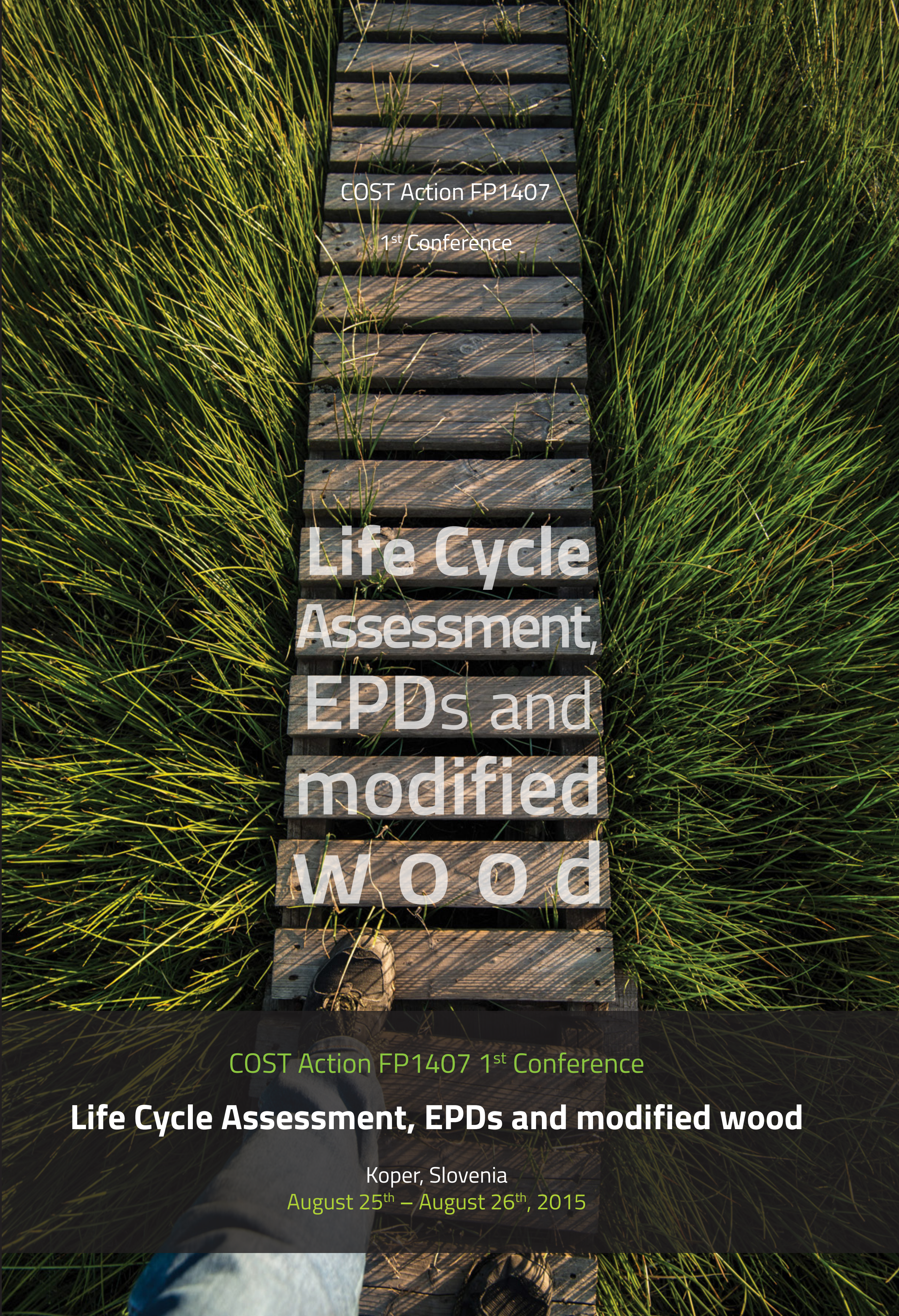

COST Action FP1407

1st Conference

Life Cycle Assessment, EPDs and modified wood

COST Action FP1407 1st Conference

Life Cycle Assessment, EPDs and modified wood

Koper, Slovenia

August 25th – August 26th, 2015

COST Action FP1407

Understanding wood modification through an integrated scientific and environmental impact approach (ModWoodLife)

Life Cycle Assessment, EPDs, and modified wood

First COST Action FP1407 International Conference
Koper, Slovenia
25 – 26 August 2015

Editors: Andreja Kutnar, Michael Burnard, Matthew Schwarzkopf, and Amy Simmons

University of Primorska
Koper, 2015

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Andreja Kutnar – Slovenia
Dennis Jones – Sweden
Dick Sandberg – Sweden
Robert Németh – Hungary
Christelle Ganne-Chedeville – Switzerland
Lauri Linkosalmi – Finland
Callum Hill – The United Kingdom
Ana Dias – Portugal
Edo Kegel – Netherlands
Michael Burnard – Slovenia
Lauri Rautkari – Finland

Content

Preface

Welcome to the first international conference of COST Action FP1407 “Understanding wood modification through an integrated scientific and environmental impact approach” (ModWoodLife), which started on March 10th 2015 with the kick-off meeting in Brussels. The conference “Life Cycle Assessment, EPDs, and modified wood” held in Koper, Slovenia August 25th and August 26th 2015 is the first event of Action FP1407. At the event researchers working in the field of environmental impact assessment and modified wood will share their research activities, discuss new solutions, and explore problems related to the topic. Industry members will also be present, especially those from Slovenia, and will contribute to COST Action FP1407’s important objective of disseminating scientific knowledge to an industrial audience that will enable optimization of wood modification processing and development of new modification processes. It is critical to merge the efforts of researchers, industry members, and other relevant stakeholders to increase the market potential of modified wood. Achieving this goal will help to facilitate Europe’s transformation into a society focused on sustainability, a cyclical economy, human well-being, and use of its renewable resources.

COST Action FP1407’s research focus is important worldwide. This is evident by the encouraging support and participation from so many countries. Although the Action started less then 6 months ago, 24 European countries are already participating in addition to 3 COST Near Neighbour Countries (Ukraine, Albania, Tunisia) and 4 COST International Partner Countries (USA, Canada, New Zealand, and Chile). Additionally, South Africa is in the process of becoming a member of FP1407. The involvement of participants beyond Europe will ensure that our work takes into account the research and development from other parts of the world and enables our group to build on their expertise. Together we will spearhead a global change in the wood sector. Additionally, our work will be disseminated beyond Europe in traditional ways and through modern channels like LinkedIn, Twitter, and Facebook. Our Action has profiles on all of these and I encourage you to disseminate FP1407 and its findings to as wide an audience as possible.

The first conference of Action FP1407 will allow us all to get to know each other, exchange our expertise, and find joint interests that we will implement together over the coming years at conferences, workshops, training schools, and STSMs.

I am convinced that our 1st conference will be a successful event, which will result in new collaborations within the FP1407 network.

Welcome to Koper!

Andreja Kutnar
Chair, COST Action FP1407

FP1407

ModWoodLife

COST Action FP1407 1st Conference
"**Life Cycle Assessment, EPDs, and modified wood**"
Koper, Slovenia
August 25th – August 26th, 2015

CONFERENCE PROGRAM

Tuesday, August 25th, 2015

09:00	Registration	
09:30 - 09:45	**Welcome**	
	Andreja Kutnar	
09:45 - 10:30	**Keynote 1**	**Chair: Andreja Kutnar**
	Frank Werner	PCR development and EPD (for wood products) - the European context.
10:30 -11:15	**Presentations**	**Chairs: Ana Dias and Franz Dolezal**
	Tellnes, L. G. F	Experiences with PCR for wood products and EPDs for modified wood in Norway – The role of biogenic carbon
	Tarmo Räty	PEnA-Db: Integration of LCI and EPDs with decision making
	Friderik Knez	Experience in environmental declarations programme ZAG EPD
11:15 - 11:45	**Coffee break**	
11:45 - 13:00	**Presentations**	**Chairs: Lauri Linkosalmi and Hermann Achenbach**
	Flavie Lowres, Elodie Macé, Nigel Jones, Ed Suttie	Materials credits within BREEAM – LCA, the Green Guide and timber
	David Hopkins, Ed Suttie, **Owen Abbe**	The Wood for Good life cycle database of timber products
	Anna Sandak	Bio-materials for building envelope - expected performance, life cycle costing & controlled degradation - Bio4ever project approach
	Jakub Sandak, Anna Sandak, Mariapaola Riggio	Bio-based building materials: aesthetical service life and customer's environmental conciseness
	Hermann Achenbach, Sebastian Rüter	Life cycle assessment of pre-fabricated timber houses according to the European state-of-the-art standards
13:00 - 14:30	**Lunch**	
14:30 - 15:45	**Presentations**	**Chairs: Anna Sandak and Rajat Panwar**
	Johann Charwat-Pessler, Rudolf Schraml, Karl Entacher, Andreas Uhl, Alexander Petutschnigg	Traceability within the wood supply chain: an opportunity defining system boundaries
	Mario Marra, Ottaviano Allegretti, Stefano Guercini	Life Cycle Assessment of ThermoVacuum treated softwood timber with comparison to untreated and preserved cladding
	Jin-Bo Hu, Campbell Skinner, Graham Ormondroyd, Gianluca Tondi Antonio Pizzi, Marie-France Thevenon	Life cycle assessment of a novel tannin-boron association for wood protection
	Lauri Linkosalmi, Kristiina Laine, Lauri Rautkari	Life cycle impacts of modified wood products
	L. Beesley, **K. Mitchell,** L. Mollon, G.J. Norton	Mobility and toxicity of heavy metal(loid)s arising from contaminated wood ash application to a pasture grassland soil
15:45 - 16:15	**Coffee break**	
16:15 - 17:30	**Presentations**	**Chairs: Alexander Petutschnigg and Monika Muszyńska**
	Mojgan Vaziri, Caroline Rogaume, Eric Masson, Antonio Pizzi, Dick Sandberg	VOC emissions from linear vibration
	P. Rademacher, P. Paril, J. Baar, R. Rousek, D. Meier, G. Koch, U.Schmitt	Improvement of wood properties due to impregnation of wood with renewable liquids from different process residues of native origin
	Benedikt Neyses, Dick Sandberg, Olle Hagman, Magnus Wålinder	Development of a continuous wood surface densification process with a reduced environmental impact
	Kévin Candelier, Marie-France Thévenon, Anélie Pétrissans, Stéphane Dumarçay, Philippe Gérardin, Mathieu Pétrissans	Primary analysis methods used to control thermal treatments of wood and effect on decay resistance
	Andreja Kutnar, Michael Burnard, Matthew Schwarzkopf, Črtomir Tavzes	InnoRenew CoE - Renewable Materials and Healthy Environments Research and Innovation Centre of Excellence
17:30	**Closing of the first day**	
17:30 - 18:30	**Core group meeting**	
19:00	**Conference dinner**	

CONFERENCE PROGRAM Wednesday, August 26th, 2015

9:00 - 9:30	**Keynote 2**	**Chair: Andreja Kutnar**
	Rajat Panwar	Advancing LCA application in the wood sector
9:30 -10:45	**Poster Session**	**Chairs: Michael Burnard and Carmen Popescu**
	Manja Kitek Kuzman, Mirko Kariž	The use of modified wood in Slovenia
	Malick Diakhaté, Seif Eddine Hamdi, Emilio Bastidas-Arteaga, **Rostand Moutou-Pitti**	Experimental characterization of wood mechanical performance in constant environment: use of acoustic emission to monitor crack tip propagation
	Patrícia S. B. dos Santos, Silvia H. F. da Silva, Caroline R. Soares, Darci A. Gatto, Jalel Labidi	Effect of natural weathering and accelerated aging on Brazilian wood Pinus
	Miha Humar, **Davor Kržišnik**, Boštjan Lesar, Nejc Thaler, Mojca Žlahtič	Characterisation of interactions between thermally modified wood and water
	Tomasz Krystofiak, Barbara Lis, **Monika Muszyńska**	Study of interactions between PVAC adhesives and wood after thermo-mechanical (TM) modification
	Seref Kurt, Hüseyin Yörür, Muhammed Nuri Günay, Taner Yildiz	Tests to increase preservative retention in fir
	Václav Sebera, Martin Brabec, Petr Čermák, Jan Tippner, Jaromír Milch	Analysis of neutral axis position in thermally modified wood using DIC
	Daniela T. Silva, René Herrera, Berta M. Heinzmann, Jalel	Decay resistance and physicochemical properties of wood preservatives based on Ocotea
	Ali Temiz, Engin Derya Gezer, Selçuk Akbaş, Gaye Köse Demirel	Effects of Bio and Epoxidized Oil on Physical and Biological Properties of Treated Wood
	Maria-Cristina Popescu, Carmen-Mihaela Popescu	Structure evaluation of the modified wood through different spectral techniques
	Giacomo Goli, Francesco Negro, Corrado Cremonini, Roberto Zanuttini, Marco Fioravanti	Feasibility of highly durable plywood production with poplar wood as a substitute of tropical species
	Andris Morozovs, Edgars Bukšāns, Uldis Spulle	Mineral-plant-fibre composite coating as cellular wood protector against fire
	Liljana Rušnjak, Michael Burnard, **Andreja Kutnar**	Waste wood management and processing - opportunities for reducing the environmental impact of ports
	Michael Burnard, Andreja Kutnar, Aleksandar Tošić	Perceptions of innovation in wood-based products from Slovenia
	Seif Eddine Hamdi, **Rostand Moutou Pitti**	Characterization of cracked wood under thermo-hydro-mechanical and viscoelastic behaviour
10:45 - 11:30	**Poster session with refreshments**	
11:15 - 12:15	**Presentations**	**Chairs: Dick Sandberg and Václav Sebera**
	Wim Willems	Novel moisture sorption model explaining parallel kinetics of transient wood moisture content
	Róbert Németh, Dimitrios Tsalagkas, Miklós Bak	Changes in the modulus of elasticity of beeswax impregnated wood during soil contact
	Straže A., Fajdiga G., Pervan S., Gorišek Ž.	Impact of thermal treatment on moisture-dependent elasto-plastic behaviour of beech wood
	Aleksandar Lovrić, **Vladislav Zdravković**, Nebojša Todorović, Goran Milić	Influence of Thermal Modification of Poplar Veneers and Plywood Construction on Shear Strength
12:15 - 13:30	**Lunch**	
13:30 - 14:45	**Working group meeting**	
	WG1: Product Category Rules	Lead by Dick Sandberg & Robert Nemeth
	WG2: Life Cycle Assessments	Lead by Lauri Linkosalmi
	WG3:Environmental products declarations	Lead by Ana Dias
	WG4: Integration, dissemination and exploitation	Lead by Edo Kegel & Michael Burnard
14:45 - 15:15	**Reports of WG leaders and conference conclusions**	
15:15 - 15:45	**Coffee break**	
15:45 - 17:00	**MC meeting**	
18:00 - 22:00	**Visit of Piran**	

PCR development and EPD (for wood products) - the European context

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Keywords: EPD, LCA analysis, PCR, wood

About the author

Frank Werner is owner of the Werner Environment & Development, which is specialised in the elaboration of decision support for a sustainable environment and resource use. Frank Werner's expertise includes product life cycle assessment, material flow analysis, environmental management, as well as project and methodology related work related to the UN framework convention on climate change. Among the services that he offers are:

- Life Cycle Assessment:

- LCAs of building products,
- Elaboration of IBU environmental declarations (EPDs) of building products according to ISO 14025 and ISO 21930 based on existing or newly elaborated LCAs,
- Review of LCAs and scientific papers in this field

- Sustainable Construction:

- Elaboration of life cycle assessments (LCAs) of building products and buildings,
- Environmentally sound selection of materials and products,
- Elaboration and use of environmental declarations of building products (EPDs),
- Sustainability assessment of buildings.

- Climate wood and development:

- Planning and implementation of afforestation and reforestation project under the Clean Development Mechanism (CDM) or for the voluntary market,
- Elaboration of afforestation and reforestation CDM baseline- and monitoring methodologies,
- Quantification, monitoring and marketing of other environmental services of forests as part of an integral approach to forest conservation.

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More information: www.frankwerner.ch (accessed August 2nd, 2015)

Experiences with PCR for wood products and EPDs for modified wood in Norway – The role of biogenic carbon

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[1] Norway, Norwegian Institute of Wood Technology, lars.tellnes@treteknisk.no

Keywords: Environmental product declarations, wood products, biogenic carbon

Environmental product declarations (EPD) for wood products have been around in Norway for about 20 years, but there has been a large increase in use and availability in recent years. The use of EPDs are for whole-building life cycle assessments (LCA) and, especially, accounting for the carbon footprint. These uses have been pushed forward by the Norwegian Government Building Company (Statsbygg) and the environmental classification system of buildings BREEAM-NOR. The Norwegian version of BREEAM gives credits for having EPDs for the major materials used in a project and this has been a game changer for the demand for EPDs in Norway.

The supply and availability was driven at the start by a few companies being proactive, but are now more and more made by companies to satisfy their customer's requirements. The third party verified EPDs for wood products was at the start mostly made for large product groups and representative for all members of the Norwegian Wood Industry Federation. The trend now is towards more specific EPDs and other industries have starting making EPDs specific for single construction projects.

The introduction of EN 15804 made it necessary to change several key methodological practices for wood EPDs in Norway on issues such as co-product allocation, modularity, biogenic carbon, end-of-waste and possibilities to include benefits beyond the lifecycle. In Norway, instantaneous oxidation of biogenic carbon had always been the common practice and studies did often not include end-of-life scenarios. The change of approach to include uptake and emissions of biogenic carbon in the modules where they appear was therefore controversial at the start. One key way to deal with this controversy was to have high transparency of biogenic carbon flows in Norwegian EPDs. The use of foreign EPDs for wood products are however often frustrating for LCA-practitioners as they seldom report the amounts of biogenic carbon.

Several EPDs have been developed for modified wood through the Norwegian EPD-foundation in accordance with EN 15804. These are presented in Table 1 along with the carbon footprint for 1 m^3 declared unit with optional modules of maintenance, repair and waste processing.

Table 1: Carbon footprint of modified wood product based on EPDs

Type of product	NEPD nr.	Biogenic carbon	Production A1-A3	Maintenance and repair B2-B3	Waste processing C3-C4	Total
Royal impregnated pine	294N	770	-652	60	824	232
Thermally modified ash	260N	1159	-430	90	1181	841
Thermally modified pine	259N	786	-258	64	801	607

Biogenic carbon significantly influences the modules where it is included, but with combustion at end-of-life, these emissions are balanced by uptake during growth. There have, however, been methods developed to account for time-adjustments to greenhouse gas emissions and these have been elaborated in Tellnes *et al*. (2014) for several façade materials. This review of biogenic carbon emphasises that the quantity of biogenic carbon must be transparently documented in EPDs so that all alternative methods can be used. The timing, amount of uptake, and emissions of biogenic carbon should therefore always be reported in a wood EPD.

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PEnA-Db: Integration of LCI and EPDs with decision making

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Keywords: Environmental Product Declarations, Decision making, ILCD, database

Introducing EPDs for buildings and building products is an EU wide measure to assure conformity of the building products over the common markets. In principle, an EPD is a standardised form of environmental communication of a product, compiled and distributed in the same form, regardless of the materials used or the place of production. Thus, products with identical intended uses should be comparable in environmental terms using standardised EPDs. In practice this ideal is often not realised, as the structures of the supply chain, applied technologies, raw materials used, and environmental conditions vary considerable over the EU. It is already challenging to harmonize EPDs for the products with the same raw material, such as wood products. It appears necessary to develop a strict and reliable system to produce EPDs, covering the whole value chain from human impacts on forest life cycles, primary transportation, processing of timber, and further processing of the wood and wood products as well as reasonable scenarios on their usage, recycling and disposal.

As an application of Life Cycle assessment (LCA), compiling EPDs is on data intensive task. Ideally, each agent over the chain of custody should contribute with their own EPDs that downstream agent can use as an input for their own EPDs. One should also make sure that comparable inventory data on environmental impacts are used when data are cumulated. Implementation of such a system is a challenging task. In an unformed system the quality of EPDs may remain poor without a reasonable economy. A system that could be further developed to support harmonized EPDs for wood products should serve three principles:

1. Primary data from the chain of custody should be used

   Comparisons of the products are meaningful only if the inventory data refer to proper chain of custodies of the products.

2. Special attention should be on primary production, where the human impact is obvious and spatially dependent.
3. Confidentiality of business data and intellectual property rights should be honoured.

Prerequisites for such a system are discussed in detail for the food value and energy chains in Usva *et al*. (2009). An operational version as a commercial service is under development and known as Ecomodules, (Ecomodules, 2014).

Fig. 1 introduces PEnA-Db (Platform for Environmental Assessment–Database), where the target is to integrate LCA datasets on decision making tools in construction. It relies on International reference Life Cycle Data System, ILCD, (European Commission, 2010) and open access data when possible.

For conformity, any LCI or LCIA dataset should meet ILCD entry level requirements. The format itself does not set any requirements for the property rights of the data. An ILCD dataset can be published in the Life Cycle Data Network under developers/owners own conditions. It is web-based and non-centralized ensuring easy access via searches, filtering, and sorting.

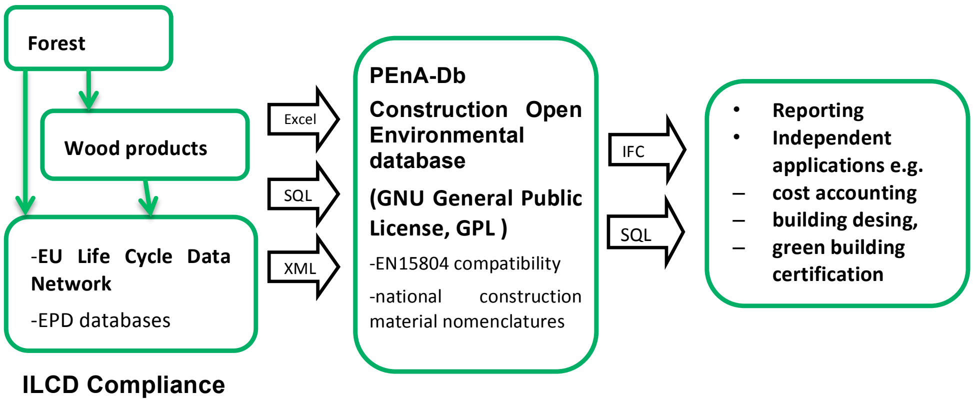

Figure 1: PEnA-Db, an integration of LCI datasets on construction decision making tools.

LCI data is usually organized according the inherent property of material (e.g. metal, wood), whereas the industrial users organize materials according their use (e.g. construction industries use their own nomenclatures: beams, pipes, heating). PEnA-Db is a necessary filter facilitating integration of LCA on construction design, budgeting and accounting. XML format used in ILCD datasets, gives relatively easy access to LCI data. The preliminary implementation of PEnA-Db uses MySQL, so that data transformations form LCI categories to construction nomenclatures is flexible. Using open access database software allows easy access to data using common access methods such as web platforms or spreadsheets.

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Experience in environmental declarations programme ZAG EPD

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Keywords: EPD programme, ZAG EPD, wood

Environmental declarations type III, according to ISO 14025, are a powerful tool to transparently communicate the environmental properties of products and materials in Business-to-Business (B2B) and Business-to-Consumer (B2C) relations. However the general methodology described in ISO 14040 and 14044 does not provide sufficient information to enable fair comparisons between alternatives. Therefore, only limited value can be extracted from an LCA itself. Considering this, an EPD programme, named ZAG EPD, was deployed in 2012 at the Slovenian National Building and Civil Engineering Institute (ZAG). Although the principles of the programme are generalised, it is used in the field of construction products only. The primary goal of the programme is to provide independent and comparable information on construction products used in Slovenia. Further, the programme serves as a basis for creating a registry of sustainable construction products that can be used in Slovenia, in the mode of other existing registries (such as Germany's Oekobaudat or Austria's Baubook)

The ZAG EPD programme follows the same basic principles of all programmes intending to comply with EN 15804. The ZAG EPD programme is also a member of the Ecoplatfom, an European association of EPD programmes with the primary goal of harmonization of programme rules.

Although direct comparison of products based on LCA is methodologically unsound, efforts to improve LCA comparability are being studied. One of these efforts is the construction of an EPD programme based on product category rules (PCRs), sufficiently precise to provide reliable guidance for LCA practitioners.

The ZAG EPD programme uses a two-fold approach: either checking, accepting, and using existing PCR or creating an original PCR. In practice, existing PCRs used by the IBU (Institut fuer Bauen und Umwelt) programme are used. The reason for selecting this particular programme as an alternative to creating original PCRs in the ZAG EPD programme is mainly comparability, as most customers of ZAG EPD are active also on German market.

The ZAG EPD programme consists of several important building-blocks:

- rules for LCA studies to be used as a basis for an EPD
- LCA project report verification requirements
- independent regulating body for PCRs,

- communication platform, including EPD format and publishing EPDs online

At the moment there are (only) three fully issued EPDs in the system, and about 10 in the pipeline to follow. ZAG's experience shows that although there is substantial interest in EPDs in the industry, the lack of tangible value prevents broader use. Sharing information between partners within the ECO Platform EPD ZAG is not a unique problem. Rather this is a common problem except in countries with a very strong tradition or certification systems.

Wood products are no exception to this general rule. EN 15804 is the basis within a ZAG EPD and biogenic and non-biogenic CO2 (or GWP) are clearly distinguised, which puts wood in a superior position compared to mineral-based products. However, data on the storage capacity and forestry practices, with an emphasis on sustainability, need to be considered in detail. This is an area where additional research would be very welcome. Second, no PCR is available for products made of modified wood. In this case, a broader basis is needed to enable modelling of production processes of modified wood.

EPDs offer several possible value propositions for the industry in Slovenia, and, to an extent, apply EU wide..

- Expression of the environmental performance through an EPD puts a producer in position to compete in the most demanding projects

- To a certain extent having an EPD provides edge in green public procurement projects

- Immediate readiness provides an opportunity to integrate EPD in the CE mark, in particular for technical assessment cases

At the EU level ZAG EPD experts take part in efforts to implement EPDs in technical assessment systems, opening a wide route to the CE mark. Aside from an EPD system, other systems of identifying a product's environmental performance are being built (e.g., PEF, promoted by DG Environment). These systems rely on the ILCD approach, which might lead to different results, especially in bio-based construction products. PEF is not limited to construction products, though.

ZAG EPD

Figure 1: ZAG EPD logo.

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Materials credits within BREEAM – LCA, the Green Guide and timber

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Keywords: life cycle analysis, green guide, BREEAM, materials, timber

BREEAM (BRE 2015) is the world's foremost environmental assessment method and rating system for buildings, with 425,000 buildings with certified BREEAM assessment ratings and two million registered for assessment since it was first launched in 1990 (Figure 1).

BREEAM sets the standard for best practice in sustainable building design, construction and operation and has become one of the most comprehensive and widely recognised measures of a building's environmental performance. It encourages designers, clients and others to think about low carbon and low impact design, minimising the energy demands created by a building before considering energy efficiency and low carbon technologies.

BREEAM addresses wide-ranging environmental and sustainability issues and enables developers, designers and building managers to demonstrate the environmental credentials of their buildings to clients, planners and other initial parties. It does this by using a straightforward scoring system that is transparent, flexible, easy to understand, and supported by evidence-based science and research.

An important component of a BREEAM assessment are the materials credits available which increasingly become more significant as the operational efficiency of buildings improves through better design and refurbishment of buildings (Figure 2). This paper focusses on the life cycle assessment for determining environmental impacts for construction product functional units (e.g. $1m^2$ external wall meeting existing building regulations), the thirteen impact categories used, and their conversion to an ecopoints score normalised to a European citizen (Figure 3) and ultimately an overall rating within the Green Guide for Specification (Green Guide 2015).

The paper looks at the timber based functional units, which typically attain A or A+ ratings within the Guide.

Figure 1: Countries with BREEAM rated buildings (green) and independent national schemes (blue)

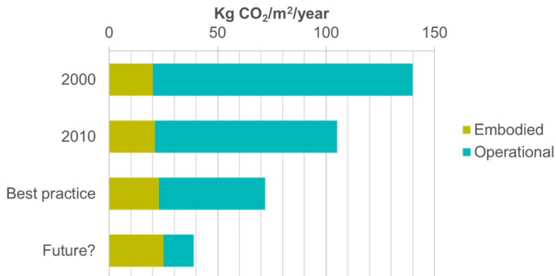

Figure 2: As operational impacts are reduced the significance of embodied material impact increases

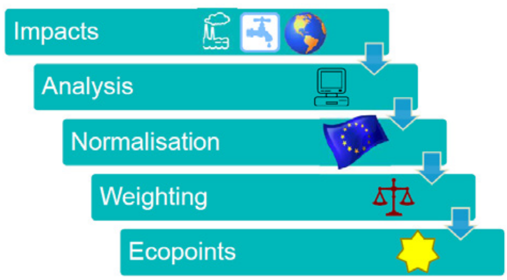

Figure 3: Measuring against 13 impact categories and conversion to an ecopoint single score

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The Wood for Good life cycle database of timber products

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Keywords: life cycle database, free-to-use, timber products

Wood for Good is the UK's wood promotion campaign which works on behalf of the whole timber industry in the UK. It aims to promote the suitability and sustainability of wood as a building material to the construction and logistics sectors and associated professionals such as architects and design engineers. Early in 2015 Wood for Good officially launched the UK's largest life-cycle assessment (LCA) database, containing whole-life environmental performance information of all major timber products. This paper presents the database.

The database – which is free-to-use – is an important first step in quantifying the environmental performance of timber in UK construction. The database includes modern-engineered solutions including cross-laminated timber (CLT) and glulam, as well as materials commonly used in timber construction, such as adhesives and steel sheets. Figure 1 shows the front page of the database available at http://www.woodforgood.com/lifecycle-database/

Assessment has been made from cradle to grave, including forestry, harvesting, transportation, processing and manufacturing, through to the various end of life options.

One of the key findings was that every timber product studied reported a carbon negative rating on a cradle-to-site basis, meaning the amount of carbon absorbed and stored in the timber is greater than that emitted in production and transportation.

Future outputs in the Wood for Good project – called Wood First Plus – include LCA case studies, a toolkit to build individual Environmental Product Declarations and a BIM element are under discussion.

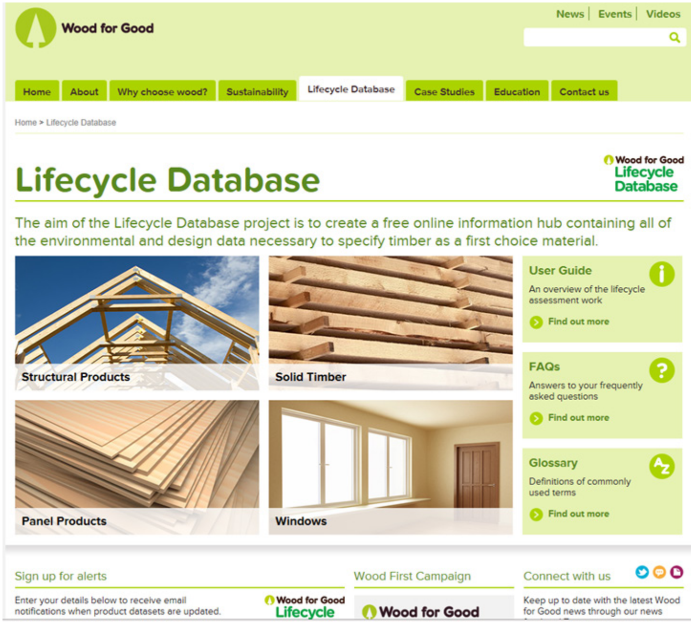

Figure 1: Front page of the lifecycle database available on the Wood for Good website at http://www.woodforgood.com/lifecycle-database/

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EN 15804+A1: 2013 *Environmental product declarations – Core rules for the product category of construction products*

prEN 16485:2013 *Round and sawn timber – Environmental Product Declarations – Product category rules for wood and wood-based products for use in construction*

prEN 16449, *Wood and wood-based products – Calculation of sequestration of atmospheric carbon dioxide*

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Bio-materials for building envelope - expected performance, life cycle costing & controlled degradation - Bio4ever project approach

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Keywords: bio-materials, sustainable design, service life performance, building envelope

The trend for rapid deployment of novel/advanced material solutions at reduced-costs through predictive design of materials and innovative production technologies is commonly observed today. Such materials are optimized for specified applications, meeting the desired properties and functionality for an elongated life, minimizing the environmental impact and reducing the 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 their products. The development of highly innovative and advanced bio-products relies on a thorough understanding of the material properties, structure, assembly, formulation, and performance throughout the service life.

The Bio4ever project is multi-disciplinary and dedicated to filling gaps in knowledge regarding some fundamental properties of novel bio-based building materials. The two driving objectives of the projects are:

- to promote the use of bio-materials in modern construction by understanding/modelling its performance as a function of time and weathering conditions
- to identify the most sustainable treatments of bio-material residues at the end of life, further improving their environmental impact.

The overall goal is to assure the sustainable development of the wood-related construction industry, taking into consideration environmental, energy, socio-economic, and cultural issues. This can be achieved by developing original, reliable tools demonstrating advantages of using bio-based materials when compared to other building resources. A comprehensive understanding of the physical/chemical properties and their connection with the material's structure will be obtained as a result of a combination of analytical/experimental methods and numerical modelling.

The expansion of bio-based product availability and the wide utilization in modern buildings is a derivative of the Europe 2020 strategies. It is foreseen that bio-materials will play an increasingly important role in the future, in order to assure full sustainability of the construction sector. Consequently, the challenges being researched in Bio4ever projects correspond to the trend of a pan-European low carbon building agenda. Results will provide technical and scientific knowledge and will also contribute to public awareness, by demonstrating the environmental benefits to be gained from the knowledgeable use of bio-based materials in buildings.

Acknowledgments:

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Bio-based building materials: aesthetical service life and customer's environmental conciseness

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Keywords: aesthetic service life, customer preferences, environmental impact

Accurate service life predictions, service life cost analyses, and the aesthetic performance of newly available bio-based building materials are essential for their promotion in the construction sector. Today's bio-based building materials, even if well characterized from the technical point of view, often lack reliable models describing their performance during service life. The appearance of bio-based building materials often changes during their service life. Therefore the aesthetic service life is often the decisive criterion for these applications. The challenge is to co-involve physics, chemistry, and mathematics, as well as psychology and customer preference research in order to improve the functionality of bio-materials over elongated service lifetimes, and minimise the environmental impact and reduce risk of product failure.

This research is an attempt to investigate the influence of material costs and environmental awareness on the choice of bio-materials used for building applications. Special focus was directed toward investigation of customer preferences regarding use of local and imported species, modified wood, and awareness of material costs. Preference tests performed on more than 250 subjects allowed investigating specific preferences influencing selection of bio-materials. The test was performed in two steps:

1: participants selected picture from a set representing various species/products shown before and after 3 years weathering (Figure 1).

2: participants re-selected picture from the above set, but considering also price and information about wood provenance (Figure 2).

Responses to both tests were collected and examined. The work presented here is a trial to generate routine tools capable to "better understand" customer preferences related their understanding of wooden products environmental impacts.

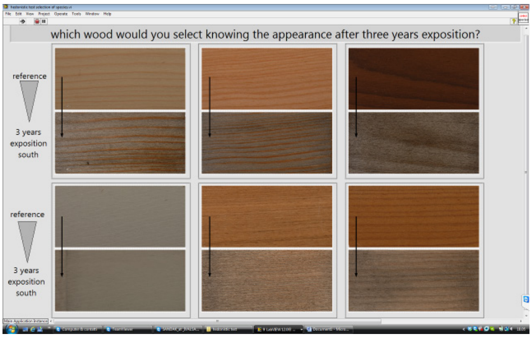

Figure 1: User interface of the preference test – step 1.

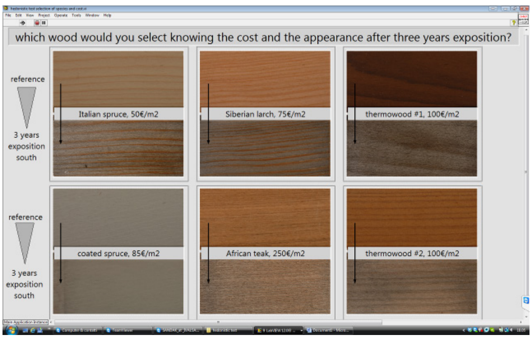

Figure 1: User interface of the preference test – step 2.

Acknowledgments:

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Life cycle assessment of pre-fabricated timber houses according to the European state-of-the-art standards

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Keywords: LCA, pre-fabricated timber houses, EN 15804, EN 15978, EN 16485

Due to improved energy savings in the use phase of a building's life cycle, the environmental impacts of the production, construction, and end of life stages are gaining more and more importance. Thus, the European Committee for Standardization (CEN) has developed a set of horizontal standards that enables the sustainability assessment of construction works including the evaluation of associated environmental impacts of building products and buildings over the entire life cycle (EN 15804:2013 and EN 15978:2012). Since 2014, the European standard EN 16485:2014 complements those standards by providing specific rules for the implementation of life cycle assessment of wood and wood-based products in the context of their use in construction.

Consistent with the European state-of-the-art standards a life cycle assessment (LCA) was carried out to determine the environmental impact of the production and construction stage of building elements (i.e. functional units scaled to 1 m² inner/outer wall, 1 m² roof element, 1 m ceiling element) and an average pre-fabricated timber house produced in Germany. The data represents the average of 12 companies belonging to the *Bund Deutscher Fertigbau e.V.* (BDF), covering 37 % of the total German production, which ensures the high representation of the study.

In order to be in line with EN 15804 the life cycle inventories (LCI) of the functional units had to be calculated using annual data of each factory site (house manufactories). Thus, the main challenge was to develop a model that calculates the annual input and output flows of the defined functional units on the factory level. The supply of average LCA data methodical aspects are also discussed. A particular focus was set on the application of the modular principle according to EN 15804/15978 to construction systems with a high level of pre-fabrication. In contrast to an LCA-study on a multi-storey wooden building by Takano *et al.* (2015) that accounted for pre-fabrication processes in the construction stage, we considered processes of pre-fabrication in the production stage (see figure 1).

The normalization to the overall German impacts shows that the contribution to the environmental categories global warming potential (GWP), acidification (AP), and to the abiotic depletion potential (ADPe) are most important. The highest impacts are caused by manufacturing the building materials (module A1) (see figure 2). However, for the categories GWP and AP, around 30 % of the impacts originate from the pre-fabrication of the building elements (A3), their transport (A4), and the processes at the construction site (A5).

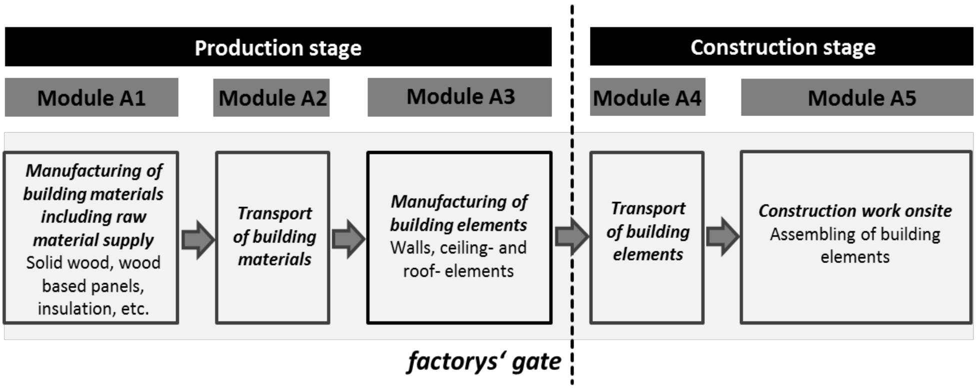

Figure 1: Modular principle of EN 15804/15978 applied to the production and construction stage of the pre-fabrication system.

Especially remarkable is the high share of environmental impacts that are caused by the transport of the building elements. On average, walls, roofs and ceilings are transported to the construction site over 350 km by 5 to 8 trucks. For the delivery the trucks require around 884 l diesel on average.

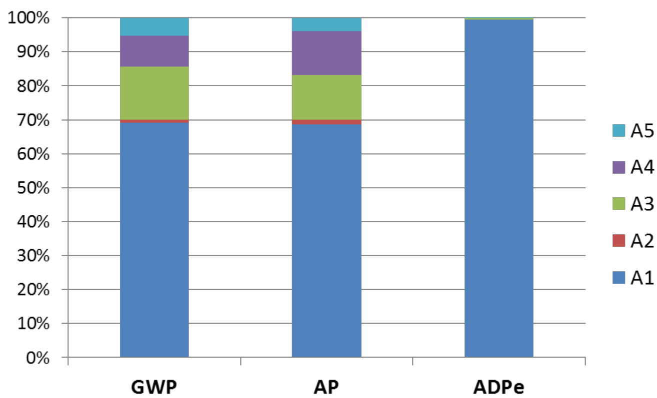

Figure 2: Main contributors to the categories GWP, AP and ADPe (preliminary results).

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Traceability within the wood supply chain: an opportunity defining system boundaries

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Keywords: Traceability, wood supply chain, log end faces, RGB, European timber regulation

Progressing deforestation noticeable worldwide calls for more efficient monitoring within the wood supply chain from felling to delivery at a sawmill. In some cases illegally harvested wood becomes legalized due to failure in controlling and monitoring systems. An example of this is shown by Lins da Silva *et al*. (2008) in the Amazon forest. Lins da Silva *et al*. (2008) suggest a management system that can provide information on wood products throughout the product lifecycle for companies and final consumers. This ensures that these products of interest originate from a legal and sustainably managed forest. Transparency within the forestry wood supply chain also benefits life cycle assessment (LCA) since product system boundaries may be more easily defined.

The European timber regulation No 995/2010 (EUTR) stipulates duties and diligence for timber and timber products on the European market with the aim to hinder global deforestation and impede imports of timber and timber products from illegally harvested forests. Since March 2013 the regulation claims disclosure of provenance of timber and timber products placed on the European market, therefore corresponding technical solutions need to be offered and researched.

In the past decades many attempts were made to track round wood from the forest to the sawmill, however, all technical solutions were limited in their application due to harsh weather conditions, costs, or other inhibiting factors. Trials conducted ranged from marking logs with paint or barcodes to RFID transponders and DNA fingerprinting (Tzoulis and Andreopoulou 2013).

In recent studies, traceability of logs by means of RGB images of log end faces was investigated within the scope of a publicly funded research project whose findings are promising. The investigations follow the idea to make a picture of the log end face immediately after felling and a second image at the sawmill after delivery. The scientific question, whether it is possible to identify a log by means of two images, is part of ongoing scientific research. The shape characteristic of annual rings (Figure 1), location of pith, and log shape are considered as unique biometric features (similar to ridges in human fingerprints) which are assumed to distinguish between logs.

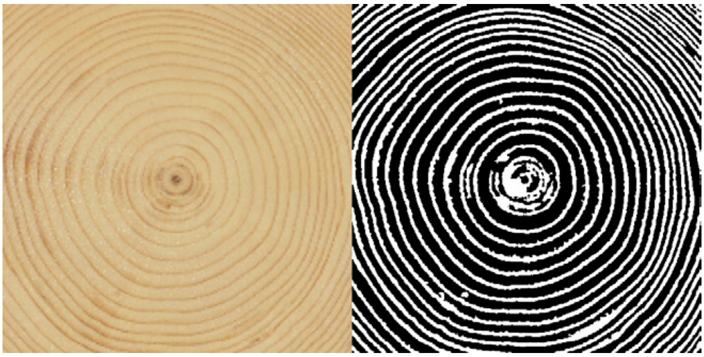

Figure 1: Sectional RGB image of log end face (left), binary image displaying segmented annual rings (right).

RGB images were used because cameras like GoPro cameras can easily be mounted on the harvester. With technical modifications these cameras can be triggered via remote control and can be placed in shock absorbent plastic housings.

A previous study used the annual ring pattern on rough log end faces for recognition purposes. This study showed that logs can be distinguished by means of a gabor filter databank using distinct block processing. Computing statistical index numbers of each block with a gabor filter forms the basis for feature vectors, allowing logs to be identified using RGB images of log end faces. The study showed that logs can even be reliably identified by images made several centimetres behind the original slice.

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Life Cycle Assessment of ThermoVacuum treated softwood timber with comparison to untreated and preserved cladding

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Keywords: LCA, LCI, Thermo vacuum modification, softwood and cladding.

A cradle-to-grave life cycle assessment was performed to identify the environmental impacts related to ThermoVacuum treated timber used for cladding purpose and to compare to alternative products. A model of the ThermoVacuum process life cycle was created and used to calculate inputs and outputs during production, treatment, use, and disposal stages. A similar inventory model was developed for untreated and preserved claddings. This study covers the LCA commissioned by ThermoVacuum4NeWood project, co-founded by the Eco-Innovation Initiative of the European Union to develop and spread this technology in the European market.

Thermal modification is a widely applied industrial treatment to improve wood properties such as durability. Softwood species, as Norway spruce (*Picea abies* Karst.), are characterized by low durability, which reduces the long-term life cycle, and low permeability that affects the chemical preservation treatment (Allegretti 2012). This prejudices the extensive use of these species. Thermal modification increases durability three or four times more than common difficult to preserve wood species. Wood modification is achieved by high temperature in an oxygen-free environment to avoid combustion. The ThermoVacuum system is a patented technology in which oxygen is substituted by partial vacuum and heating is provided by forced convection. The vacuum pump continuously removes volatile compounds from the chamber. These conditions ensure high energy efficiency, less corrosion, and reduced air emissions.

Life cycle inventory analysis

Life cycle inventory inputs, outputs, and impact indicators for ThermoVacuum treated timber were quantified using functional units of 1 m^3 timber and (about 33.3 m^2 of cladding) (Tab. 1). The functional unit for preserved cladding was 1 m^3, while it was 3 m^3 for untreated timber to account for the entire life cycle of untreated cladding (Ferreira 2014). LCA assumptions are based on information provided by an industrial project partner including the Italian plant producer, a French sawmill equipped with a 8 m^3 ThermoVacuum plant, and an end-user located in Sweden. Secondary data were collected from the Ecoinvent v3.1 and JRC ILCD databases.

Table 1: Life cycle inventory for 33,3 m² of ThermoVacuum, untreated, and preserved cladding.

			ThVacuum	Untreat.	Preserv.
from Nature	Water	kg	51,3		
from	Sawn wood, softwood, raw, kiln dried	m³	1,44		
	Sawn wood, softwood, planed, kiln	m³		3	1
	Electricity, low voltage {FR}	kWh	253		
	Transport, freight, lorry 16-32 metric	tkm	1152	67	67
	Planing	m³	1,30		
	Wood preservative, organic salt, Cr-	kg			10
Emission to air	Water	kg	46		
	10 substances	kg	9,8		
Waste	Waste water treatment	kg	25		
	Landfill of biodegradable waste (tar)	g	48		
	Waste incineration of untreated	kg	605	1350	450

Life cycle impact assessment

The impact assessment was performed with the ReCiPe v1.12 methodology processed by SimaPro 8.0.5. The results were normalized to compare the environmental impact of the representative surface cladding to the European reference impact. Figure 1 shows Untreated cladding dominates *Ecosystems*, the principal damage category, due to the impact of *agricultural land use*, because it uses 3 times the amount of wood than others claddings. Untreated cladding has a negative impact on *Human Health* and *Resources* through the recovery of energy and the avoided use of fossil resources on *Fossil depletion* and *Climate change* impacts. ThermoVacuum cladding damage categories are better than preserved claddings especially to *human health.*

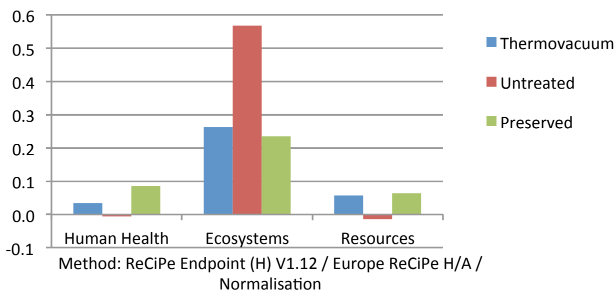

Figure 1: Damage category of ThermoVacuum, untreated and preserved cladding.

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Acknowledgments

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Life cycle assessment of a novel tannin-boron association for wood protection

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Keywords: LCA, Tannin-boron preservative, Landscaping materials, Treated timber, Low-environmental impact

Boron compounds remain in the wood preservation field and present many advantages. They are also readily leachable from modified wood and several methods have been studied to fix boron compounds for use in outdoor exposures (Obanda *et al*. 2008). Of these studies, associations between tannins and boron (TB) in the form of boric acid appear to be of interest. These TB associations allow the use of boron at very low levels (in compliance with EU restrictions, 2008/58/EC) and limit boron leaching which maintains biological resistance and fire retardant properties (Thevenon *et al*. 2009, Tondi *et al*. 2012). As a consequence, TB wooden products present an extended service life compared to boron compounds alone and were designed to be environmentally-friendly wood protection systems. Until now the TB products have been evaluated from a technical point of view and not for their potential environmental impact.

LCA's were performed on tannin-boron preservative products as well as several industrial preservative-treated timbers and concrete used in landscaping. Cr-containing inorganic salt and an alkaline copper quaternary preservative formulation, as well as concrete, have been used as referential materials to compare the environmental footprint with the tannin-boron treated system. A model was created with life cycle stages used to calculate inputs and outputs during raw material extraction, supplier transportation, manufacturing process, distribution, disposal transportation and processing. Tannin production data were based on Vieira *et al*. (2011). However, the extracted tannin in the extraction yield, the inorganic salt, and the process applied are not perfectly comparable with the extraction conditions industrially applied to Mimosa (Acacia mearnsii) extract which is the major constituent of the TB formulations. The latter is counter-current water extracted without any chemicals or with a limited amount of NaHSO3 or Na2SO3 (at 0.5 % to 1 %) at a temperature of 70 °C to 90 °C. Unfortunately, these parameters cannot be elaborated because there is no data available for the production of Na bisulphite or Na bicarbonate in the LCI data used. Other input data were sourced from the ecoinvent 3.01 database. The ReCiPe midpoint method was used to assess the environmental footprint and the CED method was used to summarise the energy-related environmental impacts in the life cycle.

The environmental factors assigned to the tannin extraction significantly impacted the impacts of the tannin-boron products (Fig.1). Overall, the results demonstrated that tannin-boron preservatives can be regarded as a low-environmental impact solution. However, the influential parameters of tannin processing at an industrial scale should now be further investigated seeing as a variety of different studies and opinions currently exist on this topic. Additionally, an economic analysis of developing of a commercially-viable tannin-boron preservative is needed.

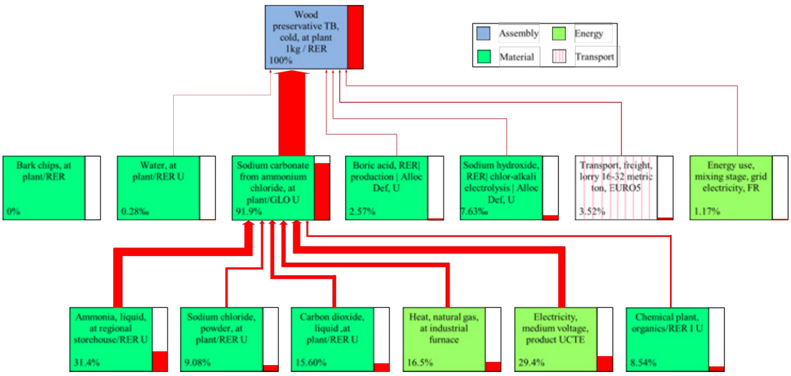

Figure 1: Dendrogram from SimaPro exposing the main contributions of TB process to global warming potential.

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Life cycle impacts of modified wood products

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Keywords: heat treatment, life cycle assessment, sawn timber, thermal modification

Wood is widely utilised in the built environment as structural and non-structural elements. Wood has excellent properties as a building material, however, some wood properties (dimensional stability, strength, and biological durability) are influenced by the surrounding moisture conditions, which may reduce the service life and increase the need for maintenance. In order to control the interaction of wood and moisture, different *wood modification* methods have been developed, thermal modification (also termed heat treatment) being the most widely spread and commercially utilised process.

Life cycle assessment is a coherent tool to identify environmental impacts through the whole life cycle of different products and can be observed in three aspects: economic, environmental, and social. From the economic view point thermally modified wood may be more expensive compared to non-modified timber due to increased processing and improved performance suited for a certain purpose. Environmental impacts may be greater in the manufacturing phase, however, the life cycle is expected to become longer and the need for maintenance is reduced due to the improved durability. The utilisation and/or production of toxic or harmful chemical compounds in the modification process should be avoided, which is not a problem with thermally modified wood as only heat and water vapour are added. However, some extractives are released during the modification process and may cause an increase of some environmental indicators. The recyclability of thermally modified wood should also be considered as one of the main factors and it is expected to be similar to non-modified timber, but the main difficulty in the recyclability of wood-based products are surface treatments, which include resins and metal fasteners that are often used in building. In order to make a meaningful analysis, the system boundary for modified wood products should always be the entire life cycle.

In the European context actual and updated environmental data is brought out through *environmental product declaration* (EPD) programmes. There are several national or field related programmes, as EPD-Norway in Norway, IBU EPDs in Germany, and Wood for Good in UK. EPDs are completed according to normative standards; general standard ISO 12025 and construction products related EN 15804 and ISO 91930. A short literature review based on valid EPDs is present in Table 1.

Table 1: Literature based comparison of cladding materials, production stage (A1–3)

	Unit	Sawn timber (pine) [1]	Sawn timber (softwood) [2]	Sawn timber (softwood) [3]	Heat treated sawn timber (pine) [4]
Density	kg/m^3	420	420	413	420
MC	%	15	15	15	5
PERE	MJ	2270	853	1330	2761
PENR	MJ	6850	1650	330	7697
GWP	kg CO_2 -e	-672	-679	-784	-258
ODP	kg CFC11 -e	0,00000551	0,00000000298	0,000000000497	0,0000461
POCP	kg C_2H_4 -e	0,0203	0,0486	0,0825	0,12
AP	kg SO_2 -e	0,339	0,612	0,242	2,12
EP	kg PO_4^{3-} -e	0,0752	0,106	0,0493	1,88
ADPE	kg Sb -e	0,0000948	0,00000781	0,0000142	0,000402
ADPF	MJ	623	1390	318	7794

Data sources 1) EPD-Norway 2) Wood for Good 3) IBU 4) EPD-Norway. Abbreviations: MC Moisture content, PERE Use of renewable primary energy, PENR Use of non-renewable primary energy, GWP Global Warming Potential, ODP Ozone Depletion Potential, POCP Photochemical Ozone Creation Potential, AP Acidification Potential, EP Eutrophication Potential, ADPE Abiotic Depletion Potential (Elements), ADPF Abiotic Depletion Potential (Fossil).

Based on these EPDs, a comparison between different products is difficult. Regarding energy consumption, primary energy increases by approximately 15% in heat treated timber compared to kiln dried sawn timber (EPD-Norway). The ThermoWood Handbook (2003) also reports a 25% increase in energy demand during the drying phase. Therefore wood modification should prolong the service life of the product to correspond (in minimum) to the increase in environmental impacts during production in order to make the modification environmentally meaningful. Emissions are always energy production related and cannot be compared directly. A more detailed comparison for whole life cycles of products would be needed more specific data and assumptions for the use stage.

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VOC emissions from linear vibration

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Keywords: flask method, formaldehyde, welding, wood

Wood welding is considered to be an environment-friendly technique that is a novel procedure for joining wood pieces with only wood itself (i.e., no adhesives) (Gfeller *et al*. 2003). The emission of volatile organic compounds (VOC) from welded wood during their service life has so far been neglected. The objectives of this study were (1) to determine and quantify the emission of VOC from welded beech wood, and (2) to study the effect of the initial moisture content (MC), i.e. the MC of the wood before the welding process, on the VOC emissions from welded products.

Experimental: Two clear samples of beech (*Fagus sylvatica* L.) with dimensions of 20 mm × 20 mm × 20 mm and 12 % MC were placed in the emission chamber for analysis. To study the impact of MC on the VOC emission, two pieces of the same dimension were prepared from saturated welded samples. Formaldehyde, acetaldehyde, and acetone/acroleine were the main compounds detected by high-pressure liquid chromatography (HPLC). Besides aldehydes and ketones, aromatic hydrocarbons such as furfural, toluene, and ethylbenzene in a variety of concentrations, were determined by gas chromatography–mass spectrometry (GC–MS).

Results: Formaldehyde, acetaldehyde and acetone/acroleine were the main compounds detected by HPLC. *Formaldehyde emission* from water-saturated specimens was lower than that of the dry-welded samples (Fig. 1).

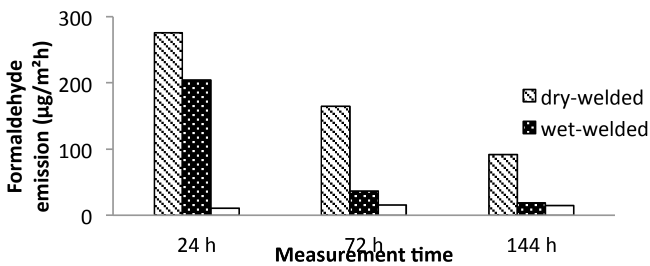

Figure 1: Dry-welded specimens had 12 % MC and wet-welded specimens were saturated in water for 24 hours [h]. Unwelded samples were used as a reference.

Acetaldehyde emission of the first day was 61 µg/m^{2}h for dry-welded specimens, which decreased to 23 µg/m^{2}h after 6 days (Fig. 2). The emission of acetone/acrolein for dry-welded samples decreased from 75 µg/m^{2}h to 41 µg/m^{2}h after 6 days (Fig. 3). Once again, the humidity reduced the acrolein/acetone emission. Furfural was one of the harmful VOC that showed very high concentration at 24 h, but its concentration decreased over time as shown in Fig. 4.

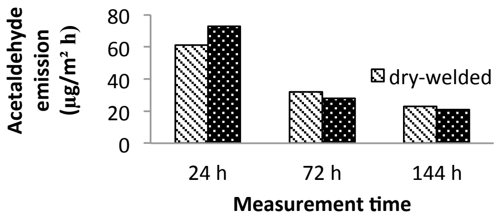

Figure 2: Acetaldehyde emission from welded beech specimens, as determined by the emission-chamber test for 6 days.

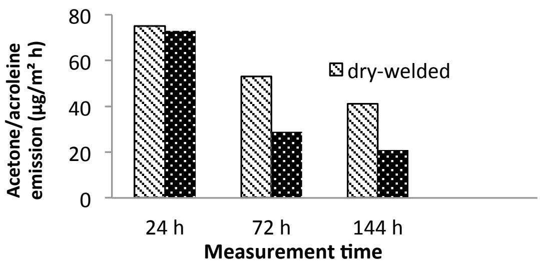

Figure 3: Acetone/acrolein emission from welded beech specimens, as determined by the emission-chamber test for 6 days.

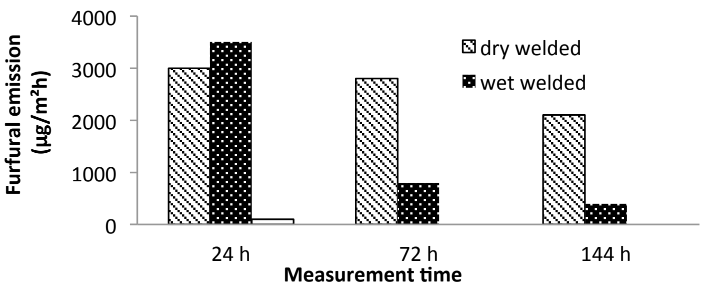

Figure 4: Furfural emission from welded beech specimens, as determined by the emission-chamber test for 6 days.

Conclusion: It was found that welded beech emitted significantly large amounts of aldehydes and ketones. The main VOC that emitted from welded wood at the end of the first day was: furfural (11000 µg/m^{2}h), formaldehyde (257 µg/m^{2}h), acetone/acrolein (75 µg/m^2 h), and acetaldehyde (61 µg/m^{2}h). High moisture content of wood could limit the emission of these VOC. Compared to wood based panels with emission from its entire surface, the welded wood samples produced a considerable amount of formaldehyde and furfural only from its thin weld-line and only during the first day. After 6 days these VOC emissions had decreased to low concentration to which one can be exposed without adverse health effects when welded wood is used indoor.

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Improvement of wood properties due to impregnation of wood with renewable liquids from different process residues of native origin

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Keywords: Wood modification, native resources, cell wall bulking, volumetric swelling, durability

Introduction

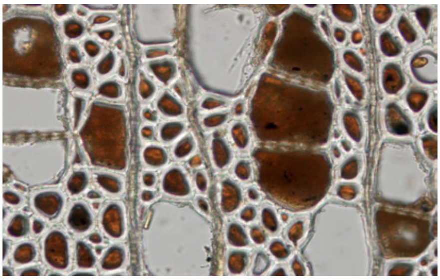
Wood modification treatments using non-toxic components are becoming more prevalent and are often used in place of biocides with negative environmental effects. However, many modification processes remain dependant, if only partly, on fossil resources. Wood modification processes, based on renewably sourced solutions, have a lesser impact on the environment and can be produced in a sustainable way (Ermeydan *et al*. 2012). The following investigations show first screening of started research project, carried out by the wood research group of Mendel University, Brno (Rademacher *et al*. 2014).

Material and Methods

- Swelling measurement: 10 samples of 14 x 14 x 28 mm^3 for each treatment
- Durability: 9 samples of 5 x 10 x 30 mm^3 (Bravery Test) for each treatment
- Production of liquid residues from thermal treatment (TT)-, Hydro-Thermal-Carbonisation (HTC)-, and pyrolysis-processes; impregnation to increase weight-percent-gain (WPG)
- Impregnation of Beech and Poplar sets of samples using vacuum 20 kPa/ 1 hour (EN 113)
- Concentrations: Pyrolysis 1:10; 1:2, original (1:1 = 100%); TT and HTC concentrated 10:1
- Conditioning, drying, volume/weight, leaching, bulking measurement following standards
- Durability tests: Bravery Test; fungi: *Trametes versicolor,* decay 6 weeks acc. to EN 113
- UMSP: UV-light absorption at 278nm, using Zeiss-UMSP 80 (Koch and Grünwald 2004)

Results and Discussion

WPG after impregnation was about 5 % to 8 % in case of hydrothermal carbonisation (HTC) and 10 % to 15 % with thermal treatment (TT) residues. Impregnation with pyrolysis liquids from Beech wood powder (liquefaction under heat and pressure) produced 40 % WPG in Beech and 60 % in Poplar (Fig. 1). After leaching, high amounts of TT and HTC solution were washed out, whereas Pyrolysis liquids stayed with 25 % to 40 % remaining in the wood. Despite higher wash out rates following the EN 84 leaching test, all treatments had a positive effect on the tested properties.



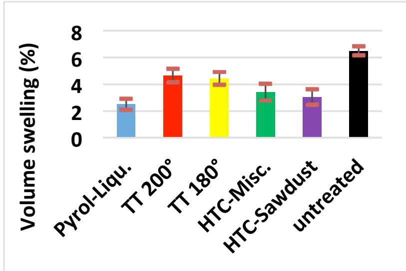
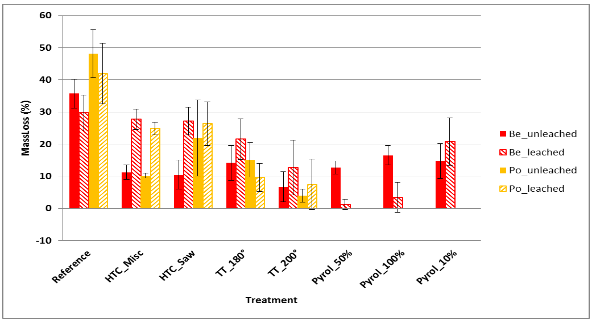


Figure 1: Pyrolisis-liquid impregnated Poplar.

Figure 2: Volumetric swelling of Poplar wood.

Volumetric swelling in 65 % relative humidity at 20 °C was reduced from 6.5 % in untreated poplar to 5 % in samples impregnated with process residues of thermal treatment at 180 °C or 200 °C. The processes using HTC liquids from *Miscanthus sp*. (Misc.) or sawdust showed reduction to 3.0 % to 3.5 % and Pyrolysis liquid treatment to 2.5 % (Fig. 2). The mass loss of untreated Beech (30 % to 35 %) and Poplar (40 % to 50 %) was reduced to 2 % with Pyrolysis, and 4 % wth TT-treatment, depending on wood species and process (impregnation or leaching) (Fig. 3). Attendant bulking tests and UV scans prove the high inclusion of phenolic compounds in cell walls (Fig. 4).



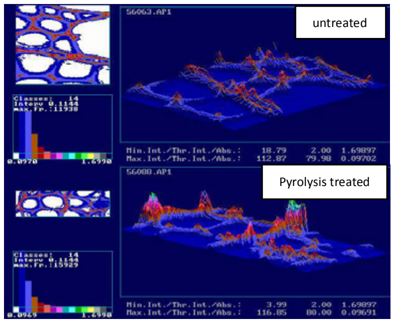


Figure 3: Mass loss of Beech (Be) and Poplar (Po) samples due to fungi decay.

Figure 4: UMSP-Scans of untreated Bravery and treated poplar fibers.

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Acknowledgments

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Development of a continuous wood surface densification process with a reduced environmental impact

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Keywords: roller pressing, wood modification, wood compression, thermo hydro mechanical processing

Surface densification has the potential to greatly increase the hardness of the outer parts of wood materials. This increases the value of low-density species, such as Scots pine and Norway spruce, which are largely found in boreal forests. The density, strength, and hardness of these species are lower than those of commonly used hardwood species such as oak, and the use of these species is rather limited in applications such as flooring and table tops. Through densification, a significant improvement in the mechanical properties can be achieved, thereby opening new fields of application.

The state of the art in the field of surface densification is well described by Navi & Sandberg (2012), Rautkari (2012), and Laine (2014). Recent studies in wood surface densification have focused on processing parameters and their effect on the properties of the densified wood. Laine *et al.* (2013a) examined the effects of compression temperature and press closing time on the hardness of surface-densified Scots pine. Rautkari *et al.* (2013) investigated the effects produced from varying degrees of densification. The thermodynamic characteristics of surface-densified Scots pine have been studied by Kutnar *et al.* (2012).

An important aspect related to densified wood is how to eliminate the set-recovery after pressing, especially when the densified wood is exposed to variations in moisture. Rautkari *et al.* (2010) observed complete set-recovery of surface-densified spruce and beech without any post-treatment (e.g. heating) of the densified wood material. Gong *et al.* (2010) were able to reduce the set-recovery of densified wood by a post-treatment involving steam injection. Laine *et al.* (2013b) used a combination of steam injection at 200°C and drying with hot air. A common feature of all these processes is the long treatment time, where the thermal treatment process exceeded 4 hours even with small laboratory specimens.

In recent research, only limited focus has been put on the economic and environmental aspects of the densification process. Rautkari (2012) studied three different surface densification approaches, two of them using an ordinary heated press and one adapting a friction welding technique. All surface densification processes are time-consuming batch processes, where a post-treatment stage is necessary in order to reduce set-recovery. This means that low value wood species become not only high value products but also high cost products, eliminating their potential advantage over inherently more expensive and harder wood species such as oak, beech, or tropical woods.

The objective of the research project proposed by Luleå University of Technology is the development of a continuous wood-surface-densification process, the aim being to shorten the process time and to lower the energy consumption in order to reduce the costs and environmental impact.

The first stage of the project focuses on determining the validity of the existing batch process parameters in the context of a continuous wood-surface-densification process, the purpose being to evaluate whether an economic, continuous surface-densification process is feasible within the process parameter limits found in the literature.

Thereafter, the focus will be on optimizing the process on a laboratory scale and improving its robustness. There is however, a realistic risk that the current batch process approach cannot be transformed into an economically feasible continuous process, in which case, further experiments will focus on reducing the process time by other wood modification means, such as impregnation. Inoue *et al.* (2008) presented an interesting approach in this context.

The later stages of the project will focus on transforming the laboratory process into an industrial process, and on evaluating the environmental impact of the process. For this purpose, it will be necessary to evaluate the process from both an economic and an environmental perspective, including the creation of an environmental product declaration (EPD).

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Primary analysis methods used to control thermal treatments of wood and its effect on decay resistance

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Keywords: Thermal treatment, mass loss, durability, prediction methods, quality assessment

Heat treatments used in wood processing are becoming increasingly popular due to their non-biocide nature and low environmental impact. This type of treatment is based on biopolymer chemical degradation by heat transfer. This process primarily improves the dimensional stability and decay resistance of wood (Tjeerdsma *et al*. 2000; Korkut *et al*. 2012). Wood becomes darker after this type of treatment altering its aesthetic appearance. These improvements and changes come at the expense of wood's mechanical properties which are often weakened (Dilik and Hiziroglu, 2012). These modifications have been extensively studied and researches have shown that heat treated wood properties are correlated to the heat treatment conditions and to the industrial process used. Recent works have focused on improving our knowledge of wood thermal degradation reaction mechanisms, modelling, quality prediction, and quality control. For example, the most efficient indicator of the treatment efficiency is the mass loss of wood due to its thermal degradation. It also remains important to develop inexpensive, fast, and non-destructive industrial methods to control the process and predict heat-treated wood quality. These different analysis tools also aim to have a reliable quality assessment tool ensuring good material decay resistance and ultimately to commercialize products which could be certified by an accredited organization.

This paper describes recent studies and synthesizes the major publications to better understand wood thermal modification and to develop control and prediction of new features brought to heat treated wood. Several studies have investigated non-destructive control methods appropriate for industrial application. Colour tests are used to determine the durability of heat treated wood, but this sort of method is not precise or efficient enough to account for the variability in wood or treatment heterogeneity (Johansson and Morén, 2006). Spectrum analyses such as NIR or FT-IR are able to give information on the extent of processing (by estimating mass loss) and on properties relevant to wood modification and heat treated wood (e.g. equilibrium moisture content, dimensional stability, and decay resistance) by using a unique spectrum of the solid surface of a heat treated wood sample (Esteves and Peireira 2008; Altgen *et al*. 2012; Sandak *et al*. 2015). The acquisition of NIR spectra can be done quickly and easily on a solid surface using a fibre probe and spectral data processing can be done immediately afterwards. This type of methodology has good potential for process and product quality control once models have been calibrated and validated for the wood species studied. More recently, utilization of mechanical testing on wood before and after a thermal modification process (non-destructive methods, such as BING®) could allow quick and easy acquisition of resonant frequency spectrums to estimate the heat treated wood properties (Welzbacher *et al*. 2007; Hannouz *et al*. 2012). Finally, utilization of wood kinetics based on a reference area is easily achievable at an industrial scale using a heat treatment device which allows for dynamic recording of wood temperature throughout the process (Candelier *et al*. 2015).

Due to differences of chemical composition and anatomical structure between untreated and heat treated woods, it is necessary to use other quality characterization methods for modified and unmodified wood.

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InnoRenew CoE - Renewable Materials and Healthy Environments Research and Innovation Centre of Excellence

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Keywords: Renewable materials, built environment, human well-being, innovation, living laboratories, ergonomic design

A consortium lead by the University of Primorska was awarded a grant by the European Commission under the Horizon 2020 Widespread 2015 Teaming grant instrument to develop a Center of Excellence in cooperation with an advanced partner from a high performing and complementary institute elsewhere in Europe. The purpose of the grant is to increase innovation excellence in Europe in general, especially in member states underperforming in innovation. The advanced partner, the Fraunhofer Institute for Wood Research – Wilhelm-Klauditz-Institut, serves as a "tutor" to support the development of the new Center. Seven other Slovenian institutes and research groups are part of the consortium that will develop the new Renewable materials and healthy environments research and innovation centre of excellence (InnoRenew CoE). This partnership brings together expertise from a wide variety of disciplines including health, information technology and computing, engineering, construction, urban development, renewable material use and management, and sustainability. The InnoRenew CoE will built upon the group's diverse expertise to bring Slovenia to the forefront of the European construction and renewable materials sectors by developing new, smart, sustainable and modern built environments for all generations. The new CoE will pursue original research, provide research, development and innovation support to the industry and undertake an extensive outreach project to promote the use of renewable materials in sustainable development (Fig. 1)

With excellence in research, innovation, and application into economy and society, the new Centre of Excellence InnoRenew CoE will improve sustainable building practices by combining the existing concepts with the Restorative Environmental Design (RED) paradigm, which combines sustainable building practices with biophilic design. This will increase the competitive advantage of the affiliated renewable resource-based construction industry, and create innovation and market pull for RED-based materials and products. Consequently, innovation and market pull for material recovery, and higher added value renewable resources will be initiated. Research and development activities will seek the optimal intersection of performance and sustainability, including economic, environmental, and societal indicators. With support and guidance from the advanced partner, Fraunhofer WKI, scientific research and development activities will be transferred profitably and efficiently to the industry and through them to society in the form of innovative new products and processes.

Figure 1: Schematic presentation of the InnoRenew CoE concept – to convert scientific, fundamental and applied, research excellence into value added innovations.

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InnoRenew CoE http://www.innorenew.eu/en/ (accessed August 1st 2015)

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Advancing LCA application in the wood sector

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Keywords: consequential LCA, attributional LCA, wood sector

Life cycle analysis (LCA) has become a popular tool in the wood sector particularly because of the heightened need to better articulate the environmental superiority of wood over substitute materials in the construction sector (Cabeza *et al*., 2014). A large number of studies across the world have been conducted to compare the environmental performance of wooden buildings (and building components) with those made of alternative construction materials. Recent studies have indeed provided us with important insights yet there are at least two areas that remain under explored.

First, the majority of the studies have adopted what is known as the attributional life cycle analysis (ALCA) approach, while the alternative consequential life cycle analysis (CLCA) is considered by only a handful of studies (Buyle *et al*., 2014). Both approaches have their relative advantages and disadvantages and address very different research questions. This presentation will draw a distinction between these two approaches and highlight the type of questions that each approach can address in the wood sector.

Second, research has not adequately dealt with corporate adoption of LCA in the wood sector. In an attempt to ameliorate this shortcoming, this presentation will discuss how and why corporations adopt specific environmental benchmarks and how LCA adoption can be increased in the wood sector.

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The use of modified wood in Slovenia

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Keywords: heat treated wood, timber housing, claddings

The use of wood as a building material is increasing due to increasing awareness of its mechanical and ecological properties. New processes were developed to improve some properties of wood and wood composites without diminishing its environmental impact.

Heat treatment is a process used to modify the properties of wood. It improves its dimensional stability, resistance to biological attack, and thermal performance by exposing wood to elevated temperatures ranging from 160 °C to 260 °C with different procedures (Militz 2002, Hill 2006). Thermal treatment avoids the use of wood preservatives and represents an attractive "non biocidal" alternative to classical preservation treatments and broadens the usage of non-durable local species in place of more durable (imported) species. Modified wood is ideal for use as a cladding, terrace flooring, railings, windows, doors, and anywhere wood is exposed to the environment, but not loaded. In Slovenia there are two manufacturers of the thermally treated wood: Silvaprodukt d.o.o. Ljubljana, and I-les Iskra d.o.o.

Silvaprodukt uses a process they developed and patented and trades its product as *Silvapro wood*. The process uses a special modification chamber, where modification starts with an initial vacuum phase. This provides a low-oxygen inert atmosphere during modification and reduces wood degradation at elevated temperatures. The chamber capacity is 4 m³ and the treatment time per cycle is from 18 to 36 hours, depends on the thickness of wood and desired treatment temperature (170 °C to 230 °C). The annual output is around 1,200 m³.

The other manufacturer, I-Les, uses Wood Treatment Technology's (WTT) process. The chamber capacity is around 4 m³ and uses treatment temperatures around 160 °C to 180 °C. The processes differ in number of steps of modification, temperatures, duration, pressures, and conditioning at the end of the process.

The choice of facade cladding and its design has typically been made using past experiences and solutions that were proven to withstand the local climate. In modern houses new designs and materials are used and environmental impact is increasingly a concern. Thermally treated wood is a new cladding option due to its improved properties.

Case study: The Tango House in Ljubljana, Slovenia

This well-planned low-energy house is artistically rich, small but spacious and rather monumental; it stands on piles similar to those used by pile-dwellers. The living spaces are located in the part that looks like a house. The owners are avid tango dancers, so the lower annexed part is reserved for a home dance studio, which continues into the living area through a wide door. The living area is characterized by an in-ground hot tub, which opens to views of the fireplace in the corner, the dance hall, and the stove. Materials were selected for their timelessness. The facade cladding is made of thermally treated spruce planks. The exterior will take on a silver/grey patina with age, but won't change much otherwise. The part of the facade between the large glass surfaces facing the garden features a blackboard intended for temporary graffiti. The piano keys incorporated into the upper facade cladding signal the spirit of this house (Fig. 1-2).

Figure 1: Ground floor and elevation (Architecture | Boštjan Debelak, Structural engineer | CBD d.o.o., Energy efficiency | low-energy, Surface | 142 m^2 Site area | 548 m^2 Construction system | solid timber Xlam construction, House technique | water-to-water, heat pump, floor heating, open fireplace

Figure 2: The modern architectural basis of this wooden structure is reflected primarily in the choice of materials and direct communication with nature.

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Experimental characterization of the mechanical performance of wood in a controlled environment: use of acoustic emission to monitor crack tip propagation

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Keywords: Acoustic emission, clustering, data mining, probability of detection, wood material

Monitoring material damage by means of acoustic emission lies in the ability to identify the most relevant descriptors of cracking mechanisms. The sudden release of stored energy during the damage process, known as the acoustic emission (AE), is a very suitable technique for in situ health monitoring applications.

In the present study, a tensile test is performed on a DCB (Double cantilever Beam) wood specimen (Figure 1) to generate mode I cracking. The AE events recorded during the tensile test are correlated to actual damage in terms of cracking length.

Various signal processing and pattern recognition techniques have been performed for damage feature extraction from AE signals. In this study, the Hilbert–Huang transform (HHT, Huang 2005) is used, for relating a specific damage mechanism to its acoustic signature. The applicability of the HHT based on damage descriptors of AE signals is discussed (Hamdi, 2013). First, the HHT is used to identify the damage signature by correlating the measured AE signals with known acoustic sources. Then, the performance of the HHT for damage propagation monitoring is evaluated.

These post-processing steps aim at both identifying the failure mechanisms of wood materials and detecting the early warning signs of crack propagation within the material. Finally, the effectiveness of the AE measurements is evaluated in terms of the probability of detection.

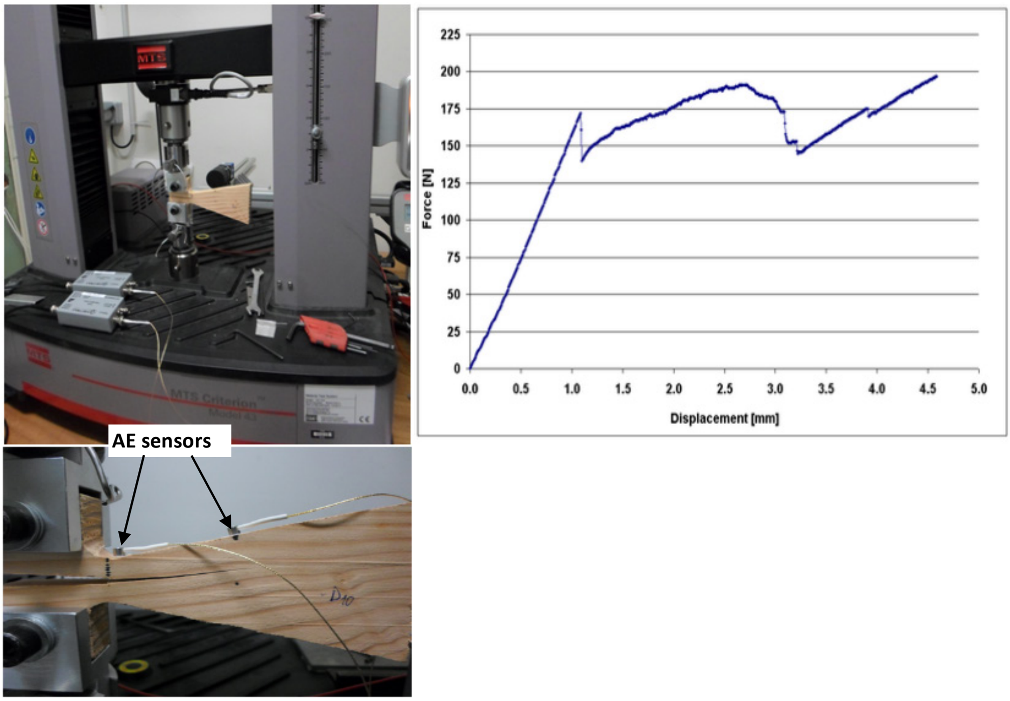

Figure 1: Acoustic emission experimental setup and mechanical result.

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Effect of natural weathering and accelerated aging on *Pinus* sp.

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Keywords: finishes, colour, roughness, wood technology

Wood is susceptible to adverse weather conditions that cause degradation through mechanisms like photo degradation. This causes surface cracking and modifies wood's properties and durability while in service. This study aimed to evaluate two methods of wood exposure in the extreme south region of Brazil where the climate is classified CFA (humid subtropical Mild) without a dry and hot summer season.

This study compared accelerated and natural weathering methods and characterized the changes of wood with various surface coatings compared to raw wood. Wood (Pinus sp.) from Brazil was evaluated for roughness, colour, and weight loss after natural weathering and accelerated aging.

The boards were dried in a climatic chamber until they reached a constant weight and were then flattened and cut in the laboratory. 15 specimens (150 mm x 95 mm x 25 mm) were created. Five specimens were treated with spray paint (bright white, Finish 1), five were treated with synthetic enamel ink (bright white, Finish 2), and five specimens were untreated controls. Both coatings were applied according to the manufacturer's guidelines and dried for 72 hours before being analysed according to ASTM G154. A standard cycle of 12 hours was comprised of exposure to 8 hours light at 60 °C, 25 minutes of condensation at room temperature and no light, followed by 3.35 hours of condensation at 50 °C. Measurements were made at the beginning and after 240 hours. For the natural weathering specimens, colorimetric and roughness measurements were performed at the beginning and after 180 days.

The data collected (Fig. 1, Table 1) from accelerated weathering for 240 hours of exposure is similar to the data collected in natural weathering for 180 days of exposure. The samples used were taken from the same region of the log, limiting confounding variables such as density or the porosity of the wood.

The surface roughness was changed with the coating application. For both methods the aging of the treated samples showed less variation in surface roughness as compared with the control.

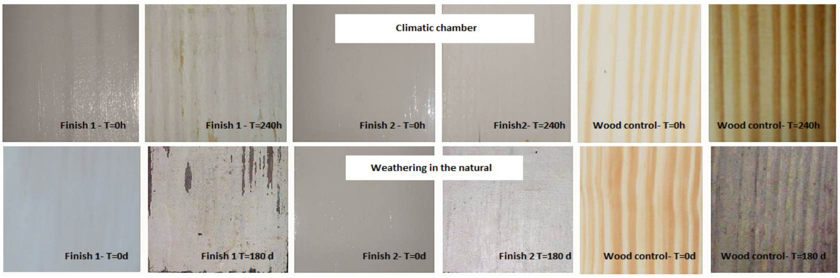

Figure 1: Colour changes of wood of *Pinus* sp. exposed to two weathering treatments. Two finishes are compared with control specimens.

In the colorimetric assay it is observed that the samples showed similar behaviour for the L * and b * parameters in both natural and accelerated weathering treatments (Figure 2). After 240 hours of exposure in the climatic chamber the photo degradation was similar to the 180 days of natural weathering. Only the parameter a* showed different results.

Table 1: Roughness changes of wood of *Pinus* sp. exposed to natural and accelerated aging.

	Average Roughness Ra (µm)			
	Weathering in the natural (days)		**Climatic chamber (hours)**	
	0	**180**	**0**	**240**
Finish 1	2.46	8.07	2.77	8.51
Finish 2	2.52	3.88	2.82	4.13
Control wood	4.99	13.92	4.92	9.98

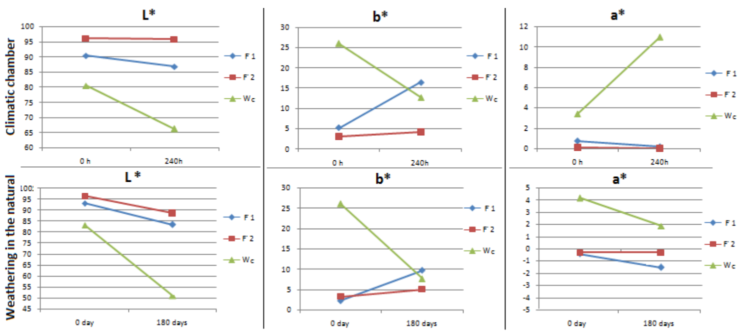

Figure 2: Colour changes of parameters L*, a* and b of *Pinus* sp. wood with different finishes.

The results of the 240 hours accelerated aging test showed a similar photo degradation compared to natural exposed wood (180 days). This study revealed that accelerated weathering are satisfactorily similar results to natural weathering in southern Brazil.

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Characterisation of interactions between thermally modified wood and water

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Keywords: thermal modification, water uptake, laboratory tests, field test, moisture content

Thermal modification of wood is one of the most important modification processes. Properties of this material predominately depend upon the modification process, temperature of modification and its duration. Mass loss during modification is one of the parameters that characterise the modified wood. In general, higher temperatures and longer modification processes result in higher mass loss. Thermal modification results in improved durability. The reasons for increased durability can be attributed to the lower equilibrium moisture content, better dimensional stability and formation of new toxic compounds. In recent research another aspect has drawn considerable attention, namely water exclusion efficacy. Although the importance of this parameter has been identified in the new edition of the EN 350 (2015) durability standard, there is still not an optimal method developed for elucidation of this parameter. The aim of this study was to compare various water uptake techniques with field test methods.

Specimens were made of Norway spruce heartwood. Two types of the specimens were prepared. 2.5 cm × 5.0 × cm × 50 cm (EN 252 size) and 1.5 × cm × 2.5 cm × 5.0 cm (EN 113 size). They were thermally modified at seven temperatures: 25 °C, 160 °C, 180 °C, 190 °C, 200 °C, 210 °C, and 230 °C. The modification duration was three hours. The process was performed following Rep and Pohleven (2004). Mass loss of the specimens was determined gravimetrically. Four were sets of tests performed. In the first set EN 252 sized samples were soaked in water for periods between 8 h and 4 days and were then positioned on load cells (HMB load cells, PMX amplifier, Catmaneasy recording software) and were allowed to dry until a constant mass was reached. In the second experiment, short term water uptake was determined with a tensiometer (Krüss) as described by

Lesar and Humar (2011). In the third experiment, load cells were transformed into a simple tensiometer. Specimens were positioned in contact with liquid water and their mass was monitored for a few days. In the last set of experiments, water exclusion efficacy was verified during the outdoor procedure. The mass of the horizontally oriented samples was continuously monitored for 100 days.

During short term water uptake there is evidence that thermally modified specimens uptake less water than the untreated control specimens, but the difference is not significant. Long term wetting results indicate that heat treated specimens retained considerably less water than control specimens (Figure 1). Similar results were observed during outdoor tests as well confirming that short term uptake is an indicative method. As short term measurements were performed on axial surfaces only, these measurements do not reflect the overall performance of wood. We believe that the long-term water uptake method is more predictable than the short term method.

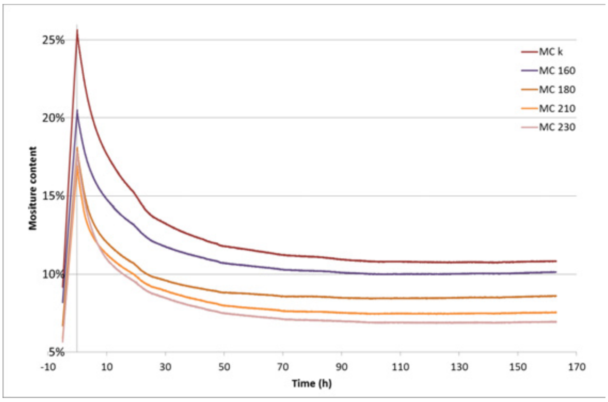

Figure 1: Drying of the thermally modified specimens in indoor conditions. Specimens were mounted on load cells.

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Study of interactions between PVAC adhesives and wood after thermo-mechanical (TM) modification

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Keywords: veneer, PVAC adhesive, densification, wettability, work of adhesion

Veneers are one of the main decorative materials used in the furniture industry and interior design. These veneers can be enhanced using modification techniques to create modified veneers characterized by improved dimensional stability and interesting colour schemes affecting the visual qualities (Bekhta *et al*. 2014). One of these techniques is thermo-mechanical (TM) modification (Kutnar and Šernek 2007). Industrial experience shows that TM modification has an impact on the process of edge veneering and formation of the glue lines affecting their relationship: substrate-adhesive-veneer. The phenomenon of wettability plays an important role in the technological process associated with creating glue connections. For evaluation this parameter the value of the contact angle (Θ) is commonly used. Contact angle is an important parameter required for the analysis of phenomena occurring at the border of contact veneer-adhesive-on the basis of Young-Dupré equation (Bekhta *et al*. 2015; Liptáková and Paprzycki 1983). In this work tests results of the impact of thermo-mechanical processing parameters on the formation the wettability of beech veneer (*Fagus sylvatica* L.) and pine veneer (*Pinus sylvestris* L.) and indicators determined based on the adsorption theory of surface interactions such as surface free energy (γ_s) and work of adhesion (Wa) is presented.

Rotary cut veneer sheets of pine wood with dimensions of 300 mm by 300 mm by 1.5 mm and with MC of 5 % were chosen for the experiments. Tangential sheets of veneer have been cut in 150 mm by 100 mm rectangular pieces for TM densification process and subsequent measurements. Each veneer was thermo-mechanically densified between the smooth and carefully cleaned heated plates of a laboratory press at temperatures of 150, 180, and 210°C and pressure of 3 MPa. Samples were densified for 3 minutes. For experiments three commercial unmodified PVAC adhesives, based on EVA copolymers and catalysed with isocyanates (EPI), were used. For all tests adhesive was applied with the applicator on the modified surface of veneers at thickness of layers of 120 µm. The dynamic Θ angle of unmodified veneers and TM sample veneers were measured with PG-3 goniometer using distilled water as the wetting liquid. A drop of water with a volume of 3.5 ml was applied on veneers by integrated micro-dispensing pump. After 60 seconds (s) of contact with the substrate, the camera recorded its behaviour. The Θ angle, the drop volume, and the diameter of the base were measured. The measurements and theoretical formulas

(γ_S, Wa, γ_{SL}) were used to calculate dispersive and polar components. All included in the experiments bonding agents were characterized by high values of Wa (Table 1), exceeding the level of 100 mJ/m^2, which is a very positive result. For beech and pine wood Wa ranks in the range of 109 to 125; 105 to 124 mJ/m^2 respectively. Most preferred relationships were obtained for the EVA adhesive.

Table 1: Effect of temperature modification of veneers on Wa PVAC adhesives

Kind of wood species	Kind of adhesive	Temperature of TM modification [°C]	Time [s]			
			5	10	30	60
			Work of adhesion [mJ/m^2]			
Beech wood	Non modified	control	109,10	111,50	112,75	112,93
		150	113,72	114,84	115,61	116,53
		180	115,94	116,28	116,86	117,83
		210	117,02	117,02	117,59	118,78
	EVA	control	125,23	129,00	132,85	133,34
		150	128,46	130,68	133,34	133,70
		180	127,78	131,28	133,08	133,94
		210	128,84	131,15	133,55	134,13
	EPI	control	116,96	117,05	118,38	119,58
		150	113,98	114,07	115,94	118,07
		180	116,69	116,69	118,31	119,17
		210	116,19	117,18	119,64	120,78
Pine wood	Non modified	control	105,81	106,43	107,15	108,67
		150	117,85	117,85	118,64	120,01
		180	119,24	119,24	119,75	120,43
		210	125,02	125,61	126,04	127,18
	EVA	control	124,19	130,00	132,40	133,09
		150	127,73	132,61	135,89	136,45
		180	128,79	132,61	136,29	136,86
		210	130,00	133,56	136,29	136,86
	EPI	control	116,96	117,05	118,38	119,58
		150	117,59	117,68	118,72	119,58
		180	120,51	120,68	121,34	122,95
		210	120,68	121,58	124,49	125,61

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Tests to increase preservative retention in fir

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Keywords: Retention, fir, liquid nitrogen

Wood is a material which is used in almost every area of daily life by mankind, including building materials, decorations, and landscaping. When exposed to outdoor weather conditions, non-pressure treated wood has a service life 70 % - 80 % less than treated wood. This is even the case with naturally resistant wood species. When using fast-growing, commercial wood species that are used in outdoor applications, they are most often pressure treated with a wood preservative. In an attempt to improve preservative treatment retention in spruce and fir, specimens were impregnated with liquid nitrogen (-190 °C) along with the wood preservative using pressure. Using liquid nitrogen as a carrier significantly increased the amount of preservative retention.

Analysis of neutral axis position in thermally modified wood using DIC

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Keywords: neutral axis, DIC, thermal modification, bending

Thermally modified timber (TMT) has been long recognized as an efficient and eco-friendly alternative to tropical species and wood treated by other techniques. Nevertheless, the range of feasible applications for TMT is limited by undesired side effects, such as reduction of mechanical properties. For a material, it is important to know the location of the neutral axis (NA). The NA can be successfully located by means of the full-field optical techniques. It is hypothesized that thermal modification affects the tensile and compressive wood stiffness parallel to the grain on a different level, so the location of the NA changes. Therefore, this paper aims to obtain the full-field axial strains by the optical technique applying the principles of the digital image correlation (DIC) for the NA localization in thermally modified wood loaded by the three-point bending.

The samples were cut from untreated and differently thermally modified (180 °C and 200 °C) wood of the European beech (Fagus sylvatica L.) as clear orthotropic blocks with dimensions of 14 mm × 14 mm x 210 mm (radial (R) x tangential (T) x longitudinal length (L)) meeting the requirements of the BS 373 (British Standard Institution 1957). Before the sampling, all source material was conditioned in a climate chamber at 20 °C and 65 % relative humidity until the equilibrium moisture content (EMC) was reached. The three-point loading of the samples in the tangential direction was carried out using the universal testing machine, Zwick Z050/TH 3A equipped with a 50 kN load cell. The deformation induced in the samples was determined by the full-field optical stereovision system consisting of two CCD cameras. The system was calibrated to an area of interest (AOI), which was 210 mm × 14 mm. The images were captured every 0.25 seconds (4 Hz) and synchronized with the applied force. The strain fields at the AOI from the partial derivatives of the displacement using Lagrange notation were calculated in Vic-3D (Correlated Solutions Inc.).

RESULTS

Fig. 1 shows that the variation in the zero axial strain position (i.e., NA location) within the sample height increased as the distance from the loading point at the midspan increased. This is attributed to the decreasing axial strain towards the ends of the sample. This is apparent as the density of axial strain contours decrease. As a consequence, the proportion of the noise related to the strain values increased and the NA location became increasingly distorted, if the constant noise throughout the AOI is taken into account. However, the NA was located at approximately half the height of the sample cross-section for all types of treatments. Based on the existing results, the following can be concluded; the thermal modification did not result in a change of the NA location.

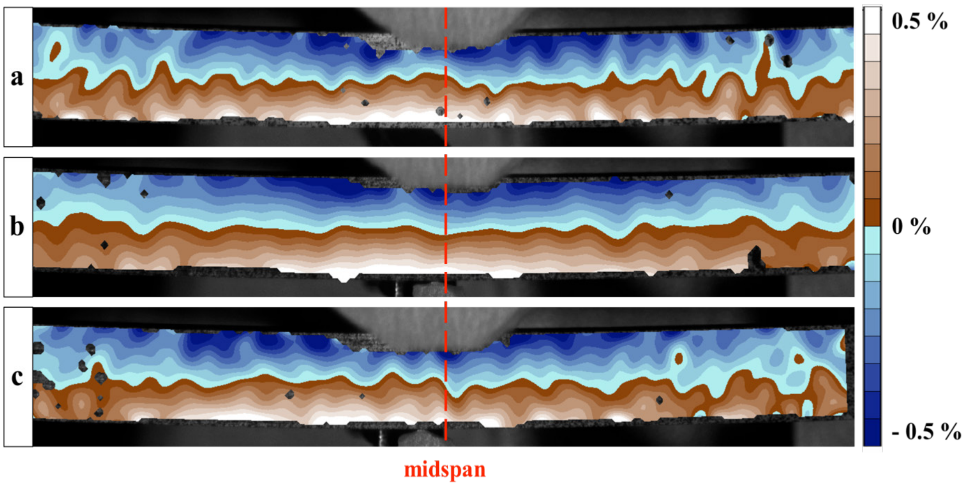

Figure 1: Axial strain plots before the failure of European beech a) untreated; b) thermally modified at 180°C; and c) thermally modified at 200°C.

Acknowledgments:

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Decay resistance and physicochemical properties of wood preservatives based on extractives from *Ocotea acutifolia* leaves

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Keywords: antifungal activity, natural compounds-based products, wood preservative

The toxicity of copper components on wood preservatives propels the search for chemical free alternatives products. The aim of this study is to evaluate the decay resistance of some low impact extracts from a native Brazilian tree, *Ocotea acutifolia* Nees (Mez) against wood-rot fungi. Leaves of *O. acutifolia* were collected in a rural area in the South of Brazil (at 29°37’ S; 53°52’ W; 203-207 m), dried at room temperature, and milled. Subsequently, powdered leaves (970 g) were extracted by Soxhlet and ethanol obtaining 90 g of ethanolic extract. This extract was dissolved in water and fractionated by consecutive liquid/liquid partition by chloroform, ethyl acetate, and butanol (Egua *et al.* 2014). Physicochemical characterization (thermogravimetric analysis, antioxidant activity, flavonoid, and total phenolic contents) of the obtained fractions (butanolic and ethyl acetate) were conducted. Furthermore, two different concentrations (1 % and 4 %) of extractives of *O. acutifolia* leaves were dissolved in ethanol and superficially impregnated (immersion by 20 h) on downy birch laminated wood (*Betula pubescens* Ehrh.). Afterwards, the treated wood samples were placed in contact with the fungal agent (*Trametes versicolor* L.) on potato dextrose agar medium (PDA) and incubated at 23 °C ± 2 °C and relative humidity of 60 % ± 5 % until the control samples presented 10 % weight loss. All characterization and assays were compared with unfractionated ethanolic extract (crude extract). The results in Table 1 showed significant differences in relation to the amount of phenolic and flavonoid compounds between fractions and crude extract.

Table 1: Comparison of DPPH assay and polyphenols from *O. acutifolia* leaves extracts.

Sample	IC_{50} DPPH scavenging^a [mg extract/mL]	Flavonoid content^b [mg QE/g]	Total phenolic content^c [mg GAE/g]
Crude extract	1.10 ± 0.08 C	83.94 ± 1.98 C	178.75 ± 12.95 C
Butanolic fraction	0.55 ± 0.03 A	112.43 ± 1.87 B	405.09 ± 16.79 A
Ethyl acetate fraction	0.74 ± 0.07 B	178.93 ± 1.03 A	360.04 ± 16.19 B

[a]*Effective concentration of sample required to 50% scavenge of DPPH radical by probit analysis,* [b]*Expressed as quercetine equivalent,* [c]*Expressed as gallic acid equivalent. Uppercase letters in the same column refer to means statistically different by Tukey test (P < 0.05). Results are exhibited as mean ± standard deviation.*

The lower phenolic and flavonoid contents on crude extract could be explained by the presence of impurities such as organic acids, which can interfere with the determination of the chemical composition (Chirinos *et al*. 2007). The butanolic fraction exhibited the most effective DPPH scavenging capacity, followed by ethyl acetate fraction and crude extract. According to Dudonné *et al.* 2009, the presence of phenolic compounds in the plant contributes strongly to their antioxidant ability. Following the TGA analysis, the first step of decomposition in all extracts corresponded to dehydration (<180°C). In crude extractives, the degradation process occurred at 250°C and at 400°C, while the fractions showed a main step approximately at 300°C (Fig. 1). This difference may be due to decomposition of crude extractives in different fractions of compounds (Ross *et al*. 2009). The results of decay test are ongoing, but as a preliminary report the antifungal activity found in the impregnated samples is related to the presence of phenolic compounds in the *O. acutifolia* leaves extracts.

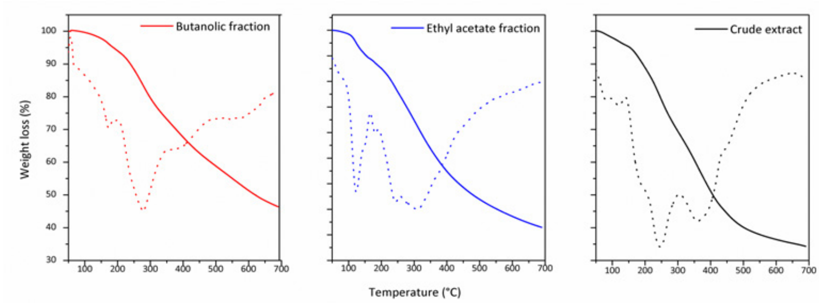

Figure 1: Thermogravimetric analysis of *O. acutifolia* leaves extracts.

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Effects of bio and epoxidised oil on physical and biological properties of treated wood

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Keywords: Decay resistance; epoxidised oil; bio oil; physical properties

Wood materials have been preferred for indoor and outdoor applications for many centuries because wood is a natural, renewable engineering material with unique properties. However, wood materials are susceptibility to decay, insects, termites, and fire, anisotropic and hygroscopic. These undesirable properties of wood materials may be improved by different modification methods (Mohan *et al*. 2008; Temiz *et al*. 2013a; Temiz *et al*. 2013b). In the last decade, different types of oils such as linseed, palm, soybean, sunflower, and other bio-oils have been investigated by several researchers for wood treatments due to the potential health and environmental hazards of wood preservatives containing heavy metals (Temiz et al. 2013b). Chemically modified oils and bio-oils have received much attention for wood treatment in the recent years (Temiz *et al*. 2013a; Temiz *et al*. 2013b; Panov and Terziev, 2015; Jebrane *et al*. 2015a; Jebrane *et al*. 2015b).

In this paper, the effects of bio-oils obtained from heat treatment processes, from pyrolysis of annual plants and epoxidised oil on physical and biological properties of wood materials were summarized based on previous studies published in some journals.

The effects of bio and epoxidised oils on water absorption and tangential swelling

The previous studies results showed that the water absorption percentage of wood treated with 20 % bio-oil obtained from a pyrolysis process at 450 °C to 525 °C for 30 min was lower than that of unmodified wood. While water absorption values of control groups showed an increase from 63 % to 89 %, that of wood samples treated with 20 % bio-oil ranged from 31 % to 71 % after 48 h of exposure in water. In order to decrease the water absorption values of bio-oil treated wood, samples were treated with epoxidised linseed oil (ELO) following bio-oil treatment. The secondary treatment of bio-oil with ELO significantly reduced the water absorption from 71 % to 37 % (Temiz *et al*. 2013a). In another study, the water absorption percentage of wood samples treated with 20 % bio-oil obtained from a commercial heat-treatment plant in Turkey was decreased to 43 %

while that of an unmodified group was 75 % after 48 h water exposure. A secondary treatment of bio-oil with ELO significantly reduced the water absorption from 43% to 21% (Temiz *et al*. 2013b).

Tangential swelling of control samples remained higher than all treated samples. A secondary treatment with ELO further reduced tangential swelling, but the effect was somewhat limited (Temiz *et al*. 2013a, Temiz *et al*. 2013b).

The effects of bio and epoxidised oils on decay resistance

The decay resistance of the wood samples treated with 20 % bio-oil obtained from both a pyrolysis process and a heat treatment process against white (*T. versicolor*) and brown rot (*P. placenta*) fungi was very effective (less than 3 % weight loss) (Temiz *et al*. 2013a;2013b).

As a summary, the hydrophobic characteristic of samples treated with bio-oil was higher than that of control (untreated) samples. Impregnation with ELO as a secondary step further increased the hydrophobicity. Decay resistance of treated wood samples with 20 % of bio-oil against brown (C. puteana) and white rot (T. versicolor) fungi was remarkable (less than 3 % mass loss).

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Structure evaluation of the modified wood through different spectral techniques

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Keywords: infrared spectroscopy, near infrared spectroscopy, chemometrics, 2D COS, X-ray diffraction

Wood is an important natural resource, which has many technical advantages, such as: high specific stiffness and strength, low processing energy, high toughness, renewability, aesthetic properties, etc. Due to its various properties, wood has many applications from engineering to artworks. However, in addition to its biodegradability and dimensional instability in environments with changing moisture levels, wood is very susceptible to weathering (especially degradation by UV light). Furthermore, photo-oxidation occurs when oxygen reacts with wood, causing discoloration and deterioration.

In order to reduce or to stop wood degradation different modification techniques have been applied. Chemical modification (where chemical moieties are covalently bonded to the wood cell wall polymers) is one method to improve the dimensional stability, decay resistance, and water sorption of wood. At the same time, thermal treatment is often used to improve the physical characteristics of wood for particular purposes, including the dimensional stability and durability of the wood if it is to be exposed to chemicals or biological agents such as fungi and bacteria, or to frequent use under natural environmental conditions.

The structural modifications induced by these treatments can be easily evidenced by infrared and near infrared spectroscopy, as well as by solid state ^{13}C CP/MAS NMR spectroscopy. These techniques can provide detailed information on the modifications at a molecular level of the cell wall components induced by the applied treatment. Moreover, 2D IR correlation spectroscopy (2D-COS) is a powerful tool used to evaluate the differences appearing during an external perturbation. Usually, this method enhances the spectral resolution giving new information, which cannot be established through conventional infrared and its derivative spectra. On the other hand, X-ray diffraction technique evaluates the modification of the crystallinity degree according to the applied modification technique.

All these spectral techniques can be used successfully to evaluate and quantify of the structural modification of wood samples after application of different chemical or thermal treatments.

Feasibility of highly durable plywood production with poplar wood as a substitute of tropical species

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Keywords: Poplar, Plywood, Durability, Heat treatment, Mechanical properties

Naturally durable tropical species such as Okoumè (*Aucoumea klaineana* Pierre) are used for the production of plywood in highly demanding environments. The use of these species could result in environmental risks and high impact operations in tropical forests and soils. In this work the feasibility of the production of plywood panels using local fast growing species with durability enhanced by heat treatment is analysed.

The heat treatment was performed on poplar (*Populus sp.*, I-214 euro-american clone) veneers to be glued after heat treatment (post) and on panels glued before heat treatment (pre) both with melamine-urea-formaldehyde (MUF) resins. Veneers and panels were treated at 180 °C for 8 hours with a dry mass loss of about 5 %. Two groups of untreated and treated samples are shown in Figure 1.

Figure 1: Heat treated (on the left) and untreated samples (on the right).

The mechanical properties were assessed according to the reference testing standard EN 310. Test results in terms of strength and stiffness reduction are presented in Table 1.

Table 1: Reduction of the mechanical properties of the panels as a percentage of the initial value.

	MOR L [%]	**MOR T [%]**	**MOE L [%]**	**MOE T [%]**
pre	38	30	10	3
post	25	37	0	7

For both cases, according to Kruskal-Wallis and Pairwise Wilcoxon Test for independent values used as post-hoc, MOE did not show significant differences compared to the control, while MOR suffered serious reductions. The bonding quality was investigated according to the EN 314 standard using the pre-treatment 5.1.2 and the shear strength (f_v) determined (Table 2). ACWF (Apparent cohesive wood failure) is not reported because a large part of the samples broke across the glue layers.

Table 2: Reduction of the glue performance as a percentage of the initial value.

	f_v [%]
Pre	69
Post	64

The panels obtained after heat treatment show very large reductions of MOR for both samples glued before and after treatment. The variation of MOR was verified not to be statistically significant. The reduction of the gules shear strength is very large. This research showed that production of heat treated poplar plywood is feasible but needs important improvements in order to avoid reductions in mechanical properties.

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Mineral-plant-fibre composite coating as a cellular wood protector against fire

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Keywords: clay, plant fibre, plant or animal protein, reaction to fire, cone calorimeter tests

An objective of construction development is cutting down of wood and woody material buildings production and mounting expenditures. Those are aroused by raw materials large mass and great energy consumption during manufacturing and mounting, as well as negative impact to environment by transportation and capital construction technologies that increase hazardous effluents in atmosphere. Specific aim of construction development by Latvia University of Agriculture is design of the innovative self-load-bearing panel and construction elements from cell-like wood material products and their mounting technologies improvement.

Light weight construction decreases mounting costs thereby improving efficiency of building technologies and decrease energy demand. Cellular wood material Dendrolight® is an alternative to decrease the mass average material density in wood construction an average of 200 kg m^{-3} A drawback of cellular construction is good air supply in the material's cellular structure that decreases its fire safety parameters (Buksans *et al.* 2013).

The coating on the bases of inorganic components and plant fibre material was designed with the objective to improve wood cellular material reaction to fire performance (Morozovs *et al.* 2014).

The reaction to fire wood cellular material with the above mentioned coating (Fig. 1) corresponded to class B according EN 13823. The fire performance of coated material will be discussed.

Figure 1: Wood cellular material with mineral and plant fibre coating after reaction to fire tests. Heat flow 50 kW m-2 and test duration 1200 seconds

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Waste wood management and processing - opportunities for reducing the environmental impact of ports

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Keywords: LCA analysis, cascade use of wood, waste management, life cycle

The transition from waste management to resource and recycling management, along with increasing price pressure and resource scarcity has required improved quality and efficiency of resource uses. This applies to businesses from commercial and municipal waste management, as well as industry, trade and service enterprises with in-house waste disposal tasks. The Port of Koper collects and separates waste generated by port activities, including waste wood. This is crucial for achieving sustainable use of natural resources. They collect between 1,500 t and 2,000 t of waste wood, mostly in the form of sawdust, shavings, wood chips and wooden packaging. Only approximately 2% of collected waste wood is not useable.

The aim of the presented research was to examine the environmental impacts of two possible scenarios for the treatment of waste wood. First, processing of waste wood into particleboards to extend its life cycle, and second, production of wooden pellets. Life cycle assessment (LCA) following EN ISO 140044 (2006) was applied to assess the environmental impacts of the product made from raw materials in comparison to the product made from waste wood. The system boundaries were defined in collaboration with Port of Koper, particleboard producer Lesna TIP Otiški Vrh d. o. o., and pellet producer Biogen, which also provided the data for the analysis. Functional units were 1 m^3 of particleboard and 1 tonne of pellets, respectively. Cradle to gate LCA analysis and Ecoinvent 3.0 database of emission factors were used. The following impacts on the environment were analysed: acidification, eutrophication, photochemical oxidation, global warming (GWP 100), non-renewable and ozone layer depletion.

The results showed that the products made of waste wood have smaller effect on the environment than the products made from raw materials. Table 1 shows results of LCA analysis of particleboard and pellets produced from raw material and from waste wood. For both, particleboard and pellets, the environmental impacts were considerably lower in case of products made of waste wood. The major contribution to decreased environmental impacts was reduced energy use for drying the material in the production of the products and shorter transportation distances of the input material to the manufacturing facilities, when the waste wood from Port of Koper is used to produce particleboards and pellets.

Table 1: LCA analysis of 1 m^3 of particleboard produced from raw material and from waste wood collected at the Port of Koper and LCA analysis of 1 tonne of pellets produced from raw material and from waste wood collected at the Port of Koper.

	Particleboard - waste wood	Particleboard - raw material	Pellets - waste wood	Pellets – raw material
Global warming (GWP 100) [kg CO_2e]	337,0	476,7	209,8	456,4
Ozone layer depletion [kg CFC-11e]	2,39E-05	2,85E-05	8,42E-06	1,47E-05
Photochemical oxidation [kg C_2H_4e]	0,608	0,729	0,5004	0,7682
Acidification [kg SO_2e]	2,21	2,59	2,06	4,91
Eutrophication [kg PO_4e]	0,514	0,658	0,776	1,92
Raw material use [MJe]	7239	8679	4002	8876

Utilization of the waste wood in particleboard and/or pellets would significantly reduce the environmental impacts of those products. Furthermore, the waste management following the cascade use of wood could reduce the Port of Koper's overall environmental impact.

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Perceptions of innovation in wood-based products from Slovenia

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Keywords: Online survey, user perceptions, innovation, forest sector, Slovenia

The goal of the What We Wood Believe project (W3B) is to develop efficient communication strategies demonstrating the relevance of the European forest sector, as well as its related services and products. As part of this undertaking, the W3B consortium has identified eight topics of interest (TOI), and is examining each in detail. However, this presentation will focus only on the wood-based innovation TOI. A questionnaire was developed and hosted online by the University of Primorska using LimeSurvey (LimeSurvey Project Team, 2015). The target population was the general public, and the sample was a convenience sample. The questionnaire focused on respondents perceptions of innovation in 13 areas: reducing environmental impacts of processing, reducing environmental impacts of forestry, production processes, paper products, nanocellulose, material substitution with wood, marketing, forest management, wood-based construction materials, composites made of wood or paper, building systems with wood, branding, and biofuels. Respondents were asked to state their level of agreement with two statements to elicit their views of innovation on these topics: 1) Since the year 2000, the forest sector has produced significant innovations related to [the topics]; and 2) To maximise sustainability, the forest sector should focus its innovation efforts over the next 20 years on [the topics]. In each case, respondents were asked to identify their level of agreement on a 5-point scale ranging from: “Strongly disagree”, to “Strongly Agree”. They were also able to select “I don’t know”. This preliminary analysis presents only complete responses (i.e., the respondent must have completed all required questions) from Slovenian respondents (n=49).

In our analysis we assigned numerical values (1 to 5) to responses: low numbers indicated disagreement, and high numbers agreement; “I don’t know” was given a non-numeric response. Fig. 1 reflects the mean level of agreement regarding where the forest sector should focus its innovation efforts over the next 20 years. Overall, respondents indicated *building systems* was the topic that should receive the most attention, but that *forest management*, *construction materials*, and *production processes* were assessed similarly. *Paper products* received the lowest level of agreement for any of the topics, but respondents agreed innovation in all areas should receive some degree of focus over the next 20 years. *Nanocellulose* was the only topic to elicit a significant number of “I don’t know” responses (n=12 or 24 % of respondents; 0 % to 4 % of respondents selected “I don’t know” for other categories).

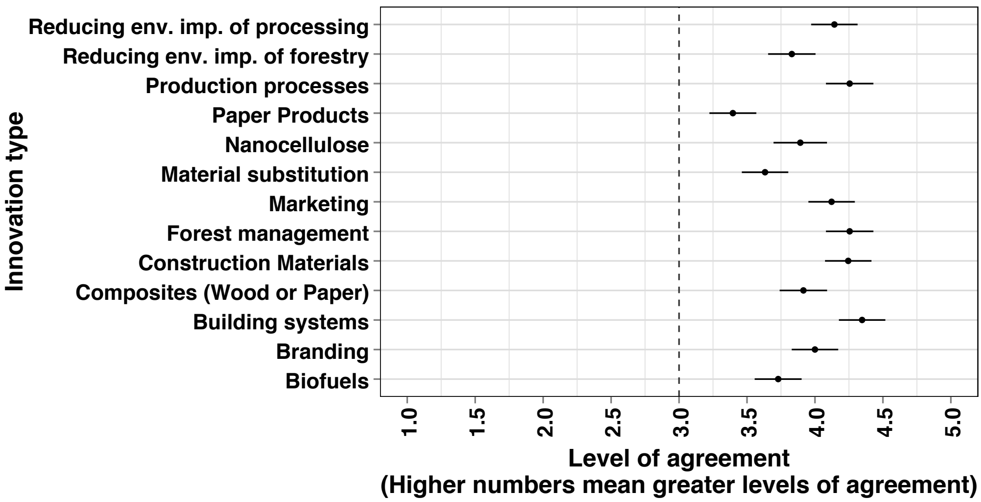

Figure 1: Slovenian respondent’s level of agreement that the forest sector should focus innovation activities on the areas listed on the y-axis. Error bars signify standard errors.

Respondents generally agreed that *building systems from wood* was the area that companies have produced the most significant innovation since the year 2000, while innovation in branding had the lowest agreement level. However, respondents indicated a large knowledge gap about the level of innovation in the forest sector as many respondents (between 10 % and 32 %) selected “I don’t know”; the greatest knowledge gap was related to *nanocelluose*.

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Characterization of cracked wood under thermo-hydro-mechanical and viscoelastic behaviour

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Keywords: Crack, wood modification, moisture content, independent integral, finite element

Cracks in wood and timber structures are due to mechanical loading, but also to environmental effects such as temperature and humidity. In this case, controlling the shrinkage or the swelling during the wood life are one of the challenges of the scientists and the engineering community in order to limit the apparition of micro-cracks at their propagation (Moutou Pitti *et al*. 2013). In addition, the effects of moisture content variation coupled with viscoelasticity effect generate more deformations detrimental to timber structures in service (Moutou Pitti *et al.* 2014).

This work examines crack propagation in wood due to mechanical and moisture content variation. The crack extension is introduced by the non-dependent integral A_v (Riahi *et al*. 2015) combining real and virtual fields in viscoelastic material introduced by a generalized Kelvin Voigt model. The mixed Mode Crack Growth (MMCG) specimen subjected to moisture variation, as depicted in Fig.1, is used in order to obtain the mixed mode configuration during the crack growth process.

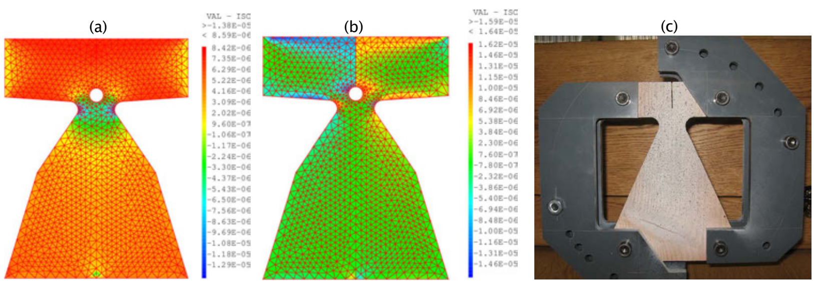

Figure 1: Wood specimen in E_{xx} (a) E_{yy} (b) directions. (c) Real MMCG specimen

Here, temperature is assumed to be constant. The properties of the MMCG specimen are summarized in Table 1.

Fig. 2 shows the evolutions of viscoelastic energy release rate in opening mode G_1 and shear mode G_2 versus time using A_v integral, under moisture level variation. We note an increase of G with the moisture level. Hence, for both modes, we can observe at first, a progressive increase of G, and then, a stationary phase with a stabilization of its evolution. Specifically, we can observe, for G_2, a highest energy release rate than G_1. A regular trend in viscoelastic energy levels illustrate the moisture effect stability in mixed mode calculated with the integral A_v without taking into account the effect of thermal expansion induced by a change of the temperature field.

Table 1: Elastic properties of MMCG specimen

Elastic constant		Value of elastic constants
Transversal Young's modulus	$E_1(MPa)$	1500
Longitudinal Young's modulus	$E_2(MPa)$	600
Shear modulus	$G_{12}(MPa)$	700
Poisson's ratio	ν_{12}	0.4

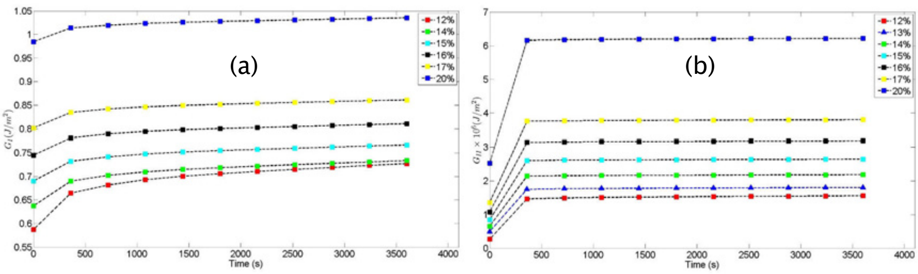

Figure 2: Viscoelastic energy release rate in opening mode (a) and shear mode (b).

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Novel moisture sorption model explaining parallel kinetics of transient wood moisture content

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Keywords: Wood moisture sorption isotherm, PEK model, Sorption site occupancy model, Water chemical potential, Water clusters, Polymer relaxation

Wood moisture sorption isotherms are thought to contain valuable information for the characterisation of modified wood and its performance in service. Many alternative physical models of equilibrium wood moisture sorption fit and explain the sigmoid shape of the adsorption isotherm. On the other hand, when other phenomena of wood moisture are considered, these models reveal serious shortcomings, such as in the transient moisture content. Qualitatively, a fast and a slow kinetic component has been identified, tentatively assigned to mass diffusion and polymer relaxation respectively (Hill et al 2012).

In this contribution, a new moisture sorption model is presented, based on a thermodynamic model of the bonding configuration of water within the cell wall. Wood moisture at low humidity is argued to be bound to two hydroxyl-groups of the wood cell wall, whereas at high humidity one extra water molecule will cluster at an already adsorbed molecule. It is shown that the fast and slow components of the transient moisture content are consistent with molecular processes in the model. A closed-form expression for the sigmoid adsorption isotherm based on the sorption model is given.

The model satisfies the principles of wood moisture sorption, described in previous work of the author (Willems 2014a,b), that the wood moisture content can be factored into a density of accessible sorption sites and a statistical occupancy of these accessible sites. The latter occupancy factor is directly controlled by the water vapour humidity and temperature, independent of the density of water sorption sites.

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Changes in the modulus of elasticity of beeswax impregnated wood during soil contact

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Keywords: Beeswax, Soil contact, Wood protection, MOE, SEM

Since biocides, due to EU regulations are increasingly restricted, waxes and wax emulsions are becoming important solutions for non-biocidal wood protection in outdoor applications to improve durability, dimensional stability and sorption properties. The objective of this study was to evaluate the effectiveness of a full cell process beeswax impregnation against the degradation of less durable wood species (poplar and beech) when they are in contact with soil for 18 months. Various beeswax impregnation intensities were examined in both poplar and beech.

Impregnation of the oven dry samples was made at 80 °C with 150 mbar pre-vacuum and atmospheric pressure. Impregnated samples were separated into three groups, on the basis of the degree of pore saturation (DPS) (Table 1). The effect of outdoor exposure with soil contact of the samples was investigated under laboratory conditions, based on the standard ENV 807. Modulus of elasticity (MOE) was determined initially at the absolute dry states of the unimpregnated and impregnated samples before the insertion of the samples into the soil, after one month of soil contact, and after 18 months of soil contact. After 18 months of soil contact, the samples were investigated with scanning electron microscope (SEM) imaging to determine the extent of the decay and the effect of beeswax on the decay.

Table 1: Sample Groups According to the Degree of Pore Saturation (DPS)

Group	Poplar1	Poplar2	Poplar3	Beech1	Beech2	Beech3
DPS (%)	20-40	40-55	55-70	60-75	75-90	90-100

Beeswax impregnation increased the MOE of beech and poplar wood. Unimpregnated beech and poplar samples decomposed completely during the 18 months of soil contact. The damage of the impregnated samples was markedly lower. This was confirmed by the MOE measurements, which showed remarkable remaining MOE of the impregnated samples after soil exposure (Fig. 1). The impregnation improved the wood's resistance against wood decaying organisms, and higher DPS resulted in less of a decrease in MOE than in samples with lower DPS.

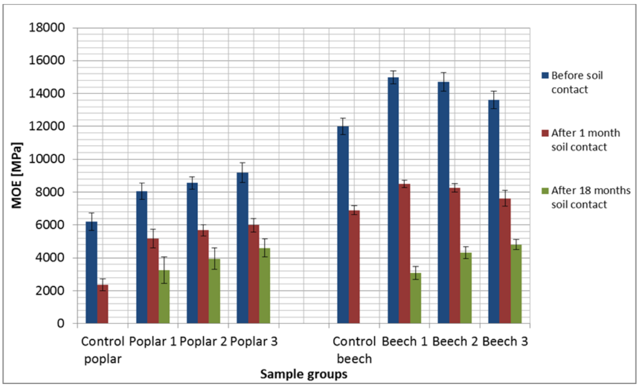

Figure 1: MOE of poplar and beech samples in the investigation periods.

SEM imaging showed that beeswax filled the lumens and separated most of the cell walls from the hyphae, which slowed the spreading of the fungi in the wood (Fig. 2). This explains the protecting effect of the beeswax, even though it does not consist of any "artificial" biocidal agents. The decomposition of cells without beeswax was much more pronounced than that of beeswax filled cells. SEM imaging showed that the beeswax impregnation slowed much more of the longitudinal spreading of the hyphae than the transversal spreading.

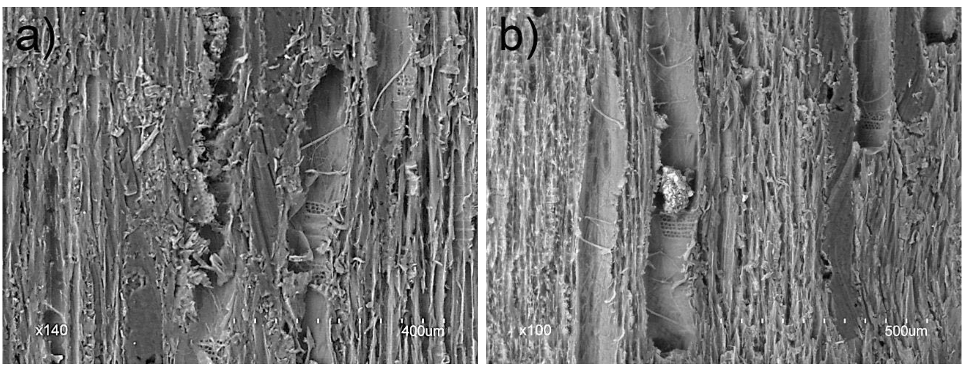

Figure 2: Spreading of hyphae and start of the decomposition on the borderline of the impregnated and unimpregnated wooden parts of poplar samples (a and b).

Impact of thermal treatment on moisture-dependent elasto-plastic behaviour of beech

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Keywords: thermo-modified wood, elasto-plasticity, compression test, moisture content

Strength and stiffness alteration are important properties of thermally treated wood, and vary with anatomical direction of wood, testing method, and wood species. Since wood density is commonly decreased after thermal treatment (Poncsak *et al.* 2006), one might expect a similar trend with material strength and stiffness. However, the reduction of hydrogen bonding and a decrease in free accessible hydroxyl groups are often present in thermally treated wood (Boonstra and Tjeerdsma 2006), and lead to a decrease in equilibrium moisture content (EMC) (Esteves and Pereira 2009). There is a known negative correlation between moisture content (MC), and strength and stiffness (Ozyhar *et al*. 2013). While there is a positive correlation between wood density and MC, which is influenced by mass loss during thermal treatment. It is expected that there will be various strength-stiffness properties of thermally treated wood when exposed to varied climatic conditions.

The relationship of mechanical properties of wood and wood MC after thermal treatment is therefore researched. Ten radially oriented beech wood boards (*Fagus sylvatica* L.) of 32 mm thickness and 2 m length, having no visible defects, were split into two halves for the control (C) and thermally treated board samples (TT). Industrial thermal treatment in an unsaturated steam atmosphere (P_{atm} = 1.2 bar) was performed at Evolen company (HR) on TT board samples with a pre-drying phase (T = 105 °C), a stepwise heating phase, heating at maximum temperature of 210 °C, followed by cooling and conditioning (20 °C / 65 % RH). Prismatic compression wood specimens (L×R×T = 20 mm × 20 mm × 20 mm) were made in a series (n = 8) from each unmodified and thermally-treated board halves. Adsorption behaviour was studied at room temperature (20 ± 0.1 °C) by putting one specimen of a series to equilibrate at a single relative humidity (RH), having a range from 0 % to 97 %. Transverse (T) and longitudinal (L) displacement-controlled compression tests were conducted on equilibrated specimens using a Universal Testing Machine (Zwick Z100), where Young's moduli MOE, proportional limit stress σ_{PL}, and ultimate strength σ_{max} were determined.

The thermal treatment generally improved the hygroscopicity of beech wood (ΔEMC = -50 %), more pronounced at upper hygroscopic range, and reduced wood density, where the mean oven-dry density decreased from 685 kg/m^3 to 620 kg/m^3 ($\Delta\rho$ = -9.3 %). The stiffness of beech wood along the grain slightly increased after the thermal treatment (ΔMOE = + 7.8 %), more significantly for the most dry wood samples, where MC – stiffness relationship remains unchanged (Fig. 1). Oppositely, a slight reduction of stiffness of beech wood after thermal treatment was confirmed in the transverse wood direction, most significant at oven dry state (ΔMOE = - 15.7 %).

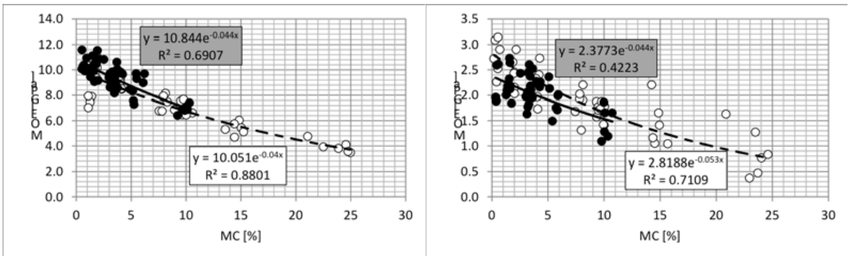

Figure 1: The relationship between wood MC and MOE of innate- (○) and thermal-treated beech wood (●) along- (left) and transverse to the grain (right).

The thermally-treated beech wood retained the ultimate strength along the grain, compared to untreated wood. Whereas ultimate strength was significantly reduced in the transverse direction (-41 %) at the whole examined MC interval. The relative strength (σ/σ_0), defined as a ratio of ultimate strength at a single MC (σ) and at oven dry state (σ_0), confirmed the equality of strength changes with wood moistening or drying in both groups (C, TT) in both directions (L, T).

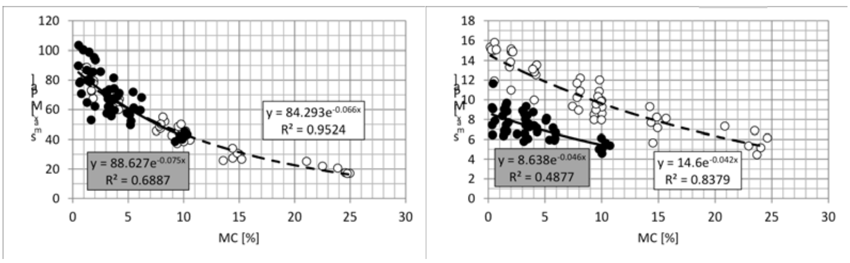

Figure 2: The relationship between wood MC and σ_{max} of innate- (○) and thermal-treated beech wood (●) along- (left) and transverse to the grain (right).

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Influence of thermal modification of poplar veneers and plywood construction on shear strength

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Keywords: poplar veneer, plywood, thermal modification, shear strength.

Thermal modification of solid wood is well investigated but there is limited research about thermal modification of wood based panels. Thermal modification of wood after panel production is one method, but thermal modification of wood before panel production (Zdravković *et al*. 2013, Fioravanti *et al*. 2013) was researched in this experiment. The main advantage of method two is that established gluebond strength during the plywood pressing is not weakened by additional thermal treatment. Plywood were produced from cultivated poplar (Populus x euroamericana I214) veneers and glued together by hot-setting MUF adhesive. This commonly used adhesive was selected due to the lower price than PUR and RF adhesive, lower formaldehyde emission, and better gluebond quality compared to UF adhesive.

Poplar veneers were prepared, heat treated, and hot-pressed into 13 different types of five-layer 15mm thick plywood panels, a total of 78 panels (Fig. 1). All panels were tested on MC, plywood density, swelling, MOR and MOE on bending and anti-shrink efficiency (ASE). WBP glue line shear tests (EN 314-1, EN 314-2 and EN 636-1, EN 636-2 and EN 636-3) were performed.

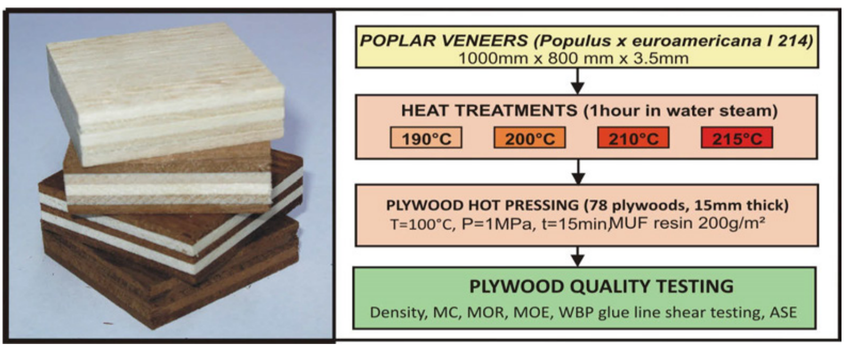

Figure 1: Plywood samples and experimental flow chart

As expected, veneer thermal modification contributed to improved dimensional stability of plywood (unpublished data) and colour equalisation of veneers produced from sapwood and hardwood zones were achieved (Lovrić *et al*. 2014). All plywood passed the test for use in dry conditions – samples have a gluebond strength higher than 1 MPa or wood failure percentage was high enough per EN 314-2 (Fig. 2). Gluebond strength decreased as treatment temperature and percentage of treated veneers in plywood composition increased. Control samples composed of untreated veneers (5U) showed the highest average gluebond strength with a value of 1.603 MPa. The plywood (5T) composed only of veneers treated at 215 °C had the lowest gluebond strength with a value of 0.837 MPa.

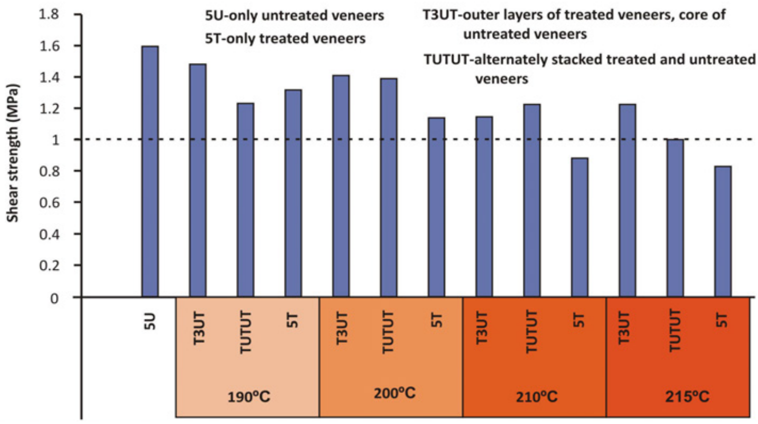

Figure 2: Average gluebond shear strength of plywoods after immersion in water for 24 h at 20 °C

After immersion in water for 24 h at 20 °C, wood failure of samples was between 39.36 % and 82.14 % with average of 62.37 %. Increasing the pretreatment temperature of samples for use in outdoor conditions and high humidity lead to a decrease of gluebond strength. This gluebond strength drop, apart from decreasing of mechanical properties of wood, was probably caused by weakening of glue-wood relation. The decrease of average wood failure percentage from 62.37 % (EN 636-1: dry conditions) to 16.56 % (EN 636-2: high humidity conditions) and 13.31 % (EN 636-3: outdoor conditions) supports this statement. These results are in agreement with Fioravanti et al. (2013) who reported that gluebond strength of MUF adhesive decreased 64 % in plywood for high humidity conditions, as compared to plywood for dry conditions.

Increased gluebond strength may be achieved by better adhesive penetration into the wood before glue setting by using lower pressing temperature and longer pressing time. In addition to better plywood dimensional stability and more attractive appearance, such plywood would be of higher quality.

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Mobility and toxicity of heavy metal(loid)s arising from contaminated wood ash application to a pasture grassland soil

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Keywords: Heavy metal toxicity, bioavailability, wood ash, arsenic, chromium

Wood modified with weatherproof protectants, paints, and preservatives historically contained heavy metals and organic compounds. After combustion of these woods for heat and power, and loss of more volatile organic compounds (VOC), the final ash is concentrated in both nutrients from the biomass and heavy metal(loid)s arising from the additive treatments (Balasoiu *et al*. 2001). One way to dispose of wood ash without dumping/landfilling is by application to soil, which has a number of benefits and potential concerns associated. For example, it has been demonstrated that the addition of wood ash to soils increases pH (Klemedtsson *et al.* 2010) and improves crop biomass and yields (Bougnom *et al.* 2012). However, studies that have used wood ash generated from reclaimed waste (contaminated) feedstocks report that heavy metals derived from the ash are bioavailable and potentially phytotoxic, negatively impacting crop yields (Lucchini *et al.* 2013) and introducing potential environmental risk.

We conducted a pot experiment to investigate the fate of metal(loid)s derived from contaminated ash (≤ 10000 mg kg^{-1} As, Cr, Cu and Zn; Table 1) added to an upland pasture soil (Aberdeenshire, UK), replicating a common disposal route for on-farm generated ash. Metal(loid) concentrations were measured after 9 weeks in pore water and ryegrass grown on the soil/manure-ash mixtures (0.1-3.0% vol. ash). Toxicity evaluation was performed on pore waters by means of a bacterial luminescence assay.

Table 1: Metal(loid) concentrations (pseudo-total) of soil, manure, and ash; values are the mean of replicates (n=5) ± s.e.m.

mg kg^{-1}	As	Cr	Cu	Zn
Soil	4.5 ± 0.2	23.9 ± 2.1	8.8 ± 0.6	23.2 ± 1.4
Manure	5.4 ± 0.4	19.7 ± 2.1	22.6 ± 2.1	169.0 ± 11.5
Ash	9259.4 ± 649.3	9914.1 ± 714.9	8793.4 ± 632.0	4666.7 ± 373.5

Both pore water and ryegrass tissue concentrations of As, Cu, and Cr were elevated by ash applications compared to soils receiving no ash. Applying ash to manure amended soil buffered some phyto-toxicity effects associated with ash application to non-manure treated soil, by regulating pH regardless of ash application volume. This was evident from improved ryegrass biomass and bacterial luminosity concomitant to soil without ash addition (Fig. 1). Pore water concentrations of As and Cu significantly correlated with ryegrass uptake, indicating that these elements were the most bioavailable of those investigated. Cr uptake was influenced by the volume of ash addition but ash had no impact on either pore water or ryegrass accumulation of Zn.

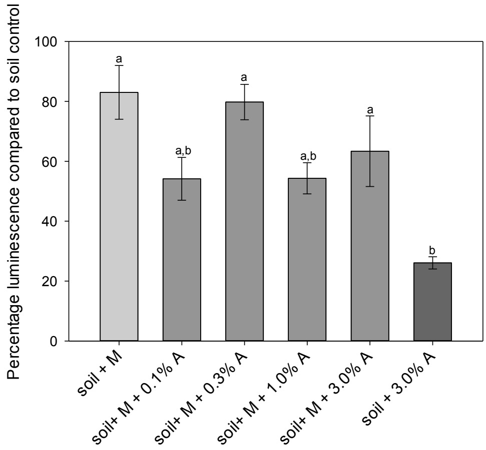

Figure 1: Bacterial biosensor toxicity tests of pore water for the different treatments (+M = with manure; + A = with ash); control was de-ionised water. Bar represent the average of the replicates and the bar is the s.e.m (n=5). Means that share the same letter are not significantly different.

There are potential environmental pollution issues associated with the application of metal(loid) contaminated wood ash to land related with leaching of contaminants out of soil and phyto-toxicity. The particular ash used in this study had high concentrations of As, Cu, Cr, and Zn so the immediate concern is that soil metal loadings will dramatically increase with high or repeat doses of ash application. Manuring soil before adding ash can buffer pH and reduce the solubility of metals in from the alkaline ash, providing binding sites for Cu and As and reducing phyto-toxicity. Ash addition to soil appeared to have no consequence on the concentration of Zn both in the pore water and in the plants. In this respect the application of Zn rich ash will only serve to raise total Zn concentrations of soil, especially if the process is repeated, with no benefits to plant nutrition. This effect may be plant species and soil specific. It remains to be seen if Zn would accumulate and re-fractionate to more soluble forms and become bioavailable. If this were the case there could be some benefits regarding fortification of crops with Zn from the ash. In general, it is unlikely that justification for repeated application of this particular ash could be gained by an increase in available Zn in any case as the risks of As and Cr leaching would prove too great.

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Working Groups

The main (although not exclusive) aim of this Action is to characterize the relationship between modification processing, product properties, and the associated environmental impacts and their comparison to normal wood based products and alternative (often) non-renewable materials. This includes the development and optimization of modified processing to maximize sustainability and minimize environmental impacts. The benefits of performance improvement need to be measured against 'baseline' scenarios with more conventional wood products. The key research and activities needed to achieve the goal are presented in Section D.1 of the MoU (available online at http://costfp1407.iam.upr.si), where academic and industry researchers along with other experts will join the interdisciplinary research theme. The Action's members are grouped in the 4 Working Groups described below, although there will be strong collaboration and networking among Working Groups.

Working Group 1: Product Category Rules

Objectives: To develop product category rules for modified wood based on the scientific and industrial state-of-the-art of commercialized and developing modified wood products and technologies. Evaluation of current PCRs and adoption where appropriate.

Activities:

- Thermodynamics and chemical reactions associated with wood modification processing
- Process parameters leading to thermal degradation and chemical, structural, mechanical, and physical properties changes
- Innovative wood modification processing for specific applications in construction and interior design.
- Performance of modified wood: machining of the wood surface (with reference to FP0802; see also partial results of E35); the impact of the combined actions of heat, moisture, and mechanical pressure (results of FP0904), surfaces (FP1006) and wider issues (FP1303).

Leader: Dick Sandberg (Sweden); Deputy leader: Robert Nemeth(Hungary)

Working Group 2: Life Cycle Assessments

Objectives: To perform objective environmental impact assessments of commercial modification processes and incorporate environmental impact assessments into wood modification processing and product development, including recycling and upgrading at the end of service life.

Activities:

- Crucial environmental aspects associated with innovative wood modification processing technologies and resulting products

- Reference service life of the product, maintenance requirements and performance in service (in cooperation with FP1303).
- Optimization of the developed processes from the sustainability point of view.
- Scenarios for up-cycling after product service life based on the cradle to cradle concept.

Leader: Christelle Ganne-Chedeville (Switzerland); Deputy leader: Lauri Linkosalmi (Finland)

Working Group 3: Environmental products declarations

Objectives: To develop environmental product declarations based on WG1 and WG2 and force a harmonization of various national EPDs in the field of wood modification.

Activities:

- Environmental product declarations of modified wood
- Product design guidelines and properties of assemblies made of modified wood
- Data to architects, engineers, and industry of the physical and structural properties, combined with environmental impacts of the wood modification processing in a clear and consolidated form

Leader: Callum Hill (UK); Deputy leader: Ana Dias (Portugal)

Working Group 4: Integration, dissemination and exploitation

Objectives: To ensure dissemination, evaluation, and exploitation of the Action's results together with establishing a strong network with the relevant industrial stakeholders.

Activities:

- Promotion, dissemination and commercialization of knowledge acquired in WG1-WG3
- Evaluation of research results of WG1-WG3 by the industry stakeholders
- Marketing campaigns on social networks with the aim to increase social awareness and acceptance
- Lobbying – reaching policy makers and European and national program operators.

Leader: Edo Kegel (Netherlands); Deputy leader: Michael Burnard (Slovenia)

COST Action FP1407

Understanding wood modification through an integrated scientific and environmental impact approach (ModWoodLife)

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