figure 1: Median wood MC of façade elements (left) and windows (right) for a period of 12 months

The total colour distance ΔE of façade elements after 12 months (Figure 2, left) was significantly affected by the intensity of rain events. ΔE of NMS was greater than of TMS in Žiri, Ljubljana and Hannover where the precipitations were more intensive, whereas ΔE of NMS was lower compared to TMS in Skellefteå and Madrid. ΔE of synthetic coated elements were less prominent and more equal between different locations. Differences between Žiri, Ljubljana and Hannover were also caused by differences in exposure on local level (micro climate). Wax (TMS-W) did not contribute to lower ΔE due to lightening of surface but prevented extensive silvering, whereas addition of brown pigments (TMS-WP) showed good and promising results. Fungal growth (0 – no colour disfigurement, 4 – extensive colour disfigurement) or intensity of moulds (Figure 2, right) was dependent especially on precipitation. Madrid and Skellefteå revealed the lowest evaluation score due to very stable conditions, low amount of precipitations, cold climate in Skellefteå and dry climate in Madrid. Meanwhile, Žiri and Hannover revealed the highest evaluation score because of the high precipitation and high relative humidity. TMS-W received very low evaluation scores and therefore the lowest amount of colour disfigurement whereas TMS-C exhibited almost no mould.

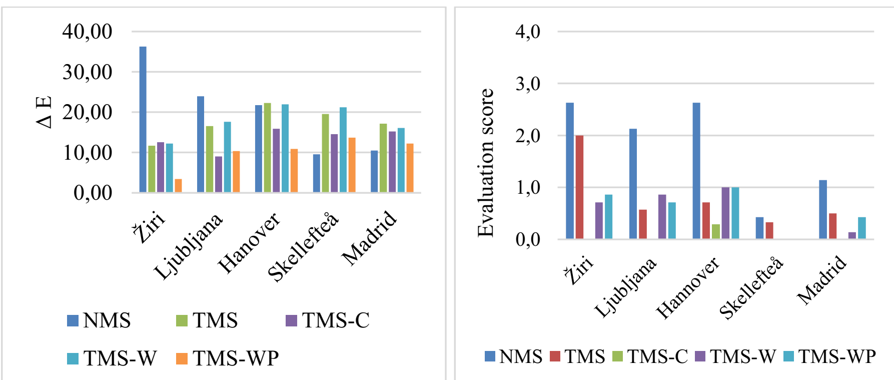

Figure 2: Colour changes (left) and mould and stain growth (right) of façade elements after 12 months of exposure

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Maintenance systems for wooden façades

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

ABSTRACT

For a long time, architectural design has tackled 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 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 and Brito, 2003).

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

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 elements more subjected to environmental agents, like meteorological events or UV rays, which are the main causes of wooden deterioration (Davoli 2001; Rüther and Time 2015).

In order to provide durability to the technological element, it is important to guarantee both the natural component durability and the possibility of skin management. In fact, the former is important to guarantee the durability of the single skin components and their composition, the latter is important for the possibility to forecast 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 the designer has to guarantee not only *the energy saving solutions during the phases of construction and use of the building,* but it has to be *also responsible for the assessment its of life cycle and maintenance solutions* (art. 23 Dlgs n 56, 2017).

The aim of this research is to identify through a set of case studies some best practices for improving the maintenance procedures of wooden envelope sand to improve the overall element durability. It will be investigated different case studies, with different functional models and different finishing solutions, to compile a list of designing suggestions for wooden façades.

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

The 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, type 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 damage for 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 eventual disassemble of the skin's components 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 repairability and the ability to be replaceable, are the requirements whose consider the possibility of assessing how the single parts can be disassembled without damaging the entire technologic element, but only the local area of damage.

In conclusion, the design of 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 aim of this research is to investigate a set of case studies to see which are the best practices to implement these capabilities and to indicate design suggestions useful to the designer approaching the design of wooden buildings.

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Towards high performance European wood materials for outdoors use

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Keywords: Wood, quality, protection, biocide, durability

ABSTRACT

Wood is without doubt the most used biobased building material. 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. Different wood types have different properties including different resistance to biological degradation. Chemical wood protection allows the extension of the service life of wood, timber, wood structures and engineered wood in hazardous situations of high moisture, in and above ground, and in the sea. This industry has been put under pressure by national and international legislation that are increasingly imposing more restrictions on the use of biocides. Even being the most cost efficient and overall best performing wood material for outdoors use, preservative treated wood is also among the cheapest. That also adds to the perception of the material by the costumers. 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. Wood modification technologies that are not based on biocides offer today a range of alternative products for preservative treated wood.

Different wood materials for outdoor applications are available on the market. The majority of these materials consist of untreated or partially treated wood transformed into products. Naturally rot resistant wood species, 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 disappointments. 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 towards guaranties.

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 products. The wood protection industry needs to focus more on 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. 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. Wood protection through preservatives or modification technologies is benchmarked on the basis of tests of treated

sapwood. However, the vast majority of wood available 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 can't be more accurately predicted.

A possible way for 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. Trying to understand costumers' attitudes, preferences and expectations is crucial. Price and performance are not 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.

A concept for an innovation in value chain towards high performance wood materials has been developed at RISE, Sweden. Structure and strategy will be shared.

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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 ressources 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 establish 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 build 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

Structural optimisation is widely used for cost reduction and effective use of structural capacities of engineering systems. Several works have used the deterministic design optimisation to design timber trusses (Šilih *et al.*, 2005). The deterministic optimisation procedure is based on minimising an objective function as the structural volume or 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 and the serviceability limit states. The deterministic optimisation procedure uses the partial safety factors to take account for uncertainties related to timber material, structural dimension and loading fluctuations. In other words, these safety factors are applied in the design constraints to ensure the safety margin. However, the decay deterioration of the wood material is not appropriately taken into account in the calibration of the partial safety factors. Thus, the use of these partial safety factors in the deterministic optimisation of timber structures subjected to decay can lead to under designed structures. In fact, 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 material resistance capacity. This exposition of the unprotected timber structures as timber bridges to high relative humidity exposure and high moisture content of wood can lead to bio-deterioration of timber with decay fungi. This deterioration reduces the strength capacity of timber structures.

In fact, the mechanical properties of timber structures over the time are affected by a combination of loading, moisture content, temperature, biological activity, *etc*. This paper focuses on the optimal design of unprotected timber truss subjected to decay. Since the deterioration processes and the structural behaviour of timber structures are complex, nowadays the deterioration models are not able to account for all influencing factors. Consequently, this study is based on an empirical model that was derived on the basis of previous in-lab experimental studies, Viitanen *et al.*, (2010) developed a model for the decay growth of brown rot in pine sapwood under variant climate conditions.

As the rational approach consists in finding the best compromise between cost reduction and safety assurance, the Reliability-Based Design Optimisation allows us to reach effectively balanced cost-safety configurations (Aoues *et al.*, 2010). This study uses the Time-Dependant Reliability-Based Design Optimisation approach (TD-RBDO) to find the best optimal and reliable design of an unprotected timber truss subjected to decay.

Several kinds of uncertainties related to wood properties, structural dimensions, and load fluctuations are considered. The time-dependant reliability-based design optimization approach aims to ensure a target reliability level during the operational life (Aoues *et al.*, 2009). The performance of the optimised solution is compared with a traditional cross-section designed according to the Eurocode 5 in terms of both costs and safety. The RBDO results indicate that an optimised solution reduces the total cost composed of the initial and the failure costs, and ensure the target reliability level during the whole structural lifetime.

a) b)

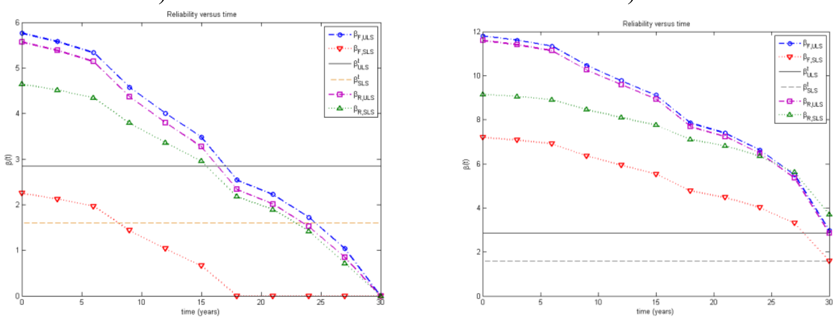

Figure 1: The reliability index of serviceability and ultimate limit states for a) optimal deterministic design b) RBDO optimal design

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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,

ABSTRACT

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. 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.

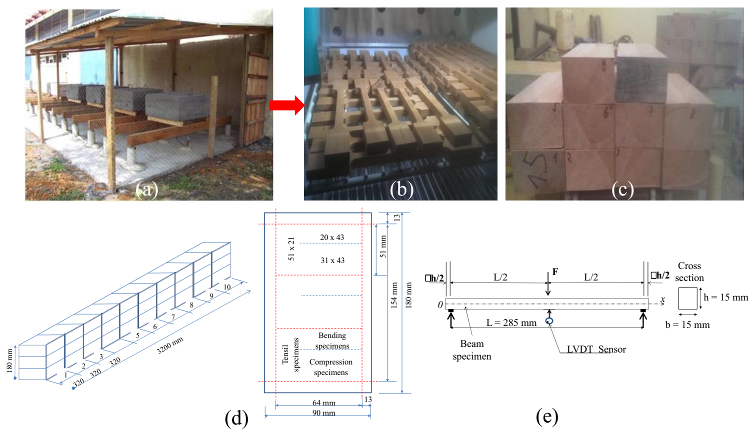

***Figure 1:** (a) Beams in sheltered outside climate; (b) specimens, (c) cross-sections, (d) Spatial specimen modelling; (e) Experimental device modelling.*

The specimens, Figure 1 (b) have been debited from two Moabi species (*Baillonella Toxisperma*) beams previously subjected to a creep-recovery test in an outdoor tropical environment over a period of 5 years, Figure 1 (a) (Manfoumbi *et al.*, 2012). The beams were cut into sections 317 mm long. These were also divided into three portions in the height direction, Figure 1 (b-c). From each portion, at least two bending, compression and traction specimens are extracted. Thus, for the two beams the section of specimens are, Figure 1 (d): Compression test: 112 test, 20 x 20 mm for 120 mm long; Tensile test: 104 test, 10 x 10 mm per 100 mm long; Bending test: 106 test, 15 x 15 mm for 300 mm long, Figure 1 (e). Figure 2 shows an example of the trajectories of bending strength for the first beam, Figure 1 (a). It was observed that different values were measured for a given length. Among the methods available in the literature to represent this spatial variability, we considered the Karhunen-Lòeve Expansion (Ghanen and Spanos, 1991). 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.

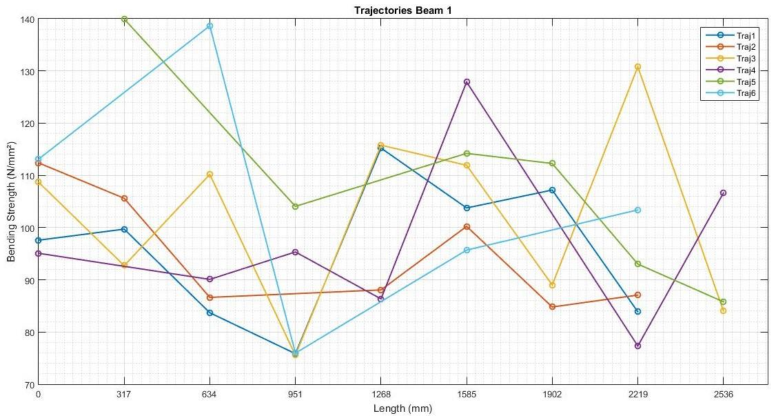

Figure 2: Bending Strength Trajectories for Beam 1.

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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

Aesthetic stability is one of the features favouring selection of the material for decorative usage. However, it is well ascertained by number of researches that thermally modified (TM) wood is not weathering resistant and its brownish colour originated during thermal modification discolours rather rapidly when subjected to outdoor environment. Moreover, it is established that unpigmented coatings cannot ensure satisfactory protection (Jämsä et al., 2000). On the other hand, just a change in colour of TM wood is often regarded as an additional benefit and therefore it would be desirable not to mask the surface by a coating. 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 was to test the efficiency of pretreatment with Fenton's reagent on resistance to discolouration of TM wood finished with non-film forming coating.

Experimental specimens (370 × 90 × 25 mm) were prepared from TM aspen (*Populus tremula* L.*)* and pine (*Pinus sylvestris* L.*)* wood boards. Half of the specimens were pretreated with water-solution of iron (II) sulphate followed by spraying with hydrogen peroxide. Three coating types were prepared with equal loadings of binder: solvent-based and water-based formulations with mixture of alkyd resins and linseed-oil as a binder and linseed-oil diluted with solvent. Considering that both UV and visible region of solar radiation causes significant discolouration of TM wood (Cirule *et al*. 2016), the same amount of transparent iron oxide pigment was included as a UV/Visible light absorbing agent in all coating formulations. Based on preliminary experiments all coatings were applied in such a quantity that no coating film was formed on both pretreated and virgin specimen surfaces, thus minimising the impact of the finishing on the wood exterior. The specimens were exposed outdoor on weathering racks inclined at 45° and facing south. The weathering of the specimens was regularly controlled by spectrophotometrical measurements.

The pretreatment resulted in TM wood discoloration and the original brown colour was changed to a darker shade. However, after applying of coatings the resulting colour was quite similar for all specimens and no disparity in surface colour was detected between the coated specimens with and without pretreatment. Thus, the pretreatment had no essential effect on the appearance of coated specimens. While the outdoor exposure for one year demonstrated that the pretreatment reduces the indications of weathering.

Discoloration of the specimens with pretreatment was considerably smaller in comparison with the specimens with the same finishing apart from pretreatment (Fig. 1). The same trend was observed for the uncoated control specimens when discolouration of pretreated ones was smaller. However, while all coated specimens had retained brown colouring after one year of outdoor exposure, the color of all uncoated specimens had turned grey and the greater discolouration of the uncoated specimens without pretreatment was caused by more severe fading.

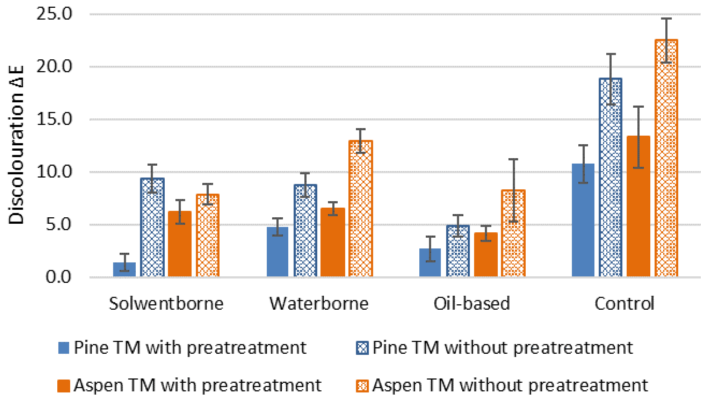

Figure 1: Discolouration of specimens after one year outdoor exposure.

Although the first results are encouraging, more prolonged weathering is required to evaluate the usefulness of the used pretreatment for reduction of thermally modified wood discoloration during out-door exposure.

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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 based on aptamers that can be applied *in situ*.

Therefore, we aimed at developing a competitive Enzyme-Linked Apta-Sorbent Assay (ELASA) for the detection of a triazole fungicide used for crop protection and in wood preservatives. Aptamers are single stranded nucleic acids that bind to a target molecule with high specificity and can be selected by Systematic Evolution of Ligands by Exponential Enrichment (SELEX) from a DNA pool. However, in our study we used an aptamer that has been reported as specific for our analyte by another research group. The principle of the ELASA format we wanted to apply is as follows. The aptamer was immobilised on a microtiter plate by avidin-biotin interaction. A biotinylated complementary sequence was bound to the aptamer. The addition of analyte should have led to a competition between analyte and complementary sequence, resulting in a structural change of the aptamer. The detection occurred by enzyme reaction from a colourless into a blue product and photometric measurement.

The competitive assay was optimised 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, we observed an association between the signal intensity and the tebuconazole concentration, in others we did not. Therefore, the ability of the aptamer to bind the analyte was controlled by different experiments using graphene oxide (GO). GO is known to be able to bind a high amount of 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 not adsorbed on GO was carried out using NanoDrop and Qubit-fluorescence measurement.

As result, NanoDrop and Qubit-fluorescent measurements showed no binding between aptamer and analyte in the presence of GO. Since the aptamer-target interaction could not

be clearly demonstrated the future objective is the selection of a new aptamer by the SELEX process.

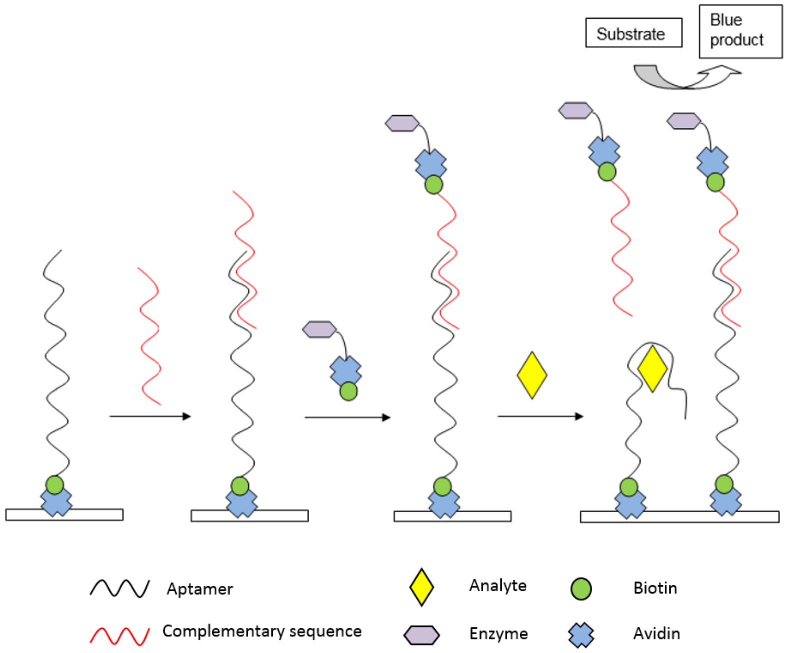

Figure 1: Visualisation of the ELASA process.

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

Experimental characterisation of beams deflections of Douglas fir (*Pseudotsuga Menziesii*) and White fir (*Abies Alba Mil*) are investigated herein, especially the impacts of the relationship of Relative Humidity (RH) and Temperature (T) on their behaviour. The creep tests are performed in an uncontrolled environment where the evolutions of climatic parameters (RH and T) and data of the deflection are continually recorded. The results show that, the deflection increases after a delayed time during the drying process and heating phases.

MATERIAL AND METHODS

One (1) beam of Douglas fir (D9) and one (1) beams of White fir (S9) are performed in uncontrolled environment in creep tests (four bending points). Table 1 shows the weight of concrete blocks applied on each beam and their MOE calculated in static bending four points before their loading. Figure 1 shows the experimental device of the tests.

Table 1: Characteristics of concrete blocks and beams used

Species	beams	weight of the concrete load (kN)	MOE (GPa)
Douglas fir	*D9*	4.150	14.162
White Fir	*S9*	3.290	8.975

Figure 1: Experimental device use during the creep tests.

RESULTS

Figure 2 shows the typical relationship of deflection versus RH (Fig. 2a) and T (Fig. 2b) of beam D9. The main information observed from this figure is that, the deflection increases during drying process and heating phases after a delayed time τ^{D9}.

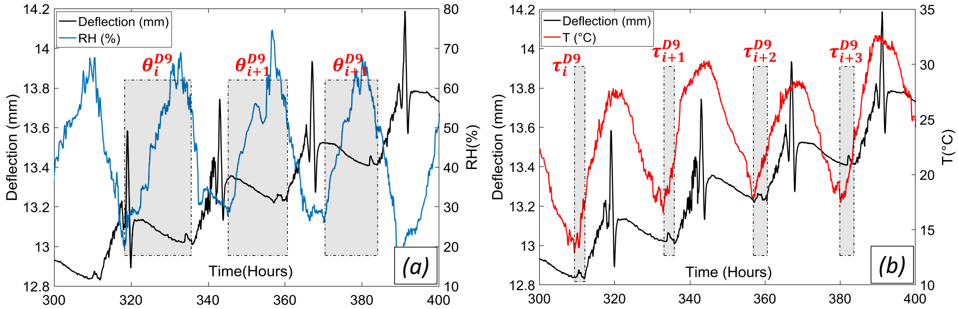

Figure 2: (a) Evolution of Deflection of beam D9 versus RH; (b) Evolution of deflection of beam D9 versus T.

Figure 3 shows the typical relationship of deflection of beam S9 versus RH (Fig. 3a) and T (Fig. 3b). According to this figure, there are direct relationships between deflection and climatic parameters (RH and T). As figure 2 and for the deflection of D9, the deflection of S9 growth during the drying process after a delayed time τ^{S9}. These results are in accordance with the literature (Merakeb *et al.*, 2009, Saifouni *et al.*, 2016).

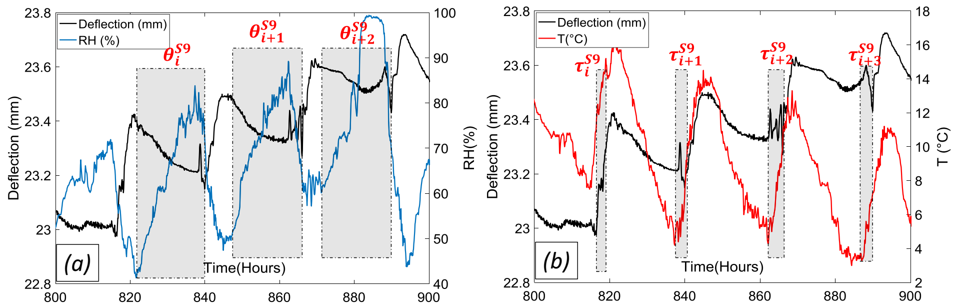

Figure 3: Evolution of Deflection of S9 versus RH (a) and T (b).

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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 aim of our long-term research was to optimise the pressing process of wood composites used for the production of formwork. The first paper of the research (Réh and Izdinksy, 2014) was aimed to the time optimisation 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 optimisation of the technological operation of their pressing.

There were produced four structures of three-layer formwork composites. Spruce slats with a thickness of 9 mm were used in all structures as the core layer. 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 our 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 practice and just tested in our 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 ± 1%.

Experimental research demonstrated that:

1. Three-layer composite formwork should have firm solid surface layers; birch plywood is a suitable material for this purpose.
2. The bending strength is 7.5% higher in the case of birch plywood in the composite surface layers 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 full formwork composites.
3. All of the abovementioned bending strength properties of composite formwork tested can also be interpreted using modulus of elasticity values having identical characteristics.
4. Dry specimens have according to the bonding quality test (EN 13354) double strength compared to the values used in practice (Zwick/Roell Z020); specimens boiled in water did not lag very much with their strength.
5. Thin OSB/3 is less suitable material for the surface layers of formwork composites.
6. The requirements of the technical standard EN 13353 have been met; requirements of the technical standard EN 13354 were almost double exceeded using time optimisation of their pressing.
7. Modified pressing diagram for formwork composites is applicable.

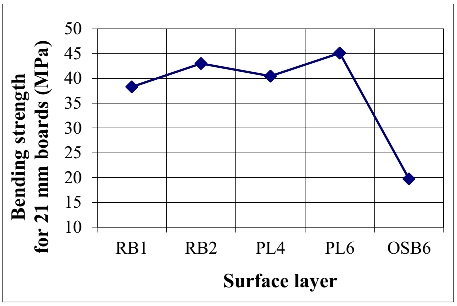

Figure 1: Bending strength of the four formwork composites depending on the alternative surface layers used

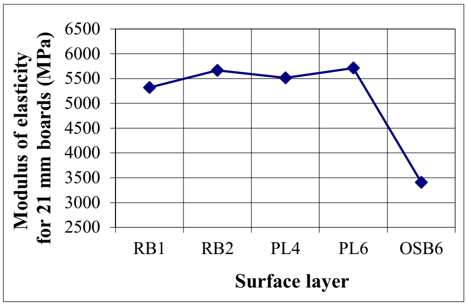

Figure 2: Modulus of elasticity of the four formwork composites depending on the alternative surface layers used

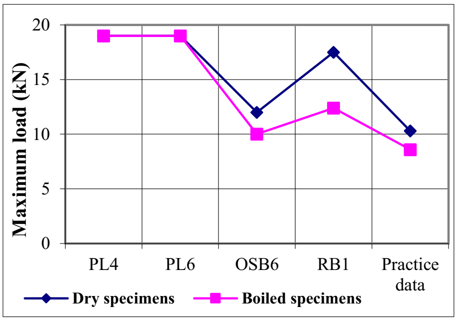

Figure 3: Bonding test of the four formwork composites depending on the alternative surface layers used

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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

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). 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 as was studied, these materials result environmentally friendly and low-cost 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. 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. 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). With the obtained information, the processing parameters for the multilayered composites could be achieved, as shown in Figure 1. Composites were elaborated 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)

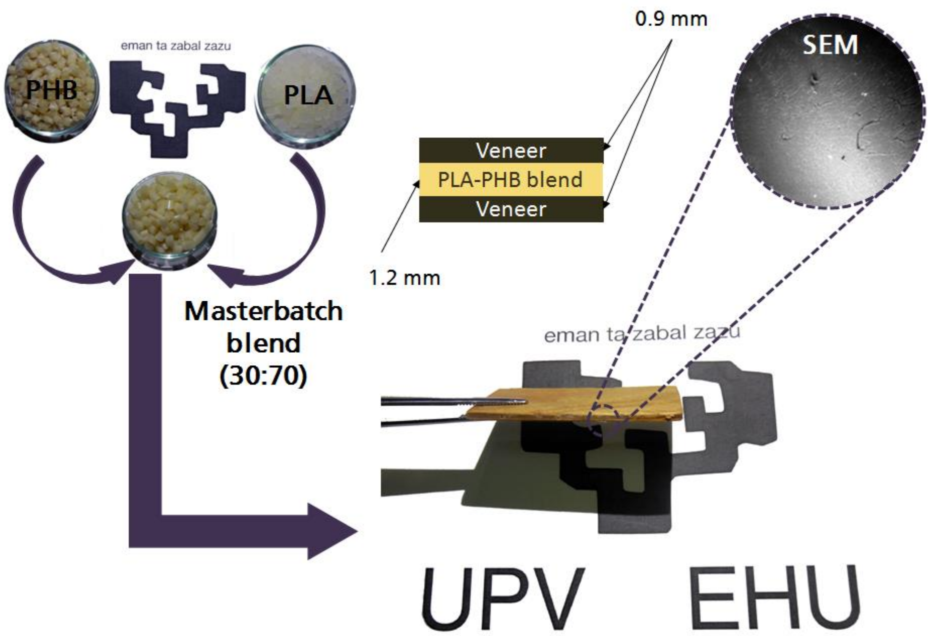

Figure 1: Schematic description of the composite elaboration.

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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-utilised 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. 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.

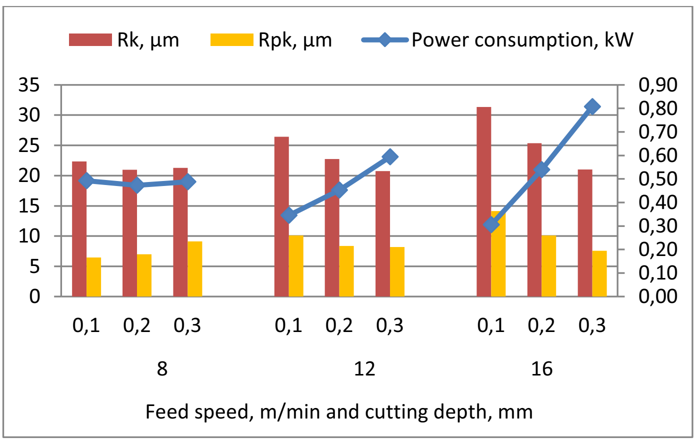

Figure 1: Variation of the surface roughness and power consumption as a function of cutting parameters

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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. Beside wood, also other bio-materials, defined here as materials derived from organic sources, become recently recognised as attractive alternative to many traditional building materials. The push for sustainable buildings and increasing environmental awareness observed nowadays helps to reactivate bio-architecture as interesting alternative to other construction trends.

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 is observed. These include novel bio-based composite materials, as well as more effective and environmentally friendly protective treatments, *e.g*. thermal treatment, densification and chemical modifications. The same revolutionary advancement is noticed with surface treatments including innovative coatings, impregnations or integration of developments of nanotechnology for wood protection. Also, other fibre-based materials (flax, straw, hemp, wool, jute, ramie, sisal, *etc*.) having low specific weight, good thermal and acoustic properties, become interesting alternatives 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 has been recently conducted in order to demonstrate performance of alternative solutions. The overall goal is to widely promote the bio-based materials and to demonstrate the best examples of architecture that use such sustainable resources. All the know-how developed within this project will be available for direct technology transfer in a form of technical handbook dedicated especially to designers and contractors. This abstract is an invitation to join this initiative and to demonstrate successful use of bio-based materials applied as a building skin.

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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 in the last 50 years, whilst the manufacturing industry has seen a two-told increase in that time. To make building industry more competitive, it is urgent to automate the construction process as much as possible. Using plywood in building structures mean ordinary straight cuttings and screwed connections. Today, together with CAD/CAM-software and CNC-workstation it is possible to produce industrially more complicated prefabricated details for building industry and thus much 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 reduced condensation risk.

My PhD Thesis consists of different hypotheses to solve designing and construction problems of 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 need special supporting system.

Self-locking system of under squinted scarf joint have been worked out to mount the semi-globe type dome-shell without supporters of plywood (thickness 12mm) on Fig. 1. Bolts M5 in the hole of diameter 8mm used only to fix details together to avoid sliding joints. Bolts did not take on the inside forces.

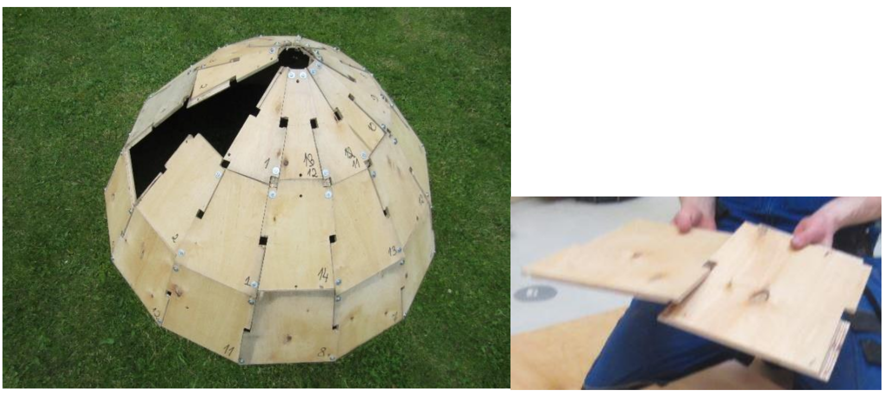

Figure 1: Semi-globe type dome-shell with self-locking under squinted scarf joints.

The details made by handicraft had a quality that was not comparable to the ones produced on CNC-workstation. Strength tests were carried out on three levels of lamellae separately to understand the behaviour different parts of shell model and to check the squinted scarf joints mode of failure. 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 separately on the lower and upper parts, as shown on Fig. 2 from four directions 90 degrees to its respective partner.

Figure 2: Pilot plant with the specimen (B-level of the semi-globe).

The results of the compressive destructive tests are shown in Table 1 (Turk *et al*. 2015).

Table 1: Data from destructive compressive testing

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

Test results from specimen at different levels obtained separately are not comparative to each other but they are good enough to go ahead with this research. If all the levels are mounted together as a dome-shell, the tension in lower edge of one level will reduce compression in upper part of another.

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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

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 substituted partially. 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 combined with chemometric techniques and 2DCOS is a useful tool for the structural characterisation of different materials, and also wood structure.

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, and 2DCOS. 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 also decreased in intensity. Further detailed information was acquired by 2DCOS.

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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/cm3. The wood was sourced from Muller (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* and *G. trabeum*.

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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.

The aim of the research was to evaluate the visco-elastic properties by means of dynamic mechanical analysis (DMA) in order to characterise archaeological waterlogged wood consolidated with methyltrimethoxysilane (MTMOS). The studied material was archaeological waterlogged oak wood (*Quercus robur*) taken from a pile excavated from the Lednica Lake in the Wielkopolska Region, Poland. Dating back to the 10^{th}-11^{th} century, the wooden pile was the structural element of the early medieval "Poznań" bridge. The pile was cut into slices 1 cm thick. 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 dehydrated with 96% ethanol for four weeks.

They were treated then with a solution of 50% MTMOS in ethanol by the 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 they were air-dried for 1 week and analysed.

Table 1: DMA measurement parameters.

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

Measurements were performed by using the Dynamic Mechanic Analyser 242 model DMA 242 E by NETZSCH-Gerätebau GmbH, controlled by the Proteus software. 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 ($\tan \delta = E''/E'$) and changes in sample length (Δl) were measured as well as static force at sample (F stat. s), real part of force at sample (Fs') and a real amplitude at sample (As') for more detailed characterisation of mechanical properties of the studied material. The data were analysed using Proteus61 software.

The correlation between the level of wood degradation (wood density and the moisture content) and mechanical strength was observed. The obtained results revealed significant differences between mechanical properties of the same material but in different forms, resulting from different drying methods. In case of sapwood samples, air-drying caused drastic dimensional changes due to cell and cell wall collapse or shrinkage. It resulted in high densification of wood material (making it more similar to sound wood density), which potentially should change its mechanical properties. The highest stiffness was observed for the densest air-dried sapwood specimens, while freeze-dried and wet samples were much more elastic and more vulnerable to compression. The results show that the DMA is an efficient tool to characterise dynamic mechanical properties of wood treated with chemicals and helps to understand the probable mechanism of interactions between wood and the chemical substance which has been used as a consolidant. MTMOS-treated samples had statistically similar mechanical properties as air-dried untreated wood or contemporary wood. This fact, combined with good properties of MTMOS to consolidate wood, makes it an interesting agent for archaeological wood conservation.

ACKNOWLEDGEMENTS

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Boostering knowledge and information about the importance of the LCA analysis in environmental impact assessment of wooden products

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Keywords: bio-based materials, LCA, low carbon economy, wood

ABSTRACT

Given that maintaining and expanding the market potential for bio-based building products remains a key activity for European industry in forestry and biotechnological sector, the aim of this STSM was to learn about the Life Cycle Assessment (LCA), especially best practices on Life Cycle Inventory in the wood sector. Special focus of the mission was to gain the competences to design the LCA study of Croatian wood flooring industry. Further aim of this STSM was to learn about Environmental Product Declarations, related legislation, strategic documents, directives and initiatives that were launched all over the EU member countries regarding development of a low-carbon economy and wood products; and projects/practices conducted in Slovenian (and other EU/non-EU countries) wood processing industry and science. The environmental impact assessment is a new topic in many scientific and teaching work fields that I am developing with the aim to move this research forward in Croatia. Additionally, I am aiming to merge the developed competences with my research activities in development of innovation processes (especially Eco-Innovations). This STSM helped me to advance my knowledge in the field of LCA and develop a collaboration with the University of Primorska. Furthermore, obtained knowledge will be used in development of the actions needed for the cascade use of wood and utilisation of wood flooring following the cradle to cradle concept in Croatia.

The most important remarks conducted within this STSM are:

- Introducing to the most important project and activities related to wood processing industry in the context of using wood and wood products in the sustainable development, resource efficiency, cyclic economy and bio economy;
- Identification of the most important EU and Slovenian strategies and documents related to the role the role of wood products in the sustainable development, resource efficiency, cyclic economy and bio economy;
- An experience in getting know to SimaPro software and its capabilities in performing LCA analysis;
- Introducing to the process of developing system boundaries for LCA analysis and defining functional unit of the product and
- Extending my knowledge regarding an Environmental Product Declaration, especially regarding Product Category Rules of Cass 31600 - Builders' joinery and carpentry of wood, including cellular wood panels, assembled parquet panels, shingles and shakes. The PCR document will help me in collecting data for LCA analysis on wood flooring (classical oak parquet).

Resistance of bio-based, synthetic and inorganic thermal insulations against attack by house mouse

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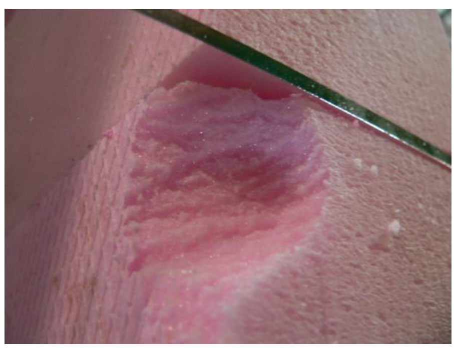
Keywords: wooden structure, thermal insulation, damaging, house mouse

ABSTRACT

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. The paper analysis resistance of selected bio-based (cellulose, straw, hemp, granulated cork, fleece), synthesised organic (expanded polystyrene, extruded polystyrene and polyurethane), and inorganic (rock-wool, glass wool) thermal insulations against the house mouse (*Mus musculus*) – var. albino laboratory mouse. In the experiments, the thermal insulations 100×175×410 mm (thickness × width × height; thickness of the bulk bio-based insulations was achieved by their pounding among two cardboards) were inserted into glass containers.

During 24-h tests the mouse males and females wanted to get from one side of insulations on their other side into a bait food (mixture of fruits, chesses, chocolates, sausages and breeding granulated food). At mouse activity were 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 from mineral substances, i.e. rock-wool (Nobasil FKD; Isover TF) and glass wool (Isover Multimax). On the other hand, the highest resistance against mouse activity showed polyurethane foam (Puren MV PUR-PIR) and extruded polystyrene (Austrotherm XPS TOP; Styrodur 2800 C) – Table 1 and Figure 1.

A



B

Figure 1: House mouse easily attacked cellulose insulation "Tempelan" (A), but only minimally extruded polystyrene Austrotherm XPS TOP (B).

Table 1: Thermal insulations – type, name, physical characteristic and resistance to house mouse.

Type	Name	Density	Thermal conductivity	Resistance to activity of house mouse		
				Pang depth in insulation [mm]		Mortality
		[$kg \cdot m^{-3}$]	[$W \cdot m^{-1} \cdot K^{-1}$]	$x_{min.} - x_{max}$	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

Between activity of the house mouse males and females was not determined difference. They were able by guns less or more mechanically disrupted all thermal insulations, except of polyurethane. They from bats of natural insulations build hideouts, but they did not consume them – except of grains present in the wheat straw insulation. Their highest mortality was at attacking the rock-wools.

Thermal insulations used in wooden structures are often inserted between solid boards (OSB, plywood, gypsum) creating composite sandwiches. Therefore, attack of such composite materials by mouse or other rodents is limited and only scarce. On the other hand, in roofs and ceilings the thermal insulations are rarely placed freely and their accessibility for attack by rodents is potentially higher – it means, that they in some cases have to be chemically protected by rodenticides.

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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 of 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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Influence of surface pretreatment to bonding quality of thermally modified wood

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Keywords: bonding, delamination, modified wood, shear strength, surface ageing

ABSTRACT

This paper presents the influence of natural surface ageing in indoor conditions to bonding quality of thermally modified wood for outdoor applications. Two unmodified and thermally modified wood species were used for the experiment: oak and beech. Samples 1000 x 100 x 20 mm (L x T x R) were planed and left for periods 2 hours, 1, 2, 6, 10 and 18 days, after which they were glued with MUF adhesive. Properties of laminated beech and oak beams, namely shear strength, delamination and contact angle were measured in order to detect 1) the suitability of species for laminations and 2) the influence of extended storage time after planing to properties of laminated wood.

Generally, both native and thermally modified beech exhibited better results compared to oak and thermally modified oak.

Results of the delamination test (total delamination) indicate a time dependence of surface ageing. Both native and thermally modified beech may be successfully laminated at least up to 2 days after planing, whereas neither oak nor thermally modified oak were suitable for lamination process under conditions presented herein.

Shear strength of glue lines did not show any influence of natural surface ageing. Average shear strength of glue lines (in dry conditions) indicated that both native and thermally modified beech and oak may be successfully laminated, no matter the duration of natural surface ageing. However, whereas beech and thermally modified beech samples exhibited almost the same values regardless the duration of surface ageing (~20 N/mm^2), there was an obvious difference in shear strength of oak (~15 N/mm^2) and thermally modified oak samples (~11 N/mm^2).

Results of delamination may be related with contact angle measurements, which indicated that a freshly prepared surface was easier to wet compared to a naturally aged surface, but also that contact angle was lowest on beech (50 °, 2 hours after planing) and highest on thermally modified oak surface (~64 °, 2 hours after planing).

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. 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 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 fungi occurring 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.

The natural durability of wood refers to the resistance to attacks by wood-destroying organisms, *e.g*. fungi, insects and marine organisms. In this study, the durability of thermally modified timber (TMT) was investigated. In a field test, according to EN 252 (2014), a variety of wood-dwelling and wood-destroying organisms occured simultaneously and led to severe attack or even failure of the samples. 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.

Concerning the durability classification of the samples, the process induced improvement of them showed a strong correlation with the classification of durability classes of the

complete test set. 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, mentioned in Fig.1.

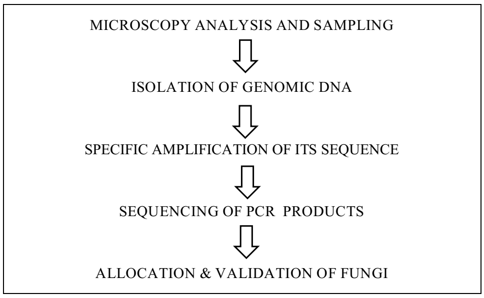

Figure. 1: Workflow of mycology diagnostics via DNA – analysis at FCBA, Bordeaux

Microscopic investigations showed different phenomena (black dots in cell-walls) and several mycelia. The black points, as visible in the radial sections of the pine sample in Fig. 2 or in transversal surfaces of the pine sample in Fig. 3 were caverns which were typical phenomena due to of soft rot in the spruce samples.

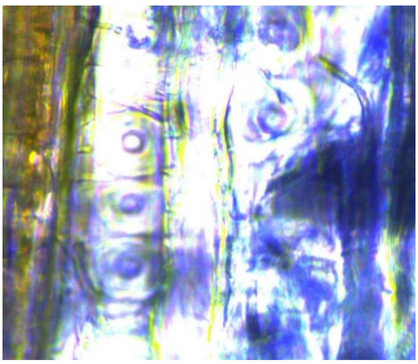

Figure 2: Pine sample untreated (radial, caverns & mycel, x 400)

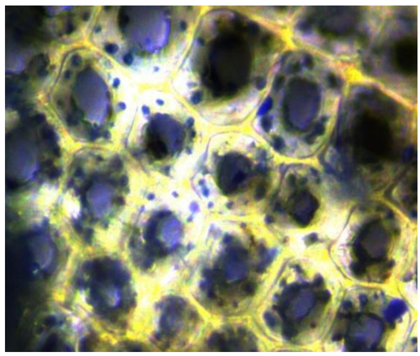

Figure 3: Pine sample untreated (transversal, caverns in cellwall, x 400)

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.

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The authors gratefully acknowledge the financial support of the COST Action FP 1303 for enableing the cooperation of FCBA & HNEE through a STSM.

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 paper is oriented on experimental verification, of sub-dimensional particles from OSB production added to the core layer particle board, how they affect selected particleboards properties. In laboratory conditions, three-layer particleboards with dimensions of 400x300x16 mm and density 620 kg/m^3 in four variants were produced 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 particle we used in PB can be seen in Fig. 1.

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.

Figure 1: Particle used in particleboard. A – surface particle, B – core particle (normally used in PB), C – sub-dimensional particle from OSB production used in core layer.

Selected physical and mechanical properties of the modified particleboards with particles from OSB production are present 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/m³]	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/mm²]	0.541 (0.06)	0.447 (0.09)	0.484 (0.03)	0.507 (0.05)
Bending strength (BS)	[N/mm²]	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 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 %), while other application properties of these boards did not significantly change: density, thickness swelling, water absorption, internal bond strength.

ACKNOWLEDGEMENTS

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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 latest 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

Wood can be affected by extrinsic factors that limits its functional and aesthetical service life. Aesthetical damage of the wooden surface is normally caused by the action of climatic agents known as weathering. Weathering is 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 micro-organisms and results in chemical, physical and anatomical changes (Griebeler and Iglesias Rodriguez 2015; Gonzalez de Cademartori *et al.* 2015; Thiis *et al.* 2015; Burud *et al.* 2016).

The weathering of wooden surfaces is affected by the exposure condition and the prevailing climate at the micro location during the service life period (Gobakken *et al.* 2010; Thiis *et al.* 2016).

The goal of the present study was to develop mathematical model for the different wood-based materials.

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 simulation grid with one node every 10 × 10 cm gave the possibility to simulate the shading effects of features like window-sill and roof eave. The software calculated the hourly solar radiation in every node for one whole year given the climate and the geographic position of the building. MATLAB (MathWorks) was used as software platform for multivariate data analysis. Local weather records from a Davis weather station were collected and sorted including sun radiation, temperature and relative humidity (RH). On that base the mould and radiation dose were calculated (Burud *et al.* 2016; Thiis *et al.* 2015; Thiis *et al.* 2016).
15 mathematical models (9 non-treated and 6 thermally modified and/or copper impregnated materials) out of 22 used materials were developed. One is shown in Fig 1.

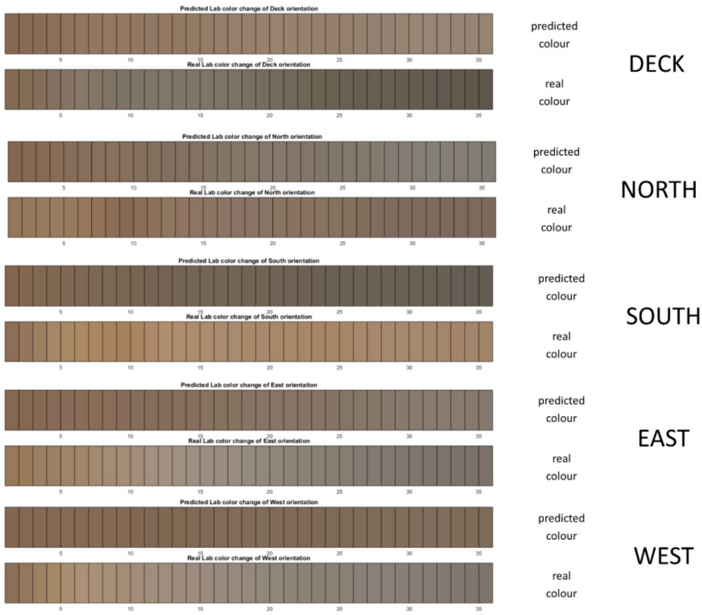

Figure 1: Modelled (predicted) and measured (real) colours for all directions of exposures for thermally modified Norway spruce.

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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 (IRGWP) 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 IRGWP 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 together with relevant information for members and end-users in general like a wood durability database or the global location of field test sites (example in Fig. 1).

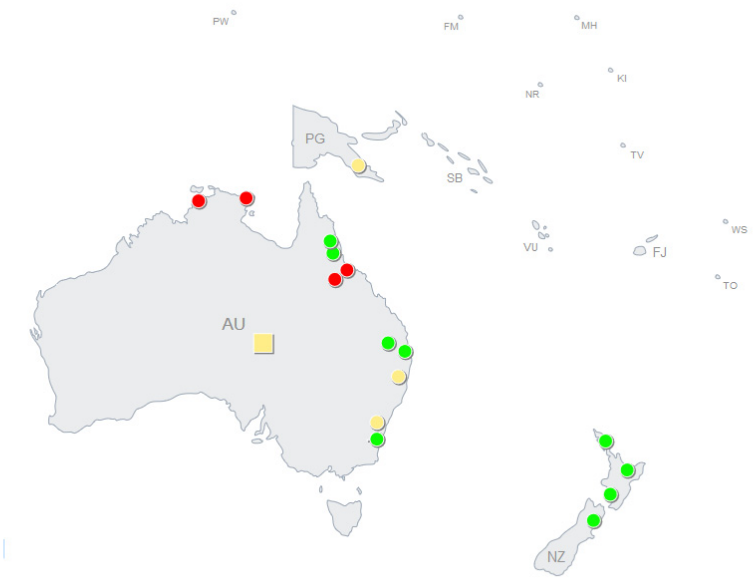

Figure 1: Test field map of Oceania.

An overview of the knowledge transfer through STSMs

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Keywords: knowledge transfer, short term scientific mission

ABSTRACT

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).

In the framework of the COST Action FP1303 among other activities 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 finalised STSMs according to each grant period are represented graphic in Figure 1.

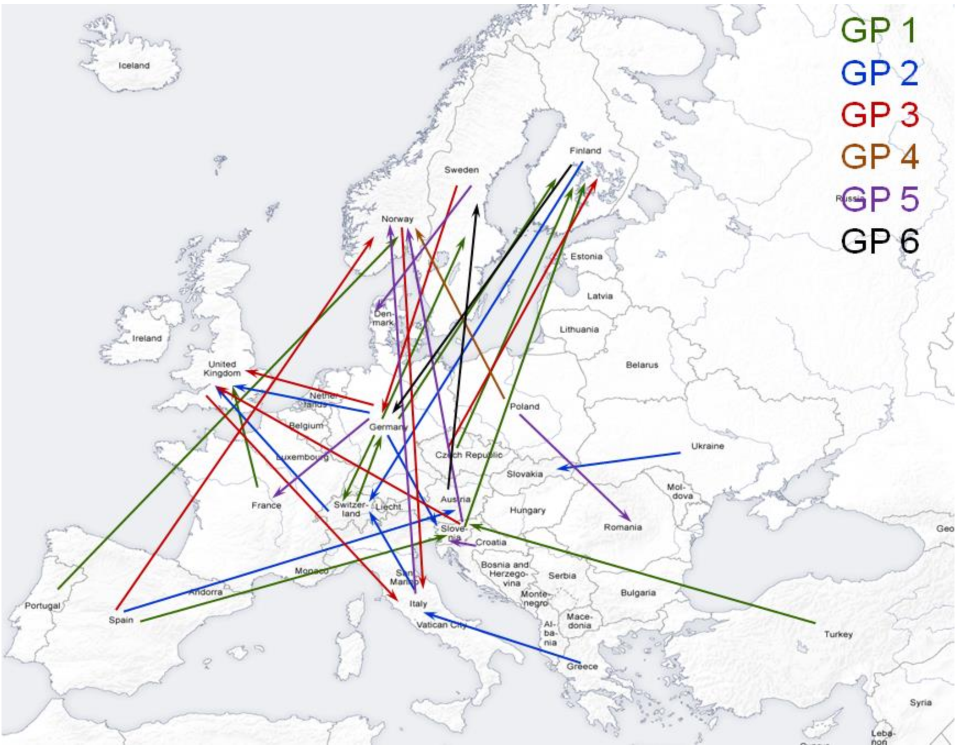

Figure 1. Accepted and performed STSMs

As can be seen, it is a well dispersed interest from almost all cost participating countries to go and learn new techniques or to assess the performances of the bio-based building materials.

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

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 optimised for specified applications, assuring at the same time expected properties and functionality at elongated life, minimising 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 utilisation 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 characterised from the technical point of view, are often lacking reliable models describing their performance during service life. The other factor, 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. Performance of 120 selected façade materials provided by over 30 industrial and academic partners is recently evaluated (Figure 1). Aesthetical aspects of service life, specific consumer demands and preferences, as well as the functionality of building assemblies are the central focus of Bio4ever. 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.

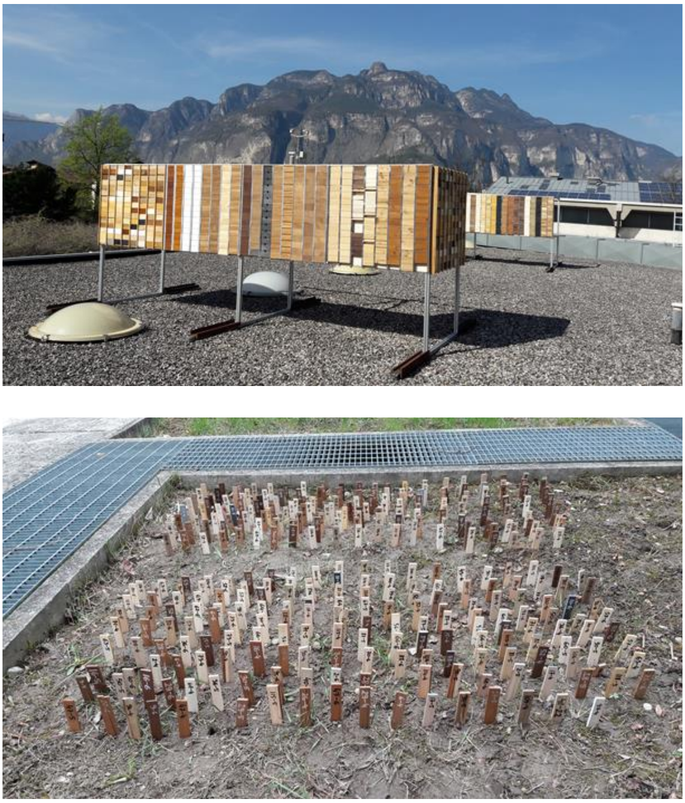

Figure 1: Facades materials exposed to natural weathering (up) and during degradation in soil – simulation of landfilling (down)

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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 to the education 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 Bioproducts and Biosystems (formerly the department 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 are asked to bring the expertise from their own field to address a pre-defined challenge and to learn from others by working with them in a research-design-and-build project team (Figure 1). From the very beginning students are asked to suggest own research ideas within the project themes, which may lead to research questions that would otherwise stay unexplored. Project-based learning encourages students to be active participants, but at the same time it develops their working life skills (Vahtikari *et al*., 2013).

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.

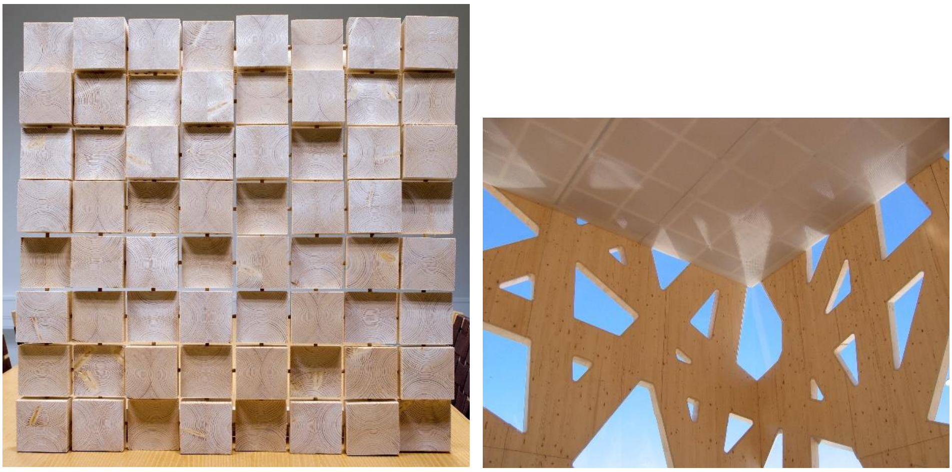

Figure 1: A prototype for a moisture buffering panel, designed in a multidisciplinary student team (on the left, image Anne Kinnunen). A detail of the pavilion designed and built by the international Wood Programme students for the Housing Fair in Espoo (on the right).

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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 applied wood by wood borers, and particularly by termites, it's 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' 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' 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 and 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.

ACKNOWLEDGEMENTS

This work was supported by the Portuguese Foundation for Science and Technology (SD grant: SFRH/BD/84920/2012) and by the National Laboratory for Civil Engineering (LNEC) within the project: "Development and optimization of biomaterials for construction".

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.

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 encourages collaborations between business and academia in order to increase competitiveness and innovation in industry. The goal of this scheme is to translate advanced knowledge from the scientific and academic community into businesses whether through the development of new products or enhancement of the manufacturing process, in order to deliver innovative solutions crucial for business growth. 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.

The current 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. 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 considerate unsuitable for construction timber. In the UK's building materials market, sawn timber is the third most imported material (National Statistics 2017). 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). Therefore, many sawmills producing wood dried to only 20% MC for outdoor constructions like fencing poles. In response to that, 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 as a construction product. 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). 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.

As a solution to drying UK grown spruce to 12%, medium-high heat and steam during the drying process has be introduced by several studies. The high temperature and steam results in the relaxation of lignin and aids in restraining the massive twists which were observed with the conventional drying methods (Riepen *et al*., 2004, Cooper and Cornwell 2005). During this project heat and moisture transfer within the wood during the drying procedure are monitored in order to predict the behaviour of UK grown spruce at a moisture content below 20%. The collected data will be used to create a heat and

moisture simulation that can be used to optimise the drying procedure for accomplishing an economically viable method of drying spruce for the production of UK grown CLT by the industry. 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 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.

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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 promoter of biodiversity conservation within the built environment. Straw in architecture is recognised and used worldwide and is important in the context of architectural heritage as a roof cover, a binder or 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. Generally speaking, SBBs are mostly built by owners and investors as a result of their desire for natural and environmentally friendly buildings. Nowadays, Straw Bale Building (SBB) is the most recognisable form of building with straw. Recently, SBBs have branched out from residential use and have been built for the commercial sector with specific for public use. Straw bale building is recognised and practised worldwide. 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. 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 recognise straw bales as an appropriate building material but mostly only as an infill where other standardise materials are used as construction system. One of the issues of not building with materials with a great environmental potential is a low knowledge of its use. The best commercial for new materials is "example of a good practice". In this paper two study cases of a good practice are presented, which also confirm the diversity of SBB design.

Developing novel applications of mycelium based bio-composite materials for architecture and design

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Keywords: Bio-composite, Mycelium, Material, Design, Architecture

ABSTRACT

The growing need for alternative materials and products that are biodegradable and derived from renewable resources, has recently led researchers from varied fields to search for more holistic alternatives, and develop natural bio-composites as a substitute for a variety of petroleum-based products and as a renewable resource that can be grown on any lingo-cellulosic material and degrade many similar synthetic reluctant chemicals, such as textile pigments, therapeutics and explosives; that otherwise would remain stable and contaminate our environment. In this research, the natural ability of fungi to bind and digest ligno-cellulose fibres, is utilised to develop natural bio-composite materials for novel applications in architecture and design.

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. This process plays a significant role in natural ecosystems and is already widely used for varied agriculture and food applications. However, the integration of fungal mycelium with the plant fibres can also provide an inherent bonding, forming a natural light weight bio-composite, in which the fungal mycelium functions as the matrix and holds the plant substrate together without the use of any synthetic adhesives. The resulting material can be applied as a biodegradable alternative for a wide range of industrial materials, products and applications.

Mycelium materials that are currently manufactured are mostly using molds filled with a substrate that is incubated with mycelium to form a desired shape (Bayer and McIntyre 2006; Montalti 2010; Ross 2016). A few, more experimental projects, demonstrate a methods such as growing mycelium on a fibrous scaffold (Tabellini 2015), using fibrous mats (Lelivelt 2015), 3D printed cellulose scaffold (Klarenbeek 2014), or growing mycelium on floating mats without a fibrous content (Hoitink 2016). 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, a systematic examination was used in order to evaluate the efficiency of mycelium development on different agricultural growth for further exploration and development of potential materials, products and applications in the field of architecture and industrial design.

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) (Figure 1); mycelium development was evaluated by rate, density and quality factors (Figure 2). By examining these fundamental materials characteristics, we aim to achieve a thorough understanding of the structural and aesthetic opportunities that this novel bio-material has to offer. The current stage of the research shows that the most suitable integrations where the samples of *P. ostreatus* grown on Apple or Vine woodchips. Future work will focus on further understanding of the structural changes in mycelium and plant material during the digestion process, and locating essential variable parameters of pre- and post-processing of the desired material, to introduce innovative properties and functions over existing industrial products and applications.

This project offers a step towards the use of mycelium bio-materials in industrial applications. Although in recent years there is a growing interest in fabrication processes of such materials in the fields of architecture and industrial design, yet many fundamental analytical and modification methods are not practiced for such applications. The use analytical quantitative and qualitative methods for material characterisation can contribute and advance the possible product applications of the integrated mycelium and plant fiber bio-composite material.

Figure 1; A. Development of Pleurotus Pulmonarius mycelium on Oak woodchips during 16 days (from left to right); B. Pleurotus Ostreatus grown on Apple (left) and Vine (right) woodchips; C. Tests for chemical parameters (from left to right); pH and conductivity, water, nitrogen and carbon contents.

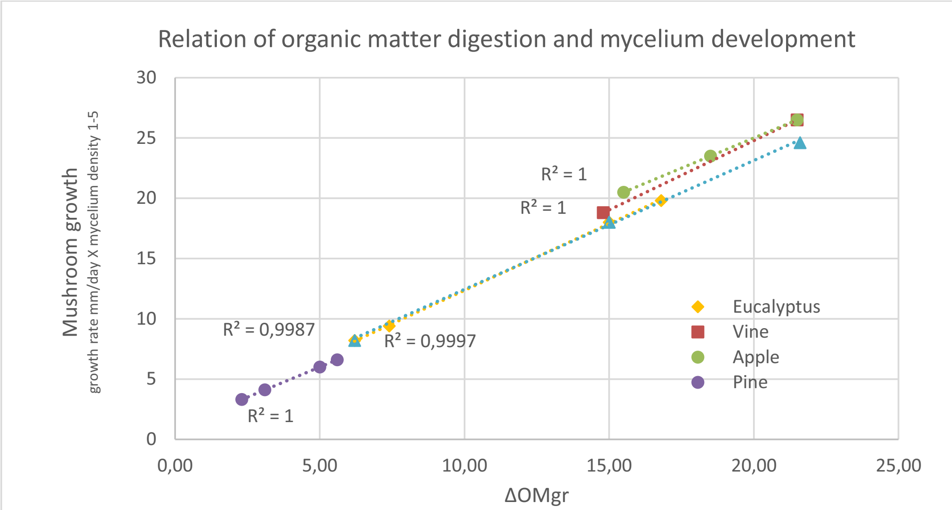

Figure 2: A comparison between the amount of organic matter loss to mushroom growth parameters (growth rate mm/day X mycelium density 1-5) shows high correlation, indicating it as reliable calculation for mycelium development.

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Durability of Zinc Borate Incorporated Wood-plastic Composites: Laboratory and 7-year field test results

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Keywords: Wood-plastic composites, decay, termite, zinc borate

ABSTRACT

Wood-plastic composites (WPC) represent a new class of hybrid material gaining great market potential in building applications around the world. After Morris and Cooper (1998) reported brown rot and white rot fungi growing on wood-plastic composites in service in Florida, a great deal of research regarding biological resistance of these composites has been conducted. Any WPC formulation without wood preservative chemical only relies on encapsulation properties of the plastic matrix against biological agents (Ibach et al. 2013). The thermoplastic matrix is expected to act as a barrier to exclude moisture and fungal activity. Six different formulations of wood-plastic composites (WPC) fabricated from wood and polypropylene (PP) were tested in the laboratory against decay and termite activities and in a protected above-ground field test in southern Japan. Variables examined included comparisons of untreated and zinc borate (ZnB) incorporated formulations, wood content ratio, wood particle size and increased surface area via surface grooves (channels) to promote moisture infusion. The WPC were produced from multi-component formulations consisting of wood, thermoplastic matrix, inorganics, process additives and pigments by Misawa Homes Co. Ltd. Japan. The formulation details of WPCs tested were given in Table 1. The following additives, 0.56 g polyethylene wax, 0.56 g calcium stearate, 0.28 g pigment I (purple oxide) and 2.79 g pigment II (Br pigment), have been added into all formulations to reach the target total weight of 60 g.

Table 1: Details of WPC formulations tested

WPC group	Wood content [%]	Particle size [mesh]	Wood [g]	PP [g]	Zinc borate [g]	Total weight [g]
1	50	60	30.69	25.12	-	60
2	50	30	30.69	25.12	-	60
3	70	60	41.86	13.95	-	60
4	70	30	41.86	13.95	-	60
5	70	60	41.26	13.95	0.6	60
6	70	30	41.26	13.95	0.6	60

Wood decay fungi and Formosan subterranean termite activity in laboratory (short-term) and field tests (long-term, 7 years) resulted in different mass losses, post-decay moisture contents and field test ratings depending on their wood and ZnB content.

The results show that as wood content increased, mass losses also increased. Addition of ZnB at 1 % (w/w) retention level significantly decreased mass losses of wood-plastic composite when exposed to laboratory decay and termite tests (Table 2). The effects of surface grooves and wood particle size were less important, compared to wood particle content. Wood-plastic composites tested regardless of formulation, wood particle size, surface grooving and zinc borate addition showed grater resistance to decay during the field exposure time. Last 18 months, however this observation was changed and higher wood content formulations (some cases even with zinc borate embedded ones) started to exhibit decay damage. All formulations tested failed to protect termite activity during the test period. For higher wood content formulations (5 and 6) zinc borate addition seemed to slow down termite damage but was not enough to provide full protection, rating 10 based on AWPA E21-11 standard, except the first 24 months of study. In light of these findings, 1% w/w zinc borate loading level in the WPCs tested must be increased if a higher termite resistance required in the climatic conditions of the field test area.

Table 2: Mean mass loss [ML (%)], mortality [M (%)] and consumption rate [CR (µg/termite/ day)] of wood-plastic composites after exposure to Coptotermes formosanus for three weeks in laboratory conditions (average of 5 replicates, values in parentheses are standard deviations).

WPC Type	Mass loss (%)*		Mortality (%)*		Cons. Rate (µg/termite/ day)*	
1	3.6 (0.26)	***a***	24.1 (7.52)	***ab***	20.6 (1.42)	***a***
2	4.1 (0.47)	***a***	35.2 (13.51)	***b***	24.1 (1.49)	***a***
3	12.1 (3.79)	***c***	14.3 (6.64)	***a***	77.8 (18.09)	***c***
4	9.7 (1.83)	***b***	18.7 (9.17)	***ab***	63.1 (16.39)	***b***
5	2.5 (0.37)	***a***	88.8 (10.17)	***c***	27.1 (5.42)	***a***
6	2.2 (0.34)	***a***	86.4 (20.26)	***c***	22.7 (4.73)	***a***
Sugi**	32.8 (2.19)	**-**	6.0 (0.67)	**-**	108.9 (6.33)	**-**

*means within each column followed by different letters are significantly different ($p \leq 0.05$), ** Sugi used as reference material and excluded from the statistical analysis.

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

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Keywords: crosslinking, 1,3-dimethylol-4,5-dihydroxyethyleneurea, N-methylol, textile resin, review

ABSTRACT

This paper reviews recent and previous findings on wood modification via wood-polymer-integration with cyclic N-methylol compounds and puts them into a common context. Originally used for the finishing of cellulose-based textiles, the treatment of wood with dimethylol compounds of ethylene urea (DMEU) has been studied in the late 1950s for the first time. Weaver *et al*. (1960) found an improved dimensional stability of Ponderosa pine (*Pinus ponderosa*) after treatment with DMEU. Militz (1993) confirmed this effect of dimethylol resins for European beech wood (*Fagus sylvatica* L.) coming along with improved durability. These initial investigations were followed by intensive fundamental and applied research on wood modification with 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU, Fig. 1) since 1990. Finally, a modification process (vacuum-pressure-impregnation, superheated-steam curing at temperatures > 100 °C) was developed up to pilot scale for Scots pine (*Pinus sylvestris* L.) at University of Goettingen (Schaffert 2006). Further investigations have been conducted using modified DMDHEU and dihydroxydimethylimidazolidinone (DHDMI) as seen in Fig. 1. Even if DHDMI allows a formaldehyde-free modification, a reduced fixation of this molecule in wood was indicated. Therefore, DHDMI was considered to be "not-suitable" for wood modification at that time. Magnesium chloride ($MgCl_2$) und Magnesium nitrate ($Mg(NO_3)_2$) were found to be the most suitable catalysts concerning the fixation (reactivity) and effects on the resulting wood properties (Krause 2006).

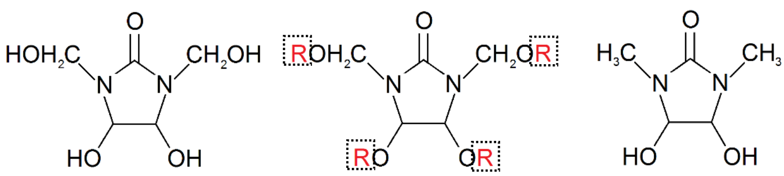

Figure 1: Structural formula of DMDHEU (left), mDMDHEU with R = H or R = CH_3 (middle) and DHDMI (right)

Previous investigations were mainly focused on Scots pine and European beech wood. Solid wood as well as veneers for plywood production have been investigated (Bollmus 2011, Krause 2006, Schaffert 2006, Wepner 2006). The modification process was optimized for Scots pine solid wood and already near the market launch (Schaffert 2006).

In general, a modification with DMDHEU highly improves the resistance against wood destroying fungi (Bollmus 2011, Krause 2006). The equilibrium moisture content (EMC) at high relative humidity (RH) is reduced and high dimensional stability was achieved caused by permanent swelling (bulking) which was found to be dependent on weight percent gain (WPG) and wood species (Bollmus 2011). The surface hardness of the material rises with an increasing WPG whereas the bending strength is almost not affected by the modification (Bollmus 2011, Krause 2006). An overview about the impact of DMDHEU treatments on further wood properties is given in the full paper.

An increased brittleness and crack sensitivity illustrate the present challenges to optimize the mentioned wood-polymer-integration process (Bollmus 2011). Two approaches are proposed for advanced investigations (Emmerich 2016). The first one is a screening of alternative crosslinking agents that might suit for modifying wood and lead to the same improvements as DMDHEU, by at once a more flexible polymer-wood-matrix. The focus will be on formaldehyde-reduced and -free crosslinking agents from the textile and paper application. Especially the latter seem to be promising in terms of high reactivity even at temperatures beneath 100 °C. However, fixation with regard to permanent effects needs to be examined. The second approach is focussed on process optimisation for further fast-growing wood species (*Pinus radiata* D.Don, *Populus* spp.), to forward this modification system in Germany and abroad since the demand of the wood working industry increases.

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Improvement of dimensional stability of wood by silica-nanoparticles

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Keywords: hygroscopicity, nanoparticles, swelling, anti-swelling-efficiency, swelling anisotropy

ABSTRACT

The improving effect of nanoparticles on wood properties is barely known nowadays. Contrarily, the nanoparticles are commonly used in other industries because of their favourable properties. For example, it is possible to improve the properties of polymers remarkably. The novelty of the research is the application of such new nanoparticles, which utilisation in the wood industry was not investigated yet. The planned treatment will likely elongate the lifetime of the wood-based products.

With the use of the hydrophobous properties of the silica nanoparticles (SiO_2) it is possible to create “hydrophobic wood”. The changes in the environmental parameters, the temperature and the humidity will have less effect on the wood material treated with the abovementioned nanoparticles. As a result of that is less shrinking or swelling, and that leads finally to the increased dimensional stability. The improvement of wood materials’ dimensional stability by nanoparticles has the favourable property contrary to earlier methods, that this modification does not decrease other physical properties of wood. For the reduction of the shrinking anisotropy, heat treatment methods are current, but they cause significant decrease in the strength and elasticity depending on the treatment parameters. Accordingly, such modified wood material is only suitable for cladding or decking, but not for load-bearing structures.

The expected result of the research is the improvement of the dimensional stability as a result of impregnation with nanoparticles. Because the wood-water relations are essential at all utilisation fields, the expected positive results of the research can serve useful information regarding the expandability of the utilisation fields of wood. It is possible to create such dimensionally stable wood material which do not have negative properties as the “price” for outstanding dimensional stability.

Two different wood species (beech and scots pine) were investigated. Two different treatments with silica nanoparticles were used. One treatment was a pure emulsion of silica nanoparticles (carrier material: tetrahydrofuran), and another one was silica nanoparticles in tetrahydrofuran carrier material in combination with polydimethylsiloxane (PDMS) as bonding agent. PDMS was used to improve the bonding of the silica nanoparticles to the wood structure.

Overall, we can state according to our investigations so far, that the impregnation with nanoparticles was successful. Shrinking and swelling properties decreased remarkably in case of both investigated wood species (Fig. 1 and 2). However, there was no significant improvement in the swelling properties of pine wood in tangential direction. The same observation was made in case of both treatment types. Application of PDMS did not provide better dimensional stability compared to the treatment without it. As a side effect of the treatments, a slight colour change could be observed as well.

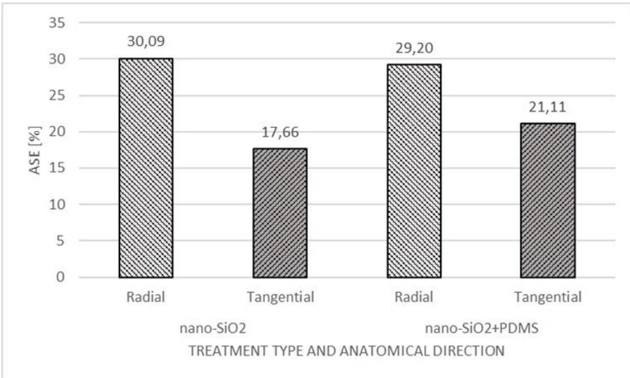

Figure 1: Effect of nano-silica treatments on the dimensional stability of beech wood

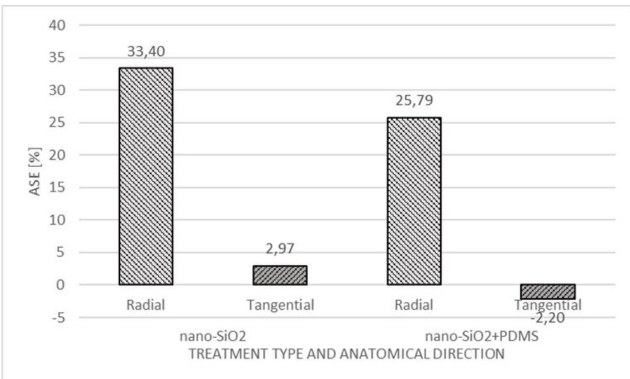

Figure 2: Effect of nano-silica treatments on the dimensional stability of scots pine wood

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Effects of Methyl Methacrylate impregnation on durability of timber.

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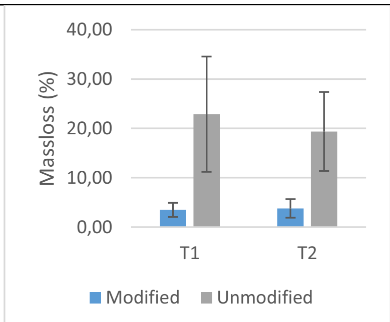
Keywords: Methacrylate, wood, modification, durability, decay

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 (Figure 1) 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.

<table>
<tr><th></th><th>White rot</th><th>Brown rot</th></tr>
<tr><td>Spruce</td><td>


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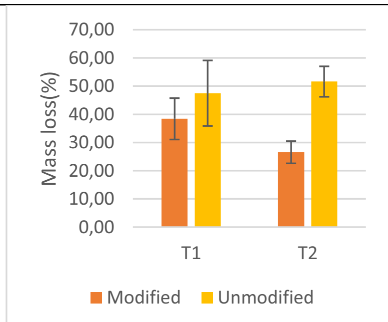

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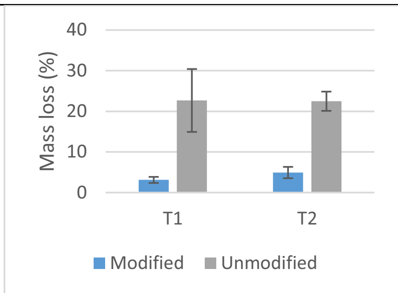
Pine



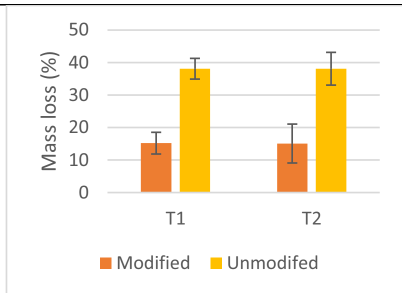


Figure 1. Percentage mass loss (based on wood mass) of treated and untreated pine and spruce samples exposed to white and brown rot fungi. Error bars show standard deviation of mean (n =4)

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