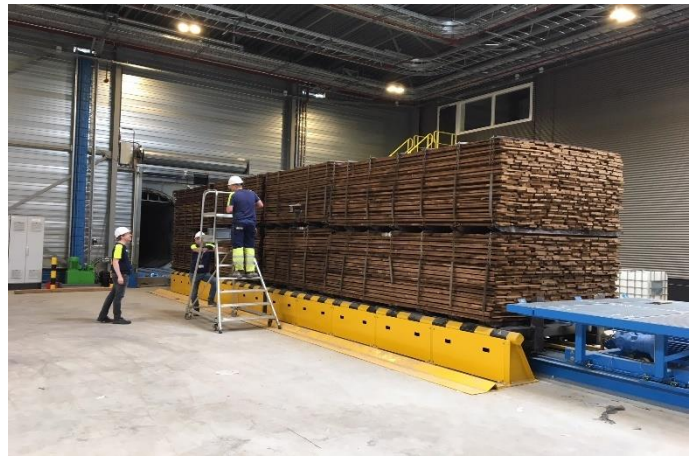


9th European Conference on Wood Modification ECWM9

September 17 and 18, 2018, Arnhem, The Netherlands

PROCEEDINGS



ECWM⁹

The 9th European Conference on **Wood** Modification
The Netherlands • Arnhem • September 17-18, 2018

PROCEEDINGS

9th European Conference on Wood Modification

**Burgers' Zoo
Arnhem, The Netherlands
17-18 September 2018**

**In association with:
COST FP1407 ModWoodLife**

**Edited by:
Jos Creemers, Thomas Houben, Bôke Tjeerdsma, Holger Militz, Brigitte Junge
and Jos Gootjes**

**Secretariat:
SHR B.V.
Nieuwe Kanaal 9b
6709 PA Wageningen
www.ecwm9.shr.nl**



Legal Notice

Although all reasonable efforts were made by the editorial team to ensure the scientific quality of the contents of these conference proceedings, the final responsibility for the contents of individual articles therein remains with the respective authors. The editors accept no responsibility for the information contained herein. The inclusion of information in this publication does not constitute any form of endorsement by the editors. The editorial team is not responsible for the contents of external websites referred to in this publication.

No permission is required to reproduce or utilise the contents of these abstracts other than in the case of diagrams, images, or other material from other copyright holders. In such cases the permission of the original copyright holder must be obtained. The proceedings may be sited as *Proceedings of the 9th European Conference on Wood Modification 2018, Arnhem, The Netherlands*.

Copyright © SHR B.V.

Nieuwe Kanaal 9^b, 6709 PA Wageningen, The Netherlands

www.shr.nl

ISBN: 978-90-829466-1-1

Preface

SHR was one of the first research institutes in Europe, who already in the 1990's did substantial research work to develop wood modification processes. It appeared, that this research area was very complex, and that for a successful application of potential processes different expertise's was needed. A good network between research partners and industry was needed and the "European Network on Wood Modification" was created. 15 years ago, in 2003, the first European Conference on Wood Modification "ECWM" was held to present the outcomes of this EU financed network. Since than, ECWM's were held each 2-3 years at different places around Europe, and now we can celebrate the 9th ECWM in the Netherlands, organized by SHR where it all began.

As already before, ECWM 9 is linked up to the European COST organisation. Thanks to the COST Action FP 1407 ModWoodLife to join and strengthen our network!

The participation of researchers of all around the world make it obvious that the name "European conference" is much too small...so: a warm welcome to researchers from industry and academia from Europe and abroad! This success has led, once again, to a large number of abstracts submitted to the organizers. In general, these abstracts were of a high quality and the members of the Scientific Committee had a hard time to select 44 full presentations and 50 poster presentations out of the many applications. We hope we have found the right balance between scientific and applied presentations to reach the key goal of ECWM: to attract researchers from academia and industry to join their expertises in this very exciting research area "wood modification".

The local conference organizers from SHR have done a great job this past year to make us feel welcome in The Netherlands and to let the conference be a success. Thank you very much to Bôke and team!



Prof. Dr. Holger Militz
Chairman of Scientific Committee
Georg-August-University Göttingen, Germany

Scientific Committee

Dr. Julia Milne e Carmo,	Carmo Group, Portugal
Prof. Dr. Callum Hill,	JCH Industrial Ecology Ltd., United Kingdom
Dr. Dennis Jones,	Timber Consultancy (UK) / LTU, Sweden
Prof. Dr. Holger Militz,	Göttingen Uni., Germany (Chairman of Scientific Committee)
Mr. Jos Creemers,	SHR, The Netherlands
Mr. Bôke Tjeerdsma,	SHR, The Netherlands
Prof. Dr. Joris Van Acker,	Ghent Uni., Belgium
Dr. Andreja Kutnar,	University of Primorska, Slovenia (FP 1407)

Local Organising Committee

Mr. Bôke Tjeerdsma,	SHR; The Netherlands (Chairman of Organizing Committee)
Mrs. Marina van der Zee,	SHR; The Netherlands
Mr. Jos Creemers, SHR	SHR; The Netherlands
Dr. René Klaassen,SHR	SHR; The Netherlands
Mr. Bas Holleboom, SKH	SKH; The Netherlands
Mrs. Mariena Mooi, SHR	SHR; The Netherlands
Mrs. Jos Gootjes, SHR	SHR; The Netherlands

Wood modification in practice

The European Conference on Wood Modification takes place on the 17th and 18th of September 2018 in Arnhem, The Netherlands and is organised by SHR. At this conference researchers and people from industry from all over the world will come together to share their knowledge and experiences with the latest developments on wood modification methods, applications and products. The conference was given the subtitle “Wood modification comes home”, which refers to the role The Netherlands and SHR have played – and still play – in the development and industrial application of modified wood.

Techniques and methods designed for improving wood properties are almost as old as mankind itself. However the scientific and industrial rise of wood modification became significant under the influence of a number of social and economic developments in the eighties and nineties of the previous century. A strong need was felt to find alternatives for the use of tropical hardwoods and preservative treated wood, which were both under pressure for a variety of reasons. The discussions regarding a clean environment, sustainable forest management, wood use and the increasing wood demands from emerging markets in Asia also had a big impact. Wood modification was recognized to have the ability to offer a more, better and sustainable way of making use of wood as a durable material in a broad range of applications. Besides that, it was found to be a supreme method for upgrading the properties of lesser used timber species and to provide technical solutions to overcome some of the natural deficiencies of wood as water uptake, decay and dimensional changes.

Over the last decades an enormous amount of scientific work has been performed and published. We have seen many innovative modification ideas, methods and techniques passing by during the previous eight ECWM's. To make a real impact, ideas need to be developed further and put into practice. We are proud that in The Netherlands we have created a setting with a high level of knowledge, innovative thinking combined with entrepreneurship, which lead to a variety of flourishing companies involved in industrial production of modified wood. Not only producing companies, but also the wood processing industry has adopted modified wood as a highly appreciated durable material. We can declare that modified wood has become a lasting factor in the wood processing industry.

For these reasons SHR and we as the organising team, are excited to welcome you all here in The Netherlands for the 9th European Conference on Wood Modification. We hope you will enjoy your stay here in Arnhem and become inspired by all attendees, presenters and new insights this conference has to offer.

Welcome!

The organising team

COST 1407 - Foreword

It is our pleasure that COST Action FP1407 “Understanding wood modification through an integrated scientific and environmental impact approach” (ModWoodLife) in part of 9th European Conference of Wood Modification. The conference brings together researchers from across Europe and beyond that jointly are addressing the mounting pressure on renewable resources (as a material source, for recreational, ecological, and other uses). By maximising the efficiency of materials derived from them, the wood modification community plays an important role. The efficiency can only be achieved if new methods to improve the functionality, durability, properties, and environmental impacts will be developed. Wood modification addresses these requirements directly, allowing wood to be used in more applications, including increased use of under-utilised species. Wood modification also addresses undesirable characteristics of wood such as fungal resistance, UV-stability, and moisture sensitivity. The COST Action FP1407 has been successful in addressing these needs in the past 3 years. We are in the last year of the Action and therefore it is even more important for us to be at ECWM9. Only sustainable collaboration and joint efforts will deliver the impacts. That objective of the Action FP1407, to characterise the relationship between wood modification processing, product properties, and the associated environmental impacts in order to maximise sustainability and minimize environmental impacts, has great value for the forest sector, for researchers, and society at large.

Wishing you a successful and memorable conference full of fruitful discussions.

Andreja Kutnar
Chair, COST FP1407

Denis Jones
Vice-Chair, COST FP1407

Table of Contents

Preface	3
Table of contents	7
 Session One: Wood Modification World-wide - keynote presentations	
Modified wood in circular economy – a critical review	16
<i>Henrik Heräjärvi, Janni Kunttu, Elias Hurmekoski, Teppo Hujala</i>	
A review of wood modification across Europe as part of COST FP1407	24
<i>Dennis Jones, Dick Sandberg, Andreja Kutnar</i>	
What is wrong with Wood Modification in the U.S.?	32
<i>Jeffrey Morrell</i>	
 Session Two: Commercial and Market Opportunities for Modified Wood	
New Standards for Approval of Modified Wood within the Nordic Wood Preservation Council (NWPC)	40
<i>Niels Morsing, Søren Bang-Achton, Emil Engelund Thybring, Morten Klamer</i>	
Kebony Clear – Produced in Belgium	48
<i>Per Brynildsen, Omar Roels, Bruno Van den Branden</i>	
Improved dimensional stability of polypyrrole enriched spruce as an indication for chemical change	56
<i>Andries van Eckeveld, Rabi Malki, Michael Sailer, Jacco Eversdijk</i>	
Practical experience of acetylated wood fibre panel products in Dutch door manufacturing	64
<i>Jeroen Lückers</i>	
Wood Modification with DMDHEU (1.3-dimethylol-4.5-dihydroxy-ethyleneurea) – Status quo and latest research activities	74
<i>Lukas Emmerich, Holger Militz</i>	
Architects perception of modified wood: a parallel study in selected countries of Europe	82
<i>Manja Kitek Kuzman, Eva Haviarova, Dick Sandberg</i>	
Enhancing the Properties of ThermoWood® with Phenolic Resin Treatment	91
<i>Reeta Stöd, Janne Pynnönen, Duncan Mayes, Bodo Caspar Kielmann</i>	

Session Three: Poster Session 1

Effect of Thermo-Mechanical Treatment on Properties of Parica Laminated Veneer Lumber (<i>Schizolobium amazonicum</i> Huber ex Ducke)	98
<i>Mírian de Almeida Costa, Cláudio Henrique Soares Del Menezzi</i>	
TanWood®: The Brazilian Process of Thermal Modification of Wood	104
<i>Leonardo Puppi Bernardi, Djeison Cesar Batista</i>	
Examining the coating performance of finishes on acetylated hornbeam wood (<i>Carpinus betulus</i> L.)	112
<i>Fanni Fodor, Róbert Németh</i>	
Colour response of heat treated spruce and pine with different surface coatings in outdoor exposure	119
<i>Niclas Björngrim, Marie Hartwig, Olle Hagman, Tom Morén</i>	
New substrates for wood modification. Characterising pore size distributions in variously dried softwood	123
<i>Warren Grigsby, Elizabeth Dunningham, Hank Kroese</i>	
Determination of resistance of thermally treated wood to weather conditions in different countries (HTW) - Preliminary results	126
<i>Idalina Domingos, José Ferreira, Luisa Cruz-Lopes, Júlia Carmo, Jorge Martins, René Herrera, Lina Nunes, Bruno Esteves</i>	
Investigation of <i>Abies alba</i> wood thermal stability according to its radial position	131
<i>Joël Hamada, Anélie Pétrissans, Julien RuellE, Frédéric Mothe., Francis Colin, Mathieu Pétrissan, Philippe Gérardin</i>	
Properties improvement of bamboo materials through furfurylation	137
<i>Li Wanju, Wang Hankun, Liu Minghui, Yu Yan</i>	
Veneer modification with fire retardant chemicals	143
<i>Saara Hautamäki, Michael Altgen, Tuomas Hänninen, Lauri Rautkari</i>	
Natural Weathering and Photostability of Wood Modified by Fatty Acid esters	149
<i>Mohamed Jebrane, Nasko Terziev, Ivo Heinemaa</i>	
Effects of thermal modification on bending properties and chemical structure of Iroko and Padauk	155
<i>Michal Kroupa, Milan Gaff, Olov Karlsson, Olena Myronycheva, Dick Sandberg</i>	
Modified wood in actual use and its weathering performance after outdoor exposure	162
<i>Ville Lahtela, Tim Kärki</i>	
Performance of thermal modified radiata pine in real cases of facades and deckings in North Spain	167
<i>David Lorenzo, Alfonso Lozano, Juan Fernández-Golfin, Manuel Touza, René Herrera</i>	

Table of Contents

Water free PEG impregnation of hardwood veneer using a roll press	173
<i>Tillmann Meints, Axel Rindler, Niklas Bugelnig, Christian Hansmann</i>	
The impact of cerium dioxide nanoparticles on thermally modified wood-coating system during weathering	177
<i>Josip Miklečić, Vlatka Jirouš-Rajković</i>	
Application of time-temperature-humidity superposition to the hygrothermally accelerated ageing of spruce wood	181
<i>Eiichi Obataya, Nanami Zeniya, Kaoru Endo, Miyuki Matsuo-Ueda</i>	
Preliminary studies on the effect of acetylation and subsequent weathering on tensile strength and stiffness of Rubber wood (<i>Hevea brasiliensis</i>)	187
<i>Samuel Olaniran, E. Cabane, M. Rüggeberg</i>	
Mild torrefaction pre-treatment of eucalypts aiming at its energetic valorisation	193
<i>Solange de Oliveira Araújo, Duarte M. Neiva, Angélica de Cássia Carneiro, Bruno Esteves, Jorge Gominho, Helena Pereira</i>	
Influence of various polyethylene glycol treatments on the dimensional stability of beech wood.	199
<i>Sabrina Puttmann, Lukan Müller, Bertil Burian, Marcus Müller</i>	
Adhesion of coatings to plasma modified wood at accelerated weathering	205
<i>Ladislav Reinprecht, rADOVANTiño, Marek Šomšák</i>	
Measuring Accessibility of OH groups in Scots Pine with Dynamic Vapour Sorption Apparatus	210
<i>Tuuli Uimonen, Saara Hautamäki, Maija Kymäläinen, Lauri RauTkari</i>	
Plasma treatment of wood veneers: a review	216
<i>Richard Wascher, Georg Avramidis, Holger Militz, Wolfgang Viöl</i>	
Saturated gaseous ammonia treatment for improved densification of beech wood – Sorption and mechanical properties	224
<i>Mario Zauer, Tobias Dietrich, Herwig Hackenberg, André Wagenführ</i>	
Water vapour diffusion through acetylated wood with different weight percent gain (WPG)	230
<i>Ava Khodabakhshi Koulaei, Asghar Tarmian, Davood Efhamisisi, Ali Abdulkhani</i>	
Session 4A: Properties 1	
The potential for use of acetylated wood in musical instruments making	236
<i>Stergios Adamopoulos, Sheikh Ali Ahmed, Chiel Lankveld</i>	
Influence on acoustical properties of resonant soundboard material through different processes of thermal modification	244
<i>David Zerbst, Lothar Clauder, Dave Olson, Alexander Pfriem</i>	

Table of Contents

Measuring the Free Hydroxyl Content in Wood Modified by Acetic or Propionic Anhydride	251
<i>Callum Hill, Greeley Beck, Erik Larnøy, Sarah Strohbusch, Holger Militz</i>	
Pre-treatment with Ionic Liquids or Organic Superbases to Reduce Spring-Back and Set-Recovery of Surface-Densified Scots pine	259
<i>Benedikt Neyses, Olov Karlsson, Dick Sandberg</i>	
Potential solutions for gluing acetylated wood in load bearing constructions	267
<i>Andreas Treu, Ronny Bredesen, Ferry Bongers</i>	
Combustion behaviour of wood chemically modified with DMDHEU-, PF-, and MF-resins	275
<i>Zhijun Zhang, Zefang Xiao, Holger Militz, Carsten Mai, Yanjun Xie</i>	
 Session 4B: Thermal Modification	
Potential to limit variation in durability of thermally modified timber	284
<i>Joris van Acker, Jan Van Den Bulcke</i>	
Thermovuoto thermal modification of eight European wood species	292
<i>Ignazia Cuccui, Nasko Terziev, Giovanna Bochicchio, Ottaviano Allegretti</i>	
Differences in the mechanical behaviour of wood after thermal modification in oven-dry or water-saturated state	300
<i>Michael Altgen, Tuuli Uimonen, Lauri Rautkari</i>	
Thermal modification of wax impregnated wood	308
<i>Miha Humar, Davor Kržišnik, Boštjan Lesar, Nejc Thaler, Aleš Ugovše, Gregor Rep</i>	
The role of accessible hydroxyl groups in reversible and irreversible EMC changes by thermal wood modification	316
<i>Wim Willems, Michael Altgen, Lauri Rautkari</i>	
 Session 5: COST FP 1407	
Wood Furfurylation as a way to valorise European Beech and promote Circular and Bio-Economy	323
<i>Christine Gérardin, Aurélie Imbert, Prabu Satria Sejati, Emmanuel Fredon, Stéphane Dumarçay, Eric Masson, Arnaud Besserer, Benoit Laibe, Rémi Laibe, Hugo Sellier, Philippe Gérardin</i>	
Dynamic Mechanical Thermal Analysis of Wood Modified with Bio-Polyesters	331
<i>Charlotte Grosse, Morwenna Spear, Simon Curling, Marion Noël, Lauri Rautkari, Tuuli Uimonen, Philippe Gérardin</i>	
Perception and evaluation of modified wood	339
<i>Dean Lipovac, Michael D. Burnard, Andreja Kutnar</i>	

Table of Contents

Valorization of Beech Wood through Development of Innovative Friendly Environmentally Chemical Modification Treatments	347
<i>Mahdi Mubarak, Stéphane Dumarcay, Holger Militz, Philippe Gérardin</i>	
Infrared spectroscopy and chemometric methods for the evaluation of the thermal/chemical treatment effectiveness of hardwoods	355
<i>Carmen Mihaela Popescu, Davor Kržišni, Miha Hočevár, Miha Humra, Nejc Thelar, Maria-Cristina Popescu, Dennis Jones</i>	
Performance of modified wood in service – multi-sensor and multi-scale evaluation	363
<i>Anna Sandak, Jakub Sandak, Marta Petrillo, Paolo Grossi</i>	
Carbon footprint of decking materials- a comparison of modified wood and preservative treated wood	371
<i>Lars Tellnes, Gry Alfredsen, Per Otto Flæte, Lone Ross Gobakken</i>	
 Session Six A: Properties 2	
Strength classification of acetylated radiata pine	380
<i>Ferry Bongers, John Alexander</i>	
Effect of DMDHEU modification on physical and mechanical properties of top-layer lamellas for multi-layer parquet flooring	386
<i>Lukas Emmerich, Holger Militz</i>	
Cutting forces when machining thermally modified poplar – preliminary results	396
<i>Giacomo Goli, Rémi Curti, Bertrand Marcon, Antonio Scippa, Marco Fioravanti, Gianni Campatelli, Louis Denaud</i>	
Properties of MMA treated thermally modified Norway spruce wood	401
<i>Boštjan Lesar, Luka Škrlep, Miha Humar</i>	
Differential expression of <i>Postia placenta</i> wood decay genes in modified wood	410
<i>Rebecka Ringman, Annica Pilgård, Martina Kölle, Klaus Richter</i>	
 Session Six B: Chemical Modification	
Suitability of Lignin-Derived Monophenols to Replace Phenol in Phenol-Formaldehyde Resin for the Use in Wood Treatment	419
<i>Vladimirs Biziks, Marco Fleckenstein, Carsten Mai, Holger Militz</i>	
A new method of wood protection by chemical modification with polyglycerol succinate copolymer	427
<i>Clément L'Hostis, Emmanuel Fredon, Marie France Thevenon, Philippe Gérardin</i>	
The effect of humidity and temperature on the dynamic-mechanical behaviour of phenol-formaldehyde impregnated beech wood veneer	435
<i>Leo Felix Munier, Tom Franke, Nadine Herold, Alexander Pfriem</i>	

Table of Contents

Biopolyesters for wood modification: technical validation towards implementation	441
<i>Marion Noël, Charlotte Grosse, Ingunn Burud, Marie-France Thévenon, Philippe Gérardin</i>	
The Maillard reaction for wood modification: The influence of reagent concentrations, reaction temperature and soaking time on the leachability and cell wall penetration of reagents	449
<i>Kelly Peeters, Andreja Kutnar, Črtomir Tavzes, Jaka Pečnik, Callum A.S. Hill</i>	
Session Seven: Poster Session 2	
Wood thermal modification and impregnation: some aspects of double treatment	458
<i>Bruno Andersons, Dace Cirule, Nīna Kurnosova, Ilze Irbe, Ingeborga Andersone, Oskars Bikovens, Andis Antons, Edgars Kuka, Žanete Zommere</i>	
Hydrophobisation of hardwood surfaces by means of environmentally-friendly fine wax particles	464
<i>Benjamin Arminger, Wolfgang Gindl-Altmutter, Christian Hansmann</i>	
Further Treatment Option after Longitudinal Wood Compression	469
<i>Mátyás Báder, Róbert Németh</i>	
Effect of combined modification processes on the physical properties of wood	475
<i>Miklós Bak, Róbert Németh, Norbert Kelemen</i>	
Bending properties and strain fields around knots in thermally modified timber	481
<i>Joran van Blokland, Stergios Adamopoulos, Anders Olsson, Jan Oscarsson</i>	
Thermomechanical (TM) treatment of beech wood (<i>Fagus sylvatica</i> L.) to substitute Indian rosewood (<i>Dalbergia latifolia</i> ROXB.) in musical instruments - mechanical and acoustic properties	487
<i>Tobias Dietrich, Dr. Mario Zauer, Robert Krüge, Prof. Dr. André Wagenführ</i>	
4 years field study in contact with the ground of thermomodified Scots pine sapwood	493
<i>Andrzej Fojutowski, Andrzej Noskowiak and Aleksandra Kropacz</i>	
Mineralization of wood with calcium oxalate	498
<i>Tom Franke, Thomas Volkmer</i>	
Preparation of thin functional coatings on wood and WPC materials using atmospheric pressure plasma jets	504
<i>Sven Gerullis, Andreas Pfuch, Florian Kettner, Katharina Plaschkies, Bernd Grünler, Mario Beyer, Gennadi G. Volokitin</i>	

Table of Contents

Investigation of Birch Wood Impregnation with Phenol-Formaldehyde (PF) Resins	510
<i>Juris Grinins, Ilze Irbe, Vladimirs Biziks, Janis Rizikovs, Sascha Bicke, Holger Militz</i>	
Thermal properties and density profile of poplar wood (<i>Populus nigra</i> L.) thermally and thermo-mechanically modified	516
<i>Marek Grzeřkiewicz, Karol Poddębski</i>	
Water sorption properties of surface charred wood	522
<i>Maija Kymäläinen, Saara Hautamäki, Lauri Rautkari</i>	
Energy dispersive x-ray fluorescence (ED-XRF) for the multi-elemental analysis of thermally modified wood treated with coatings systems	528
<i>René Herrera Díaz, Marco Fellin, Martino Negri, Jalel Labidi</i>	
Thermowood® vs Termovuoto process – comparison of thermally modified timber in industrial conditions	533
<i>Mohamed Jebrane, Ignazia Cuccui, Ottaviano Allegratti, Ernesto Uetimane Jr., Nasko Terziev</i>	
Study on Drying Characteristics of Poplar Wood Impregnated with Urea-formaldehyde Resin	539
<i>Yang Lihu, Yuan Haiguang</i>	
Life cycle assessment of bio-based façades during and after service life: maintenance planning and re-use	545
<i>Marta Petrillo, Jakub Jakub, Anna Sandak, Paolo Grossi, Andreja Kutnar</i>	
Raman spectral imaging of chemically modified Scots pine	551
<i>Carmen Mihaela Popescu, Lauri Rautkari, Michael Altgen, Tiina Belt, Mikko Mäkelä</i>	
Changes in longitudinal modulus of elasticity of Douglas-fir during low temperature thermal treatment	557
<i>Dan Ridley-Ellis, Carmen-Mihaela Popescu</i>	
Investigation of the effect of moderate heat treatment on wood hygroscopicity by NMR relaxometry	563
<i>Leila Rostom, Denis Courtier-Murias, Stéphane Rodts, Sabine Caré</i>	
Effect of wood modification and weathering progress on the radiation emissivity	569
<i>Anna Sandak, Jakub Sandak, Marta Petrillo, Paolo Grossi</i>	
Composition of monosaccharides in aqueous extracts from thermally modified wood	575
<i>Ekaterina Sidorova, Olov Karlsson, Dick Sandberg</i>	
Insights into stability of glued joints between thermally modified timber: adaptation of an artificial weathering test	581
<i>Morwenna Spear, Raisa Teciu, Graham Ormondroyd</i>	

Table of Contents

Water resistant tannin polymers	587
<i>Gianluca Tondi, Lukas Sommerauer</i>	
Dynamic and static mechanical properties of <i>Eucalyptus nitens</i> thermally modified in an open and closed reactor system	592
<i>Maximilian Wentzel, Christian Brischke, Holger Militz</i>	
Session 8: Performance	
Enhancing the material properties of wood through furfurylation	600
<i>Wanju Li, Changhua Fang, Hankun Wang, Xuexia Zhang, Dan Ren, Yan Yu</i>	
Comparative studies on the biological durability of identical thermally modified wood from field and laboratory tests	608
<i>Sven Hertrich, Lothar Clauder, Silke Lautner, Alexander Pfriem</i>	
Appearance of solid wood decking: requirements and assessment	616
<i>Wolfram Scheiding, Philipp Flade, Katharina Plaschkies, Björn Weiß</i>	
Monitoring the performance of Accoya in different applications	623
<i>René Klaassen, Bôke Tjeerdsma, René Hillebrink</i>	
Performance of chemically modified wood under marine conditions during nine years of exposure	630
<i>Christian Brischke, Antje Gellerich, André Klüppel, Holger Militz</i>	

Life cycle assessment of bio-based façades during and after service life: maintenance planning and re-use

Marta Petrillo¹, Jakub Jakub^{2,3,4}, Anna Sandak⁵, Paolo Grossi⁶ and Andreja Kutnar^{7,8}

¹CNR-IVALSA, via Biasi 75, 30010 San Michele all'Adige, Italy [email: petrillo@ivalsa.cnr.it]

²InnoRenew CoE, Livade 6, 6310 Izola, Slovenia [email: jakub.sandak@innorenew.eu]

³CNR-IVALSA, via Biasi 75, 30010 San Michele all'Adige, Italy [email: sandak@ivalsa.cnr.it]

⁴University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technology, Glagoljaska 8, 6000 Koper, Slovenia

⁵CNR-IVALSA, via Biasi 75, 30010 San Michele all'Adige, Italy [email: anna.sandak@ivalsa.cnr.it]

⁶CNR-IVALSA, via Biasi 75, 30010 San Michele all'Adige, Italy [email: grossi@ivalsa.cnr.it]

⁷InnoRenew CoE, Livade 6, 6310 Izola, Slovenia [email: andreja.kutnar@innorenew.eu]

⁸University of Primorska, Andrej Marušič Institute, Muzejski trg 2, SI-6000 Koper, Slovenia [e-mail: andreja.kutnar@upr.si]

Keywords: bio-based material, cascading, end-of-life, façade, life cycle assessment, re-use, service life

ABSTRACT

New developments in the field of wood protection, coupled with the European political determination to lower the environmental impact of the building sector, designates wood and bio-based materials as an excellent option for building façades. Despite that, the share of wood in the European wood construction market is low, with the exception of some North European countries. For that reason, it is necessary to increase a confidence in bio-based façades by demonstrating their environmental performances during and after the service life by means of solid scientific tools and experimental evidences. As a pilot study, we investigated the interactive LCA in two maintenance scenarios (high and low intensity), assuming two diverse cladding bio-materials (untreated sawn wood and chemically modified wood). A dedicated software tool was developed for the needs of these analysis allowing dynamic simulation of environmental impact and immediate visualization of the LCA contributions. The end-of-life options were assessed with a different approach. Firstly, several alternative scenarios for re-use that are available on the market were identified and listed. Secondly, we established a weight-based expert system expressing importance/advantage of each scenario in order to classify each end-of-life option according to its provision of environmental benefit. Finally, we assessed the suitability of each defined end-of-life option for all evaluated bio-based materials.

INTRODUCTION

The construction sector represents a large proportion of the consumption of the earth's non-renewable resources in terms of materials used for construction and energy consumption for operation of buildings. Aggregate, concrete and bricks are the most used construction materials in Europe, covering 45%, 42% and 6.7% of the total volumes respectively. At the same time, the share of timber structures accounts for only 1.6% of the total (Herczeg *et al.* 2014). Energy consumption of buildings in developed countries comprises 20-40% of the total energy use, more than industry and transport sectors (Pérez-Lombard *et al.* 2008). To reduce the use-phase costs of buildings, the selection of optimal building envelope systems can be crucial. However, materials for building envelope can have a high manufacturing costs (both economic and environmental). It is reported in several studies that the bio-based building materials have lower

embodied energy than traditional ones (Kovacic *et al.* 2016, Lugt and Bongers 2016, Lupíšek *et al.* 2015, Werner and Richter 2007, Zabalza Bribián *et al.* 2011). Moreover, as bio-based materials are renewable, these are suitable at the end of service life for diverse paths of re-use (Thonemann and Schumann 2018). In spite of the economic crises, the production of some now well-established engineered wood products for structural use, such as cross-laminated timber (CLT), is intensively growing in Europe and globally (Brandner *et al.* 2016). Moreover, the improvements of the new wood-based products make these suitable to substitute some fossil-based raw materials. It is foreseen that there is a potential to doubling the added-value of the wood industry by 2030 (Hetemäki and Hurmekoski 2016). Furthermore, recent technological developments allow mass production of wood-based products (modified wood) that still few years ago were at the prototype stage (Mantanis 2017, Sandberg *et al.* 2017). The environmental impact of the production phase is disclosed for some modified wood products in dedicated EPD documents or LCA-related literature. For example, the carbon footprint of 1 m³ of chemically modified wood can vary between 258 and 511 kg CO₂eq (Lambert and Daae 2015, Vogtlander 2015), while that of 1 m³ of thermally modified wood can be between 131 and 133 kg CO₂eq (Ferreira *et al.* 2018). Nevertheless, the data differ greatly based on wood species, process-specific inputs and outputs, type of production plant, transportation, among the others. The environmental impact of the service life of wood-based façades has been rarely assessed, also because it is complicated to properly define the service-life duration, the limit state for maintenance operations and, consequently, to calculate the maintenance frequency (Grüll *et al.* 2011). In order to fill this gap, we developed a software tool that calculates the environmental impact of the maintenance of wood-based façades. The system was tested on two case scenarios of maintenance: high frequency/intensity and low frequency/intensity for two diverse wood-based façade solutions.

EXPERIMENTAL

Life cycle assessment (LCA) method was applied to four elementary maintenance operations typically executed on façades: cleaning, sanding, recoating and replacing (Petrillo *et al.* 2018). Figure 1 presents a graphical representation of the abovementioned operations/modules, including summary of the life cycle inventory data as used for environmental impact computation. All the modules can be combined together in an interactive LCA, where the user can define several variables describing the real-life scenario of the façade usage. The intensity of maintenance, material performance, local macroclimate as well as the owner's tolerance for aesthetical deficiencies are particularly important factors affecting the LCA results. We tested the cleaning operations considering both presence or absence of a detergent in addition to the water. Therefore, the output can be only water or water contaminated with the detergent. These two options were tested in two different scenarios. The use of electricity was included to account for the use of pressure-machine (power 1,5-2 kW, work efficiency 0,015-0,025 h/m²) in the cleaning operations. The sanding operations include sandblasting with pressure machine (power 1,5-5,5 kW, work efficiency 0,025-0,008 h/m²) and a natural abrasive media, such as corn cob or walnut shells. The type of waste flow can be different: only sawdust in the case of sanding natural, untreated wood, sawdust and waste paint in the case of coated wood, sawdust with chemicals in the case of impregnated wood. Three scenarios were calculated considering the re-use of the abrasive media. Usually, this operation is a preliminary step before re-coating.

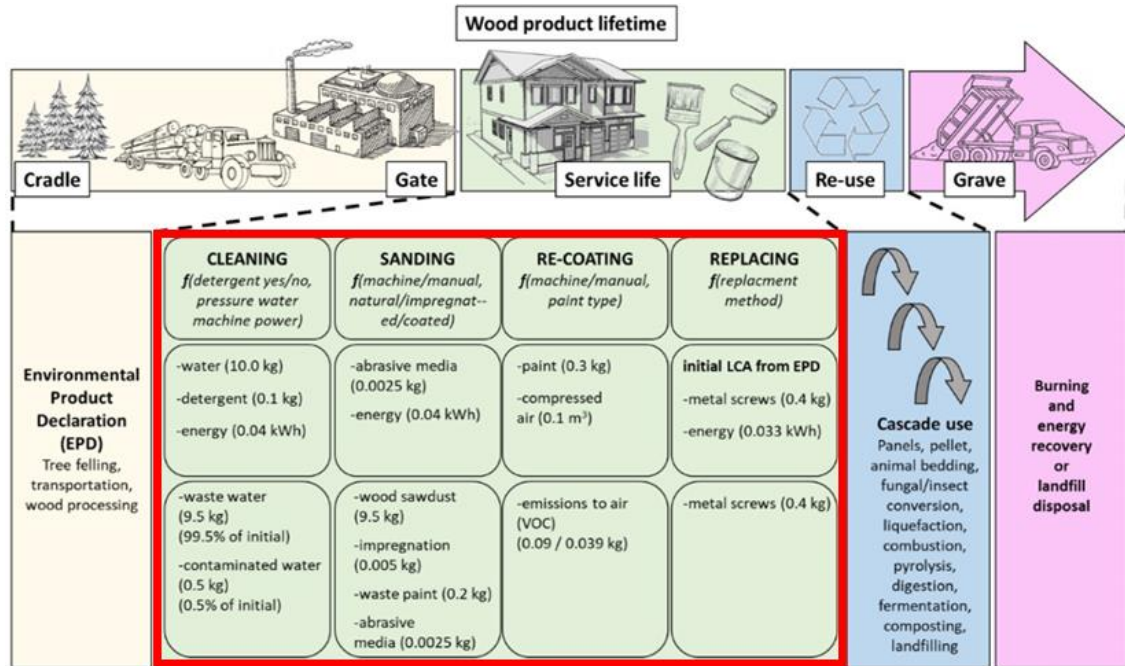


Figure 1: Lifetime of wood products with emphasis on service life. Maintenance modules are described in terms of input and output of materials and natural resources (life cycle inventory) (Petrillo et al. 2018).

The options for re-coating were based on acrylic and alkyd paints, water- or solvent-based. Moreover, all paint types were calculated for the options: hand-painting or machine-painting (spray-machine with compressed air). For the replacement operations, we considered the substitution of 25% of the façade in terms of the new material (data from available EPDs) and the environmental impact of the operations for replacement (metal screws, screwdriver energy demand). Then, we hypothesised two maintenance scenarios: high level of maintenance, due to harsh climate and high esthetical standard, and low level of maintenance, due to mild climate and low aesthetical standard. Based on practitioners' experience, scientific literature and technical data provided by material producers, we defined the maintenance options and their frequency in the four cases, as represented in Table 1.

Table 1: Condition for simulation of four case scenarios in 20 years of service life

	Case 1	Case 2	Case 3	Case 4
Climatic conditions	Harsh	Mild	Harsh	Mild
Material type	Natural wood (conifer)	Natural wood (conifer)	Chemically modified wood	Chemically modified wood
Owner aesthetical standard	High	Low	High	Low
Cleaning (times in 20 years)	6	2	9	3
Sanding + Re-coating frequency (times in 20 years)	2	1	0	0
Replacing frequency (times in 20 years)	1	0	0	0

Finally, we defined a system to weight different end-of-life (EOL) scenarios. The system takes into account for each EOL option the factors which are relevant for the calculation of LCA, such as: the potential for multiple re-use, the demand of additives for the new use, the energy required for the process and, finally, the possibility to recover energy at the end of the re-use cascade.

RESULTS AND DISCUSSION

The results indicate that the environmental impact of the use phase can vary greatly due to the climate and user, as represented in Figure 2.

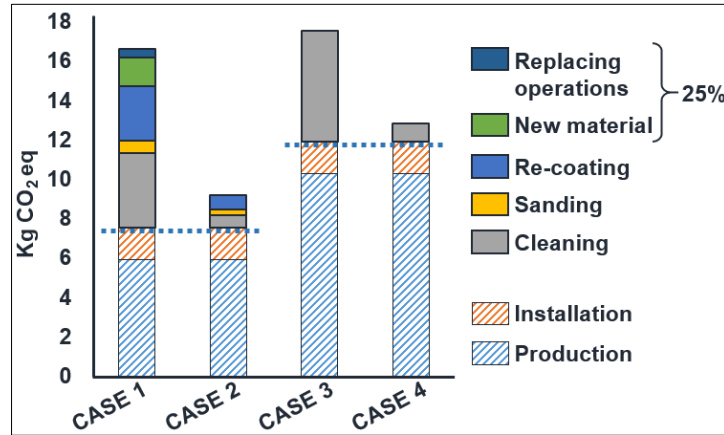


Figure 2: Environmental impact of production, installation and maintenance of 1 m² of façade made with untreated wood (case 1 and case 2) and chemically modified wood (case 3 and case 4) in high maintenance scenario (case 1 and case 3) and low maintenance scenario (case 2 and case 4).

For high frequency and intensity of maintenance, the total environmental impact of the natural wood façade and that of the chemically modified wood façade are comparable. In fact, the lower impact of the production of natural wood in comparison to the chemically modified wood is compensated by the higher impact of the maintenance operations for natural wood façade. However, in the mild climate, the natural wood has sensitively lower impact than chemically modified wood. The proposed system for interactive LCA is suitable for every possible combination of climate, material, design and customer aesthetical standard. Finally, in Table 2 we present the selection of the end-of-life scenario.

Table 2: End-of-life (EOL) features and their weights based on environmental impact. The total score indicates the environmental friendliness for each end-of-life option.

	Allow re-use	Require additives	Reuse without processing	Reuse with processing	High energy	Low energy	Energy recovery	No energy recovery	
Weights for EOL feature	10	-5	7	3	-5	-1	5	-7	Total score
Landfilling	0	0	1	0,1	0	1	0	0,9	0
Composting	0	0	0,1	0,9	0,1	0,9	0,2	0,2	2
Liquefaction	0,8	1	0	1	1	0	0,7	0,2	3
Fermentation	0,2	0	0,1	0,5	0,1	0,9	0,8	0,2	5
Anaerobic digestion	0,2	0	0,2	0,5	0,2	1	0,8	0,2	6
Combustion	0	0	0,1	0,9	0,1	1	1	0	7
Incineration	0	0	0,1	0,9	0,1	1	1	0	7
Pelletizing	0,4	0	0	1	0,9	0	1	0	8
Gasification	0,2	0	0,1	0,9	0,2	1	1	0	8
Pyrolysis	0,2	0	0,1	0,9	0,2	1	1	0	8

	Allow re-use	Require additives	Reuse without processing	Reuse with processing	High energy	Low energy	Energy recovery	No energy recovery	
Animal bedding	0,5	0	0	1	0,1	0,9	0,5	0,1	8
Panel manufacturing	0,9	0,5	0,2	0,8	0,8	0,2	1	0,1	10
Fungal conversion	0,7	0	0,8	0,4	0,1	0,9	0,4	0,2	13
Insect conversion	0,7	0	0,6	0,8	0,2	0,9	0,5	0,1	14
Re-use in solid products	1	0	1	0,1	0,1	1	1	0,1	20

CONCLUSIONS

In conclusions, the interactive LCA system that we propose allows rational choice of material and maintenance operation during service life. In fact, based on the location it will be possible to forecast a realistic maintenance plan, which will be customized according to the aesthetical expectation of the user.

ACKNOWLEDGEMENTS

The BIO4ever (RBSI14Y7Y4) is a project funded within the call SIR (Scientific Independence of young Researchers) by MIUR. The authors gratefully acknowledge the European Commission for funding the InnoRenew CoE project (Grant Agreement #739574) under the Horizon2020 Widespread-Teaming program.

Special acknowledgments to COST FP1303, FP1407 and TU1403 for funding STSMs that contributed to the project and all BIO4ever project partners.

REFERENCES

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G., and Thiel, A. (2016). Cross laminated timber (CLT): overview and development. *European Journal of Wood and Wood Products*, **74**(3), 331-351.

Ferreira, J., Herrera, R., Labidi, J., Esteves, B., and Domingos, I. (2018). Energy and environmental profile comparison of TMT production from two different companies – a Spanish/Portuguese case study. *iForest*, **11**, 155-161.

Grüll, G., Truskaller, M., Podgorski, L., Bollmus, S., and Tscherne, F. (2011) Maintenance procedures and definition of limit states for exterior wood coatings. *European Journal of Wood Product*, **69**, 443-450.

Herczeg, M., McKinnon, D., Milios, L., Bakas, I., Klaassens, E., Svatikova, K., and Widerberg, O. (2014). Resource efficiency in the building sector. *Final Report for DG Environment*.

Hetemäki, L. and Hurmekoski, E. (2016). Forest products markets under change: Review and research implications. *Current Forestry Reports*, **2**, 177-188.

- Kovacic, I., Waltenbereger, L., and Gourlis, G. (2016). Tool for life cycle analysis of facade-systems for industrial buildings. *Journal of Cleaner Production*, **130**, 260-272.
- Lambert, N. and Daae, J. (2015). LCI/LCA report: Kebony Scots Pine Cladding, Roofing and Decking. Kebony AS, Norway.
- Lugt, P. Van Der, and Bongers, F. (2016). Environmental Impact of Constructions Made of Acetylated Wood. *Proceedings of the WCTE 2016 World Conference on Timber Engineering*, Vienna / Austria, August 22-25, 2016.
- Lupíšek, A., Vaculíková, M., Mancík, S., Hodková, J., and Ržika, J. (2015). Design strategies for low embodied carbon and low embodied energy buildings: Principles and examples. *Energy Procedia*, **83**, 147-156.
- Mantanis, G. I. (2017). Chemical modification of wood by acetylation or furfurylation: A review of the present scaled-up technologies. *BioResources*, **12**(2), 4478-4489.
- Pérez-Lombard, L., Ortiz, J., and Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, **40**(3), 394-398.
- Petrillo, M., Sandak, J., Grossi, P., Kutnar, A. and Sandak A (2018). Long service life or cascading? The environmental impact of maintenance of wood-based materials for building envelope and their recycling options. *IRG/WP. Proceedings IRG49 Annual Meeting 2018*, Johannesburg, South Africa, April 29-May 3, 2018.
- Sandberg, D., Kutnar, A. and Mantanis, G. (2017). Wood modification technologies - A review. *iForest*, **10**, 895-908.
- Thonemann, N., and Schumann, M. (2018). Environmental impacts of wood-based products under consideration of cascade utilization: A systematic literature review. *Journal of Cleaner Production*, **172**, 4181-4188.
- Vogtlander, J. (2015). Accoya wood – cladding, decking and planed timber for joinery applications. Report nr. 1, Accsys Technologies PLC, The Netherlands.
- Werner, F., and Richter, K. (2007). Wooden building products in comparative LCA: A literature review. *International Journal of Life Cycle Assessment*, **12**(7), 470-479.
- Zabalza Bribián, I., Valero Capilla, A., and Aranda Usón, A. (2011). Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Building and Environment*, **46**(5), 1133-1140.



zekerheid met meerwaarde



ModWoodLife

ISBN: 978-90-829466-1-1