COST Action FP1303 Performance of Bio-based building materials

# Performance and maintenance of bio-based building materials influencing the life cycle and LCA

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Kranjska Gora, Slovenia
23-24 October 2014

Editors: Andreja Kutnar, Miha Humar, Michael Burnard, Mojca Žlahtič and Dennis Jones

University of Ljubljana Biotechnical Faculty and University of Primorska

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**INDEX**

## Preface

Welcome to the first annual conference in COST Action FP1303 "Performance of Biobased Building Materials". This conference, held in Kranjska Gora, Slovenia on 23-24 October 2014, represents the culmination of a busy and very successful first year within the COST Action.

Maintaining and expanding the market potential for bio-based building products in indoor and outdoor construction uses remains a key activity for European industry in the forestry and biotechnological sector. Performance data for many environmental friendly building materials are lacking as well as suitable comprehensive test methodologies to determine their resistance against mould, stain, and decay. The similarity in terms of decay hazard, resulting response on climatic loads and thus performance of different bio-based building materials has not yet been recognised adequately, wherefore this Action will provide a platform for networking and scientific exchange between different disciplines, such as material sciences, wood technology, biology, biotechnology, building physics and engineering.

During our first year, we have held a workshop in Paris, a session at the 7th European Conference on Wood Modification in Lisbon and now this conference. In addition, there have been several Short Term Scientific Missions and a very successful Training School, held in Hannover in June. Also we have launched an evaluation trial, with test samples now under test at some 28 sites across Europe. These trials have created interest from other countries, which may lead to test rigs being exposed at sites globally!

When we started exactly one year ago with our first Management Committee meeting in Brussels, experts from 23 countries had joined the Action. Our family has grown slightly – now there are 27 EU countries, as well as Ukraine and we are in the process of finalising the participation of Scion from New Zealand. Given the worldwide activities in understanding the performance of materials for our built environment, it is hoped that more countries will join during the remaining three years.

Since the opening meeting in Brussels, our Action has attracted interest from a lot of young researchers, who have had opportunities to discuss ideas and their research with many of the foremost experts in areas such as wood and fibre treatments and modification, biological and performance testing of products, composite technology, building physics, material-moisture interactions and environmental considerations (including Life Cycle Assessments and Environmental Product Declarations). Having such a group of experts present in one place makes these meetings a vibrant exciting place to be!

For any meeting to be successful, it is essential to have a good team working together. I wish to express my sincere gratitude to the local organisers and scientific committee for their help and advice in making this conference a reality. In addition, a meeting is judged on the quality of the presentations given and I wish to thank all those who submitted the abstracts within this book. Just by looking at the agenda and reading the abstracts, it is obvious we will have two intensive days covering a wide range of topics, accompanied by many discussions.

I wish to welcome everyone to Kranjska Gora and hope you all have two interesting and scientifically stimulating days!

Dennis Jones
Chair, COST FP1303

**Foreword**

Wood is an important renewable resource in Slovenia (60% forest area coverage in Slovenia, with 71 naturally occurring tree species). Norway spruce, beech and silver fir represents almost 80% of the wood stock in the forests. However, the potential wood harvest allowance has been underutilised by approximately 50% in recent years. Unfortunately, Slovenian forests were seriously damaged by the ice storm this winter. Approximately 9 million $m^3$ of wood was damaged and has to be processed into an array of composites that can be used for various building applications. This damage further reduces the value Slovenia can gain from a raw resource that is predominately exported for primary processing. Despite this, the internal share of wood-based construction in Slovenia has risen from 3 to 10% in the last 15 years. In 2012, Slovenia produced 649 wood-based manufactured homes; two-thirds of them were exported. It can be expected that this number will continue to increase due to European and Slovenian environmental policies as well as human awareness of the quality of life provided by wooden construction. Furthermore, raw material availability is one of Slovenia's competitive advantages in the sustainable building arena.

The importance of wood based building materials is increasing in recent years as well. One of the reasons for this is support from Green Public Procurements process. In the Buildings category, it is in generally required that 30% of in-built material by volume must be wood or wood-based (50 % of that –15 % total volume – can be substituted by products certified with EcoLabels I or III). It is expected, that in the near future, the Green Public Procurements will predominately be based on LCA studies and the corresponding EPDs.

Research, development, and innovation in built environments, which will be discussed at the 1st FP1303 conference, "Performance and maintenance of bio-based building materials influencing the life cycle and LCA," is a very important step towards achieving of the goals laid out in the Slovenian Action plan "Wood is beautiful" (Les je lep) 2012-2020. This action plain aims to revitalize Slovenian forest-based value chains through radical implementation of innovation. We believe that this meeting will contribute to improvements and increased acceptance of wood as sustainable and reliable building material.

Prof. Miha Humar, University of Ljubljana
Assist. Prof. Andreja Kutnar, University of Primorska
Local organizers

# UBC: A Living Laboratory for Sustainability

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**Keywords:** living lab, sustainability, carbon, sequestration, wood

Situated on a forested peninsula on the westernmost point of Vancouver, Canada on the Pacific coast, the University of British Columbia (UBC) campus has a total area of 405 hectares and more than 400 buildings. UBC is a community of 75,000 people that use the campus infrastructure and facilities for academic, residential, commercial, agricultural and operational purposes

Sustainability is a growing priority for higher education institutions around the world. Many universities are responding to global imperatives by committing to strong environmental sustainability goals and targets (Cayuela et al. 2013). UBC has enacted polices and formulated technical guidelines with strong sustainability performance criteria that all campus projects and development initiatives must comply with (Warburton et al. 2012).

Under UBC's Campus as a Living Lab (CLL) initiative, UBC is transforming its campus into a living laboratory for sustainability to demonstrate—at a scale that is useful for replication beyond the campus boundaries—sustainable practices and technologies that engage faculty, students, staff and community partners and leverage operational innovations (Cayuela et al. 2013). In parallel to this effort, UBC is using the concept of the *sustainability gradient* as a continuous improvement model to ensure that the performance of new and retrofitted projects on campus adhere to increased sustainability stringency targets. The rationale for pushing sustainability performance up this *gradient* over time is that society needs to abandon the current environmental paradigm of *less-harm* approaches and fully adhere to *restoration and regeneration* sustainability frameworks.

At UBC, sustainable design, construction and operations include effective resource management that supports human health and well-being, as well as environmental integrity. Additionally, UBC is designing long-lasting buildings that are adaptive to change and can be deconstructed at the end of their useful life (Warburton et al. 2012). In this context wood has emerged as a key material in achieving UBC's sustainable design and construction goals. Wood is an optimal building material due to its structural, aesthetic and low environmental impact characteristics: It sequesters carbon; it is a renewable resource; it is durable; it can be locally sourced; it has an optimal strength to weight ratio for structural building products/materials and; it is versatile and can be reused and recycled for new products and applications.

In response to the enactment of British Columbia's *Wood First Act* in October 29, 2009 (that facilitates a culture of wood for construction in BC; promotes the use of wood in provincially-funded projects; encourages communities to use wood as appropriate; strengthens forest-dependent communities; and assists in meeting BC's climate change goals), wood-frame and mass-timber construction has been utilized in a variety of UBC buildings, including UBC's sustainability flagship project, the Centre for Interactive Research on Sustainability (CIRS). These projects provide a foundation for the expanded scope of wood in sustainable buildings, at UBC and demonstrate the important role that cultural significance, technical capabilities, and environmental benefits play in wood construction. The amount and variety of wood in building construction is increasing at UBC and wood is becoming integral to the character and identity of the UBC campus.

Figure 1: The main lobby/atrium of the Centre for Interactive Research on Sustainability on the UBC campus in Vancouver, Canada.

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# Wooden products in WECOBIS - Bio based building products in a web based information system for health and environmental issues

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**Keywords:** WECOBIS, web based information system, wooden products, health, environment

In the past few years sustainable building has gained more and more importance. Building certification schemes, such as the BNB-system (Assessment System for Sustainable Building) are increasingly applied. Within a certifying process, there are several aspects of sustainability interacting directly together. One main aspect is the environmental performance of a building. Therefore life cycle assessment data of building products are provided by environmental product declarations (EPDs) and publicly available databases (e.g. the German "ÖKOBAU.DAT", Ökologische Baustoffdatenbank).

In addition to these mainly numerically provided data for certain assessment schemes, WECOBIS (web based ecological information system for building products) is addressed to architects, planners, house builders as well as the interested public and gives more general information on environmental and health issues for building products. Launched in 2000, WECOBIS is operated by the Bavarian Chamber of Architects (ByAK) and the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), which is a departmental research institution under the portfolio of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). WECOBIS covers 31 basic construction materials (e.g. concrete, steel, plastics) and contains more than 160 product groups (e.g. mineral wool, floorings, particleboards). Specific expertise for the articles of the website is delivered by 10 different external editor groups from universities, federal research organizations and other research institutes.

In WECOBIS each product group is introduced by general information, such as the main ingredients, scope of application and the technical properties. Additionally, the web pages provide detailed insights in environmental and health issues for the life cycle phases raw material extraction, manufacturing, assembling, use and end of life.

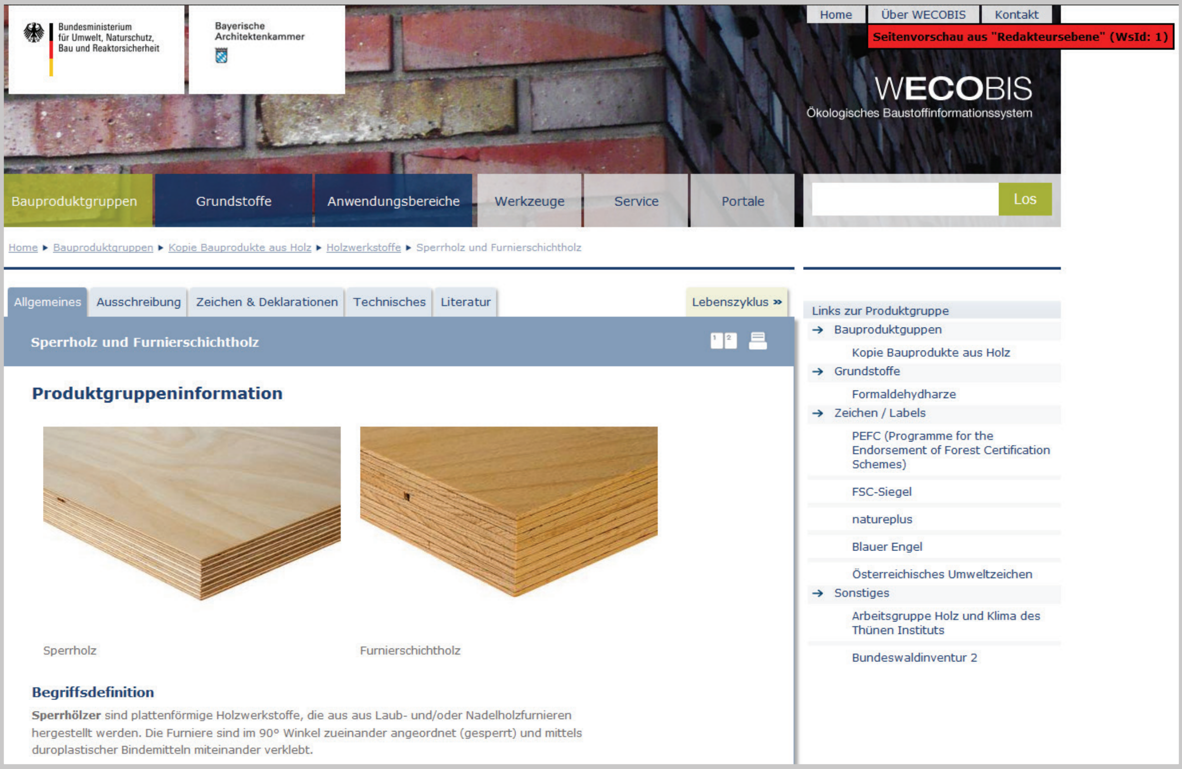


Figure 1: Screenshot from WECOBIS showing general information on plywood and laminated veneer lumber

As external editors, scientists of the Thünen Institute of Wood Research contribute with their expertise on wooden products. From sawn wood and glued laminated timber to plywood and particleboards, the editors highlight the special characteristics of each product with a focus on ecological issues. Starting with sustainable forest management the user gets information on typical transport distances of round wood, energy demands of sawmills or panel factories as well as emissions and waste occurring along the whole supply chain. Health related characteristics are especially mentioned for the use phase. Pages on the end of life introduce the waste wood categories as well as the different treatment options after use. In addition to information from the industry sector and from specific literature, the research results from the Thünen Institute are provided on life cycle assessment, VOC-/formaldehyde-emissions and on wood preservation.

Up to now, WECOBIS supplies information about mere building materials. The BBSR aims at expanding the website to structural and non-structural building elements. In the case of wooden products, the Thünen Institute intends to contribute on doors and windows as well as wood-based walls, ceilings and roof constructions.

# Survey of allocation methods in life cycle assessments of wood based products

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**Keywords:** wood products, sawmill, allocation method, allocation factor

Allocation is the tool for partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. Wherever possible, allocation should be avoided by either dividing the unit process or expanding the product system. If related co-production processes are not independent and can't be separated; allocation has to consider primary purpose of processes and assign it to all relevant products and functions adequately. Jungmeier et al. 2002 describes a three step procedure, how to deal with situations where an allocation is necessary. As a first step, wherever possible, allocation should be avoided. As a second step, the inputs and outputs should be partitioned in such a way that reflects the underlying physical relationship between them. Where physical relationship alone cannot be used as the basis for allocation, different relationships (e.g. economic values) can be chosen.
It is discussed which of these methods should be applied on wooden products, in order to picture reality in the most convincing way. Therefore, using the example of sawn timber and residues in sawmills, the first step in the production of wooden building products. Different approaches are analyzed and resulting allocation factors compared.

**Comparison of physical and economic allocation**
Precondition to use physical values for allocation is that the physical values reflect the main characteristics of a product. In many cases – usually corresponding to multi-output co-products with different revenue – such physical values are not available. Mass or volume is in most cases not an appropriate figure to describe the technical value of a product. In lack of appropriate physical data, market prices are a possibility to value the products.
Comparative calculations with different price scenarios indicate the negligible impact of volatility of prices of saw mill products on LCA when applying economic allocation.

**Case study – different allocation procedures in a sawmill**

In the following case study, mentioned allocation procedures have been applied on a sawmill in Austria. The different steps of the life cycle of sawmill products, that has been analyzed, and where system boundaries for the following calculations of allocation factors in sawmills and particle board production have been drawn is shown in Fig. 1.

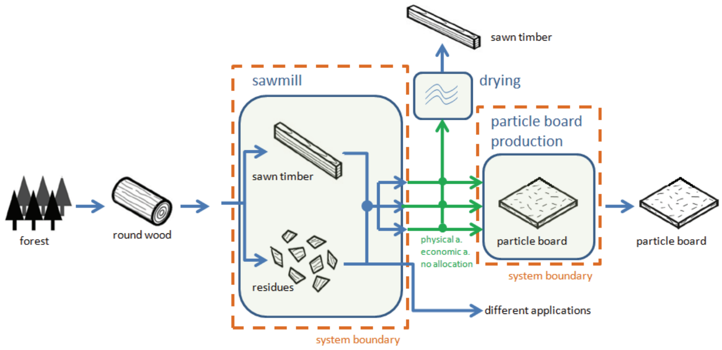


Figure 1: Table of investigations with system boundaries of carried out calculations

In contrary to (Jungmeier et al. 2002), results in Fig. 2 show huge discrepancies between the different methods. This means that, applying mass allocation, leads to lower environmental burdens for the main product (sawn timber) but higher ones for products made of residues (e.g. pulp, energy, wood pellets and particle boards). Results of environmental indicators like GWP, AP, EP etc. show huge differences as a function of the chosen allocation method.

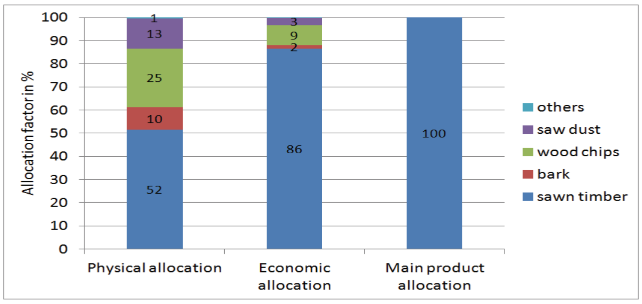


Figure 2: Allocation factor in 3 different allocation methods (own analysis)

Analysis of these case studies show, that choice of allocation method has a significant impact on results of LCA of sawmill products. With physical allocation, large burdens are attributed to low value products, if they are produced in large amounts (Lundie et al. 2007). The example of the sawmill shows the profound impact of the selected allocation method on LCA results of sawn timber. This implicates different assignment of environmental burdens to downstream processing industries like paper and particle board or building industry as well. Therefore, in a further step, investigations in the impact of allocation method decisions in sawmills on particle board production were carried out and discovered negligible influences on environmental impacts.

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# Life Cycle Assessment of maritime pine wood

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**Keywords:** environmental impacts, Life Cycle Assessment (LCA), maritime pine, wood

**Introduction**

Although wood frame construction is not common in Portugal, wood is used in building works both in carpentry and joinery. The most important wood grown in Portugal for these purposes is that from maritime pine (*Pinus pinaster* Ait.). Wood production comprises a number of operations carried out during forest management activities that are the origin of several environmental impacts The objective of this study is to quantify the environmental impacts resulting from the production of maritime pine wood in Portugal using Life Cycle Assessment (LCA).

**Methodology**

A cradle-to-gate approach is adopted and, therefore, all the forest management operations carried out up to the log loading onto trucks at the roadside were considered. The production of fuels, lubricants and fertilizers is also considered. The functional unit is the production of one $m^3$ (fresh) of roundwood under bark.

Data representative of management practices of maritime pine forest in Portugal were used. For example, the amounts of fuels consumed in motor-manual and mechanized operations were calculated based on the effective work time needed to perform each operation and the respective fuel consumption per hour of machine work. These site-specific data were complemented with data taken from literature and Ecoinvent database for the production of fuels, lubricants and fertilizers.

Different intensity levels of forest management exist within the country and, besides, different operations can be used to achieve the same goal (e.g. felling can be undertaken with a chainsaw or a harvester). Thus, three management scenarios were simulated, reflecting different management intensities and logging equipment:

(1) Scenario 1 – represents high intensity management, characterized by the adoption of the best management practices; logging is accomplished by harvesters and forwarders for wood felling and extraction;

(2) Scenario 2 – represents high intensity management as in Scenario 1; logging is carried out with more traditional machinery, namely chainsaws for wood felling and modified farm tractors for wood extraction;

(3) Scenario 3 – represents low intensity management, characterized by carrying out only logging operations, which are undertaken with chainsaws for wood felling and modified farm tractors for wood extraction.

The impact assessment was performed using characterisation factors recommended by the International Reference Life Cycle Data System (ILCD) (EC 2012). The following impact categories were considered: climate change, photochemical ozone formation, acidification, freshwater eutrophication, marine eutrophication, and mineral and fossil resource depletion.

**Results**

The results obtained for each impact category show a relatively wide range of variation for the different management scenarios. The most intensive scenarios (Scenarios 1 and 2) lead to larger impacts; the impact of Scenario 2 (where chainsaws and adapted farm tractors are used) was smaller than that of Scenario 1 (where harvesters and forwarders are used). However, the differences between them do not exceed 27%. The exceptions are the impact category freshwater eutrophication, for which the impact is the same in the two scenarios, and the impact category photochemical ozone formation, for which the use of chainsaws and adapted farm tractors generates the highest impact.

Scenario 3 leads to the smallest impacts as only logging related operations are performed and, therefore, lower amounts of fuels, lubricants and fertilizers are consumed. Again, photochemical ozone formation is an exception due to the highest impact associated with logging operations carried out with chainsaws and adapted farm tractors.

Logging operations have the largest contribution to the impacts for all the categories analysed other than freshwater eutrophication. For this impact category, the impacts are dominated by emissions derived from fertilization required at planting.

**Conclusions**

This study estimates expected ranges of variation for the impacts associated with the production of maritime pine wood in Portugal using LCA and identifies the hotspots. As maritime pine is a raw material for several products, these results could be integrated in LCA studies of those products.

**Reference**

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# Cost effectiveness of passive windows made of thermally modified spruce (*Picea abies*)

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**Keywords:** life-cycle cost, passive window, thermally modified wood

The European Energy Performance of Buildings Directive (EPBD, 2010) demands that Europe's member states achieve "nearly zero-energy" housing by 2020. One way to achieve such demands is by building energy efficient buildings according to passive standards. A generic definition of the passive house is a building with an energy demand for heating ≤ 15 kWh/m$^2$a (Feist, 1992). Such a building has a high level of insulation, an airtight building envelope, ventilation with highly efficient heat or energy recovery, is free of thermal bridges and includes well insulated window frames and glazing (IPHA, 2014). In such a building, windows present the weakest part of the building envelope and so deserve special attention. Window frames, especially, play an important role as they cover around 30 % of window area and are the weakest point of the window. The basic demand for passive window is to achieve a thermal transmittance of the window ($U_w$) of ≤ 0,80 W/m$^2$K (1,23 m × 1,48 m) with an installed insulated glass unit with thermal transmittance ($U_g$) of of 0,7 W/m$^2$K.

Timber frames of passive windows are produced in several ways. The most popular approach to achieve sufficiently low thermal transmittance of frame ($U_f$) is to install insulating material with low thermal conductivity (λ) e.g., aerogel, polystyrene, polyurethane, wood fibre board, cork, etc. or to produce profile with air cavities which work as an insulator. In all cases production of such windows is time and cost consuming. Alternatives to such approaches are to produce very thick timber frame which need special production line or to use an alternative wood species with low λ value. Spruce (*Picea abies*) is the most commonly used wood species for window production due to its good physical characteristic and relatively low λ value. Most other commonly used wood species used for window production have higher λ. However there is relatively new technology of wood modification with which λ value of e.g. spruce is decreased by almost 20 % - thermal modification (Table 1).

Windows made from thermally modified spruce have, beside better thermal characteristics, higher durability and better dimensional stability. Recently a new passive window (Natura Optimo XLT) was developed by Slovenian company M SORA. The window is made of thermally modified spruce without additional insulating materials and has a certified $U_w$ of 0,79 W/m$^2$K (1,23 m × 4,18 m). Even lower values (up to 0,66 W/m$^2$K) can be achieved if using better glazing.

Table 1: Thermal conductivity of commonly used wood species for windows

| Wood species | Thermal conductivity - λ [W/mK] |
|---|---|
| *Quercus* spp.*, Eucalyptus grandis, Robinia pseudoacacia* | 0,18[a] |
| *Shorea platyclados* | 0,16[a] |
| *Larix* spp., *Pinus sylvestris*, *Shorea argenifolia* | 0,13[a] |
| *Picea abies*, *Abies alba* | 0,11[a] |
| Thermally modified spruce (*Picea abies*) | 0,090[b] |

[a]*ISO 10077-2:2012,* [b]*Silvapro® thermally modified spruce*

In 2014, the *Passivhaus Institut* announced its "*Component award 2014*". In the scope of the competition, a calculation of life-cycle cost (LCC) of a passive window (40 years), based on the *Passive House Design Package* (PHPP) calculation tool and consumer window price was made. This was compared to LCC of standard timber window (double glazing) in accordance with German legal requirements served as reference (Table 2). A detached passive house (15 kWh/m$^2$a) located in Frankfurt am Main served as the evaluation basis and the surface area of all windows was 42,77 m$^2$.

Table 2: Comparison of basic thermal characteristics of passive and reference window

| | $U_{w,av.}$ [W/m$^2$K][a] | $U_{g,av.}$ [W/m$^2$K][b] | $g_{av.}$[b] | Annual heating demand [kWh/m$^2$a] |
|---|---|---|---|---|
| **Passive window Natura Optimo XLT** | 0,74 | 0,63 | 0,61 | 14,7 |
| **Reference wood window** | 1,41 | 1,2 | 0,60 | 28,2 |

[a]*ISO 10077-1:2007/AC:2010 or ISO 10077-2:2012 ,* [b]*EN 673,* [c]*EN 410*

Results demonstrated a 23 % LCC savings – 228 l/m$^2$ of oil for heating and 570 kg $CO_2$-eq/m$^2$ – with such a window installed over a life time compared to the use of a standard timber window. The analysis showed cost effectiveness and reduced $CO_2$ emissions if using an entirely wooden passive window.

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# Environmental considerations for biobased materials in modern methods of construction

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**Keywords:** biobased building materials, assessment, MMC

The construction sector is constantly looking to improve building performance through efficient design, better construction practices (either through onsite or offsite construction) and the use of innovative materials. Often the innovation is a result of the 'marriage' of different materials that were previously used in stand-alone applications. A good example of high performance materials, but not necessarily of biobased materials, is the manufacture of structural insulated panels (SIPS). These combine materials with high insulative properties (such as polyurethane foams) with composite materials and aluminium foils. Whilst much of the drive for development is as a direct response to governmental legislature, the desire by construction companies to stay 'one step ahead' of rivals and the increasing understanding of the general public of environmental and sustainability concerns. In order to make informed judgements and to provide impartial guidance, it has been necessary to compile a range of assessment tools to critically evaluate materials and building design. Over the first years of many of these assessment tools, emphasis was placed on using a range of synthetic materials, as they were perceived as providing better results. However, the past few years has seen a considerable increase in interest towards biobased materials, so combining performance with environmental considerations and life cycle aspects.

In terms of sustainability, one of the key factors that has grasped public imagination has been the reduction in the carbon footprint of new buildings, as well as gradual improvement of refurbished stock. European actions have been led through activities in delivering the Energy Performance of Buildings Directive (EPBD). First adopted at the end of 2002, the EPBD requires all European Union members to reduce the carbon emissions of their building stock by some 80% by the year 2050. Its revision in 2010 (Directive 2010/31/EU) meant EU Member States faced changes aiming at new and retrofitted nearly-zero energy buildings by 2020 (though the target is 2018 for public buildings).

Another tool of importance across Europe is the Construction Products Directive, which ensures free movement of certified construction products within the European Union. CPD introduces harmonised standards and European technical approvals based on product performance. All products conforming to CPD have to carry "CE" markings to demonstrate their meeting rules defined in the directive.

These methods along with assessment tools such as Building Research Establishment Environmental Assessment Model (BREEAM), CASBEE, LEED, Green Star and HQE have been developed to provide a scoring system to assess a product (Jones et al. 2011). Of these BREEAM, originating from BRE in the UK, is gaining greater international recognition. Due to their differing rating scales there is no direct comparison between assessment tools.

Current construction practices refer to the U values of materials used. The U value measures the thermal transmittance of a material (the heat conduction is given by lamda or k values). It is used in the building industry to compare the efficiency of insulating products, a good insulator having a low U-value. Some typical examples of wall systems incorporating biobased materials are shown in Table 1 (Forestry Commission Scotland 2009).

Table 1: Examples of wall systems with improved U values

| | **Basic Building Regulations** | **Enhanced** | **Enhanced (High Thermal Mass)** | **Timber High Insulation** | **Low Emissions** |
|---|---|---|---|---|---|
| Wall System | 89 x 44 Timber kit | 145 x 44 Timber kit | 145 x 44 Timber kit | 194 x 44 stud | 300 web stud |
| Wall insulat-ion | Sheathing ply / 90 mm glass fibre Service zone / 25 mm Crown Polyfoam Linerboard | Panelvent/ 145 mm cellulose (Warmcell) /OSB internal Service zone Plasterboard | 35 mm Isolair wood-fibre board/ 145 mm sheep's wool/ Paneline Service zone /Plasterboard | 60 mm Pavatherm wood-fibre board/ 194 mm sheep's wool /Paneline Service zone/ Plasterboard | Panelvent/ 300 mm cellulose (Warmcell)/ OSB internal Service zone/ Plasterboard |
| **U Value** | **0.25** | **0.24** | **0.2** | **0.14** | **0.12** |

This paper will review a range of biobased materials, their performances and evaluation according to current assessment tools and their general acceptance to date within the building sector.

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# The environmental impacts associated with wood modification

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**Keywords:** environmental product declaration, life cycle assessment, life extension, wood modification

Wood modification results in environmental impacts in addition to those associated with the production of the timber alone. In order to determine these impacts a search was made of the literature for examples of life cycle assessments and environmental product declarations related to modified wood products. A preliminary analysis of the carbon footprint of three processes has been undertaken and this is compared to the carbon storage potential of the products, calculated using European Commission Joint Research Centre (Institute for Environment and Sustainability) methods. From this it was possible to determine at what point in time the added environmental impact of the wood modification process could be offset by the life extension of the material. The impact of wood modification in reducing maintenance requirements has also been studied. This paper considers only global warming potential as an impact category, as an illustration of the principle involved. The carbon balances for the modified woods calculated according to ILCD methodology are shown in Figure 1. It is to be stressed that this is a preliminary study and that further work needs to be performed to improve the accuracy of the data, but nonetheless the graphs can be used to illustrate some important issues. It should be stressed that these data should not be used to make comparisons between the different products. The data is preliminary and requires much refinement. According to this analysis, the point at which carbon neutrality (CN) is achieved, when the carbon storage is calculated according to ILCD methods, is greater for the modified wood compared with the unmodified wood. It should also be noted that CN is reached in a shorter time for Scots pine compared to radiata pine because of the higher density of Scots pine. It also apparently takes a longer time for Accoya™ and Thermowood® to reach the CN point compared with Kebony®, but such a comparison is not sensible given the source of the data. For example, in the Accoya™ EPD, there are credits given for the acetic acid by-product, included in the downstream process, which is not included in this analysis. With Kebony®, the furfural alcohol used in the modified wood is derived from a renewable resource and therefore contains biogenic carbon, but this has not been included in the present calculation. The data for Thermowood® does not include any possible use of biomass for the thermal modification process. Based upon the data used in the calculations, it can be seen that a life extension of approximately 2½x is required for Accoya™ and Kebony® in order to compensate for the environmental impact associated with the modification process. Rather longer is required for the Thermowood® as a result of the lower density of the modified wood compared to unmodified, resulting in a reduced quantity of sequestered atmospheric carbon (however, no account has been taken here of changes in the C,H,O ratios due to thermal modification). Given the improvements in durability associated with each modification, the necessary life extensions should be readily achievable in practice. The effect of increased time between repainting for the modified timbers is explored in Fig. 2.

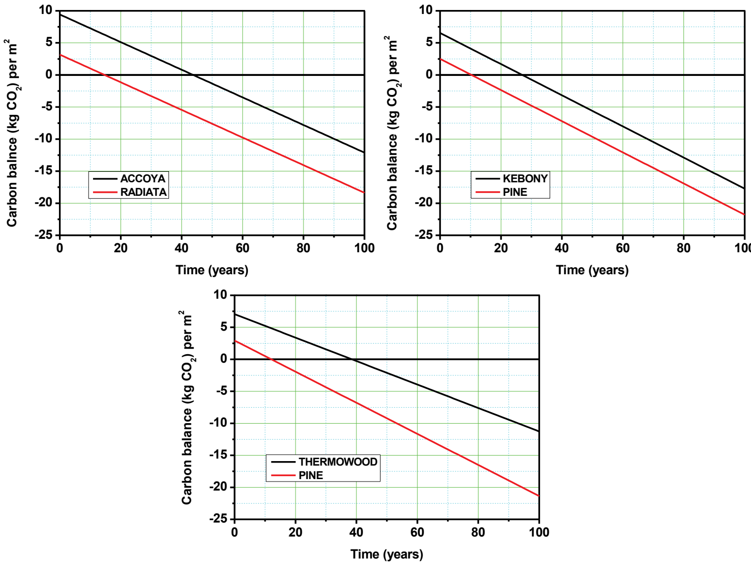


Figure 1: Carbon balances for unmodified radiata pine, Accoya™, Scots pine and Kebony®, Scots pine and Thermowood® including maintenance cycles calculated according to ILCD methodology

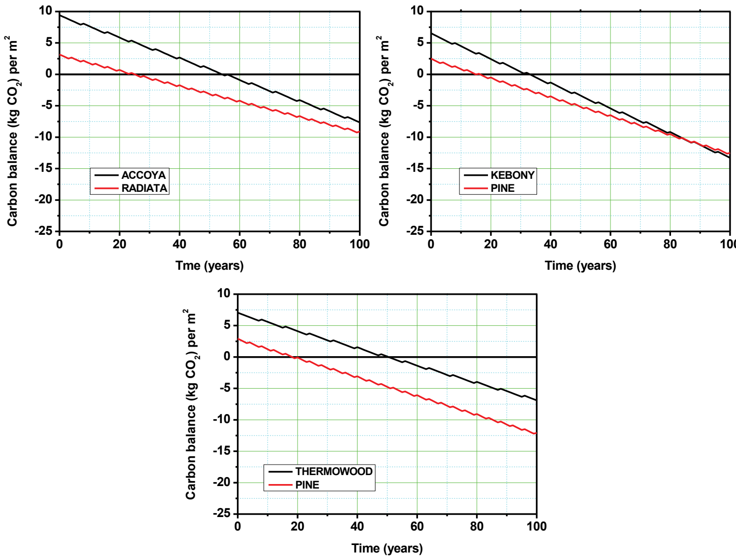


Figure 2: The effect of extended maintenance times on the carbon balance for modified wood

# Susceptibility of wood-polymer composites against mould, wood staining fungi and algae

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**Keywords:** wood-polymer composites, fungi, mould, algae, weathering

Wood-polymer composites represent a product group of increasing interest for decking profiles in Europe. WPC terrace decking materials reached a market share of nearly 20 % in 2012. An increase to 27 % is expected by 2015 (Langen 2013). WPCs consist of small wood particles embedded in a polymer matrix of polyvinylchloride (PVC), polyethylene (PE) or polypropylene (PP) by means of adhesives. Optical variations are possible by pigmentation. Wood content may be up to 80 percent, therefore wood decaying organisms have to be considered. Up to now, the durability against wood decaying basidiomycetes has been extensively investigated. In general, the decaying rates caused by basidiomycetes depend on particle size and wood content and are low in comparison to non-durable wood species (Verhey et al. 2001, Verhey und Laks 2002). The most important factor is the low moisture sorption of the embedded wood particles, which limits the activity of decaying fungi (Rowell et al. 2002, Wang and Morrell 2004, Shirp and Wolcott 2005, Ibach and Clemons 2007). Mould and wood stain fungi (ascomycetes and zygomycetes) can affect the material by colonisation of the surface layer with sufficient moisture in this area. So, they can cause optical alterations in short times especially in connection with pollutants, which commonly occur in the environment. Under special hard conditions with low solar radiation, which leads to extremely high moisture on the surface, algae can colonise the material. The risk of a surface effect is more important than real material damage. Nevertheless, both the test against basidiomycetes and mould fungi are required in part 4 of the EN 15534, which specifies the characteristics of WPC decking profiles and tiles.

The aim of the presented work is to investigate which kinds of microorganisms colonise WPC products during outdoor exposure under different technical conditions and which lab tests can give a real assessment of the susceptibility. The wood content of the material provided by a German manufacturer was 70 %. The standard mixture of hard and softwood particles was embedded in polypropylene. Brushed and unbrushed, fluted and unfluted materials were compared and the effectiveness of a standard biocide was tested. During outdoor exposure, all materials were exposed slanted to the north with a 45° disposition for 3 years, some materials have been exposed horizontally near the ground for 12 months. Further, some products were tested in the laboratory; some specimens were exposed to accelerated ageing procedures.

Wood staining fungi and mould fungi were identified as first colonisers on the material. Depending on the kind of weathering procedure, the infestation by these fungi was observed within 3 months after exposure. Terrestrial microalgae appeared as a green film more than 2 years after exposure; the green algae *Apatococcus lobatus*, *Stichococcus bacillaris* and *Klebsormidium* sp. were identified. The biocide additive achieved a clear effect in the laboratory tests against mould fungi and algae in contrast to a very low advantage under weathering conditions. Basidiomycetes fungi were found in no case. Surface structure alteration during the field weathering was detected by microscopic investigations.

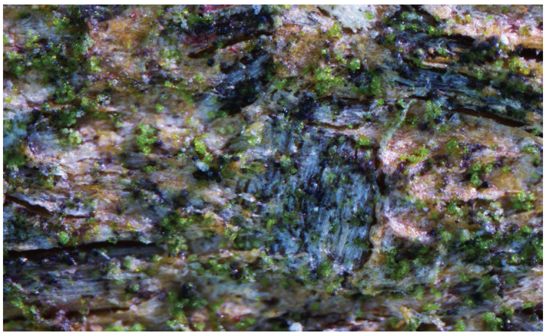

Figure 1: Infestation of WPC by algae and wood staining fungi (reflected-light microscope 50x, Weiß/IHD)

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# Aesthetical aspects of discolouring fungi on wood in-service

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**Keywords:** aesthetical appearance, discolouring fungi, façades, influencing factors, wood substrates

In Northern Europe the use of untreated and uncoated wood in building façades has increased over the last 15-20 years. As a consequence the interest in the aesthetical character and appearance of wood materials and wood products used outdoor has increased. An evenly weathered, grey and homogenous uncoated wooden façade found on traditional older barns and mountain huts is well accepted, and serves as the desired aesthetical expression strived for on new buildings by many end-users, building owners, entrepreneurs and architects. The benefits of using uncoated wood in facades are several: low maintenance, low environmental impact, a contemporary look, a 'breathable' envelope. Unfortunately several building projects with uncoated wooden facades have a design and/or material selection which give the building an aesthetically unfavourable appearance. The reaction from the public is then often negative and this gives wood a bad reputation as a building material.

Architects, end-users, entrepreneurs and building owners seek information on how the wooden material will perform in an application, and not only the technical or functional service life – but also the aesthetical appearance over time. This work summarizes results on factors influencing growth of wood discolouring fungi and indicates the possibilities the discolouring fungi hold as a design element.

The weathered grey surface colour on wood is caused by photo degradation of lignin, wetting/leaching of the upper layer of the wood surface and growth of wood discolouring fungi. The shade and intensity of the grey colour and the amount of discolouring fungi growth will vary considerably due to a range of influencing factors: time, wood substrate, surface finish, surface structure, wood properties, design, manufacturing characteristics, craftsmanship, climate, maintenance. Studying the influencing factors and developing performance models regarding aesthetic service life allow us to identify the most important factors contributing to discoloration of the wood surface (Table 1).

Surveys among end-users showed that a homogenous wooden surface is preferred over a more heterogeneous surface, which was shown for knot distributions in wooden indoor panels and outdoor wooden facades (Høibø and Nyrud 2010, Nyrud et al. *in prep*). Since an even grey colour on the whole wooden façade is often looked upon as ideal, several approaches and studies target this, like application of an iron sulphur solution to the wood surface, establishing a biofilm that gives an even grey colour (Sailer et al. 2010), and furfurylated cladding and decking promoted by Kebony® to hold a 'natural silver-grey patina'.

Table 1: Influencing factors and their impact on discolouring fungi on wood in-service (based on Gobakken et al. 2010a, 2010b, 2011, 2014)

| Influencing factors | Uncoated | Coated | Influencing factors | Uncoated | Coated |
|---|---|---|---|---|---|
| Exposure time | +++ | +++ | Surface structure | (++) | ++ |
| Wood substrate | +++ | ++* | Craftsmanship | (++) | (++) |
| Wood properties | +++ | +* | Design | (+++) | (+) |
| Coating | N/A | +++ | Material climate | +++ | ++ |
| Colour | (++) | + | Cardinal direction | ++ | ++ |
| Man. characteristics | (+) | - | Climate (meso / macro) | ++ | ++ |

*+++=great impact, ++=moderate impact, +=impact, - =no impact, ( ) ='expert' opinion/inspections, *=depends on the type/product of coating*

Knowledge about the impact of the influencing factors can be actively used to extend the aesthetical service life of wood and will also offer predictability, and further be exploited in the process of creating façades and elements that are in demand from architects, building owners and end-users.

WOOD/BE/BETTER – *Increased use of wood in urban areas* - is a research project where one of the main goals is to facilitate communication between architects, building owner, entrepreneurs, civil engineers, mycologists and wood scientists. One of the tasks within the project is to develop a combined model and tool that simulates and predicts future service life of wood in urban architecture and this will enable knowledge-based decisions regarding design and material selection. This will also include identification of materials with the best aesthetical appearance for specific applications.

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# Communities of mold fungi in moisture damaged building materials studied with molecular methods

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**Keywords:** building materials, fungal communities, DNA-based methods

The critical conditions needed for the development of mould and decay fungi have been modelled for different building materials (Viitanen et al. 2010a, 2010b, 2011). However, current knowledge of indoor microbial species growing on building materials relies on culture-based methods and more advanced molecular biological techniques should be employed to study the complex microbial communities in building materials. In this study molecular biological techniques were optimized and used to study microbial diversity in building materials exposed to different moisture conditions.

Table 1: Test specimens in the chamber test

| Specimen | Size [mm] | Surface modifications |
|---|---|---|
| Pine sapwood | 50x25x15 | planed |
| Spruce, edge glued | 50x50x20 | sanded |
| Light weight concrete | 50x50x20 | original surface/sawed |
| Mineral wool | 50x50x20 | cut |
| Polyester fibre insulant | 50x50x25 | original/cut |

Materials were collected from previous research, where materials were exposed to high humidity conditions (relative humidity RH 98%) or lower humidity (RH 90 %) at +22 $^{o}$C for three years (Table 1). The experiment was carried out in constant conditions in closed plastic chambers. Before the exposure, the surface of the samples was inoculated with a fungal spore suspension (NT Build 338). The spore suspension included four different species: *Aspergillus versicolor* E1, *Penicillium* sp. 1017, *Cladosporium sphaerospermum* R7 and *Paecilomycetes variotii* D-83214. After the test samples were taken out for DNA-based analysis and culture-based analysis using a direct cultivation method where dust from the surface was removed on the agar petri dish. In addition the mould index was evaluated visually and microscopically.

For DNA-based analyses, samples were weighed and cut in to pieces. DNA was extracted from the samples with a PowerSoil DNA extraction kit (Mobio Laboratories, Inc., CA, USA) according to manufacturer´s instructions with some modifications. Fungal communities were studied by fungal ITS region targeted PCR-DGGE and Sanger sequencing (Anderson et al. 2003). DGGE-gel images were normalized with the Bionumerics software package (v. 5.10, Applied Maths, Sint-Martens-Latem, Belgium), calculating the similarity of band profiles using Dice’s coefficient of similarity.

Dendrograms were constructed via UPGMA clustering. Obtained sequences were manually checked and edited in Geneious Pro (v. 6.1.0, Biomatters Ltd., Auckland, New Zealand) prior to comparison with NCBI's and UNITE nucleotide database with the BLAST tool.

After the experiment mould growth was detected visually and microscopically in building materials exposed to high humidity conditions (RH 98%). Only slight growth was detected in lower humidity (90%) conditions. Fungal community analysis with PCR-DGGE method showed differences in fungal communities between building materials and lower and higher humidity conditions. Cluster analysis from the PCR-DGGE clustered communities together in different building materials in lower humidity conditions and communities in higher humidity conditions comprised their own cluster. This suggests that fungal community depends more on humidity conditions than building material type.

Fungal diversity was higher in building materials exposed to higher humidity conditions, as expected. Most of the fungal species identified from high humidity conditions belonged to fungal order Trichocomaceae and more specifically to genus *Aspergillus* that were found in all building material types and *Penicillium* that were identified in wooden and mineral wool samples. Sequences belonging to the fungal genus *Phaeophyscia* were also found in light concrete and mineral wool samples and *Oidiodendron* in wooden samples. The most abundant fungal species identified from building materials exposed to lower humidity conditions belonged to genus *Aspergillus*. No *Penicillium* species were identified. Fungal diversity was highest on wood-based materials and lower in light concrete and insulation materials. With the cultivation method only species belonging to genera *Aspergillus* and *Penicillium* were found from all material types and *Stachybotrys* was identified from light concrete material.

Molecular biological techniques provide more information about microbial communities in moisture-damaged buildings and these techniques could offer new tools to understand the complicated relationship between moisture, material, microbes and indoor air quality. One important thing to remember is that there is no single method to determine the degree of the moisture damage. Therefore, a combination of several methods, including visual and technical inspection of the building, measuring of surface moisture and taking of microbial samples from surface, materials or indoor air for determination of their microbial contents are considered to be the best means of identifying building mould problems.

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# Simple test setups for assessment of performance outdoors

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**Keywords:** performance, outdoors, biobased, decking, cladding

The issue of surface performance of wood and biobased building materials is of increasing concern, and is becoming the most critical evaluation parameter in consumer choice. Today there are several options of materials for decking and cladding available on the market. Different qualities of untreated and preservative treated wood, durable hardwoods, modified woods and WPCs with a large range appearances, properties and prices are being commercialized. Furthermore, new impregnation and surface treatment products for protection against fungal growth have also made their way into to the market. These are often described as being environmentally friendly, less toxic, and as effective as traditional fungicide containing products.

Several of these materials with or without treatment have been in service for some time and reports on poor surface performance of claddings and decking are increasing. The great majority of complaints concern appearance. Materials that look fairly nice on brochures, homepages and even at the shop turn to behave in differently depending on service conditions (position, closest environment, climate, and other factors). Other complaints may concern dimension stability, crack formation, surface coatings, and even decay.

In order to rapidly alleviate misconceptions and misunderstandings on material properties and performance it is imperative that rapid performance tests be used by research and testing organisations. A great deal of material performance data may be acquired in relatively short periods of exposure outdoor with quite simple methodologies. One example is the decking-cladding rig configuration proposed by Lonza Wood Protection. The setup consists of four horizontally placed boards (20 x 95 x 700 mm) to simulate a deck, and four vertically placed boards (20 x 95 x 700 mm) to simulate a façade. The boards are mounted on a framework of preservative treated wood (Figure 1). The number and size of boards can be adjusted according to the material being tested and thus may vary. The complete setup is easily movable and can be placed in any position. In Sweden the rigs are usually positioned facing south or facing north depending on the desired climatic pressure on the samples. The low profile and proximity to the ground helps accelerate the deterioration process. Material performance can be evaluated according to many parameters around the whole set up (Jermer and Bardage 2013). Depending on the location and period of exposure results may be obtained in less than 2 month.

Figure 1: Decking-cladding rigs exposed outdoors.

Another method is the use of already existent structures such as piers and bridges located at severe environments where for instance the original decking can be replaced with new materials for testing purposes (Figure 2). At these sites materials may be exposed to the elements as well as to deterioration caused by human activity.

Figure 2: A pier on a bathing-beach in Malmö on the West coast of Sweden.

Very useful results have been obtained from such simple setups. This information allows for quick guidance on material properties for developers, producers, sellers and consumers.

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# Assessment and modelling of discolouring fungi on wood in an outdoor environment

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**Keywords:** hyperspectral imaging, surface moulds, blue stain fungi, wood substrates, field test

Growth of discolouring fungi on the surface of coated and uncoated wood depends on the wood substrate and the climatic conditions. A way of better understanding the mould growth process is to develop growth models for materials exposed outdoors (e.g. Gobakken et al. 2010). Moreover, an objective and non-destructive technique for assessing the amount of mould growth is essential for the accuracy of the models. Recently NIR hyperspectral imaging technology was applied for identifying and quantifying growth of discolouring fungi on the surface of coated and uncoated wooden samples in a controlled environment using a monoculture of fungal species on a limited number of wood substrates (Burud et al. 2014).

In this study, fungal growth on wood substrates exposed in an outdoor environment are assessed and modelled. The start-up time of the test was August 2013 – and the test is still running. Five different wood substrates (uncoated Aspen, uncoated Pine heartwood, uncoated Spruce heartwood, uncoated acetylated Southern Yellow Pine and coated Spruce heartwood) were exposed vertically facing North and South at the Sørås test field, Ås - Norway, in a specially designed test set-up, shown in Fig. 1 (left). The mould growth was evaluated using hyperspectral images and visual assessment according to EN 927-3 (2006). This resulted in two mould growth curves, one with mould growth index 1-5 and one with % mould growth evaluated on a score image from a Principal Component Analysis (PCA) of the hyperspectral image (see Fig. 1 for examples of a regular photo (RGB image) and a PCA score image).

Sensors measuring wood moisture content and temperature were mounted at 3mm depth on selected samples. Moreover, a nationally served meteorological monitoring station is placed in the immediate area of the test rig, and data for a range of meteorological attributes are available. These climate data were used as input for a one-dimensional Finite Element Heat and Moisture (HAM) simulation (WUFI, Fraunhofer IBP) yielding values of surface moisture of the samples. We found good agreement between the measured and the modelled moisture values at 3mm depth (see Fig. 1 right panel). Therefore we suggest that the values of relative humidity at the surface of the samples from the HAM simulations can be used as input parameters to the model development of the mould growth. The simulated data of temperature and relative humidity (RH) take into account the solar irradiation and the material climate, and ought to provide more accurate data for the surface conditions of the samples than the ambient values and the measured values at 3 mm depth.

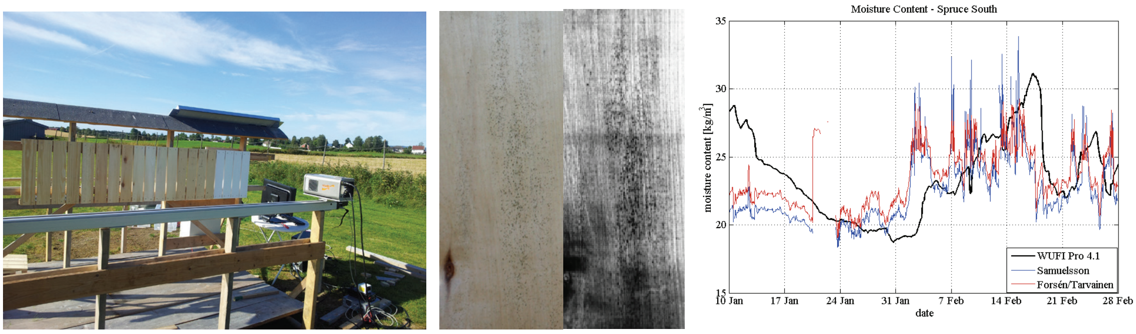


Figure 1: Left: Setup of wood panels and hyperspectral camera at Sørås test field, Ås. Middle: An RGB image (left) and a PCA score image (right) of an Aspen panel facing north (on October 9th 2013). Right: Comparison of the temperature corrected moisture measurements for uncoated Spruce and simulated moisture value from WUFI at the same depth of the sample (3mm from the surface).

The mould growth on the uncoated Spruce (north and south) has been modelled with a Partial least Square (PLS) regression algorithm (MATLAB and PLS Toolbox from Eigenvector) (Fig. 2). The input X-values to the model were the number of hours since the beginning of the experiment and the fraction of time within each time interval with climate conditions for mould growth. The latter was estimated using the lowest isopleth for mould growth from Sedlbauer et al. (2001). The dataset consists of 64 measurement points: 8 measurements of 8 samples of uncoated Spruce. The PLS model was constructed from 56 data points, and 8 points, one for each time of measurement were picked randomly from the 8 samples, to validate the model. There is a good agreement between the model prediction of these 8 data points and the measured values both for the visually assessed mould index and the % mould coverage from the hyperspectral images (see Fig. 2 left and right panel, respectively).

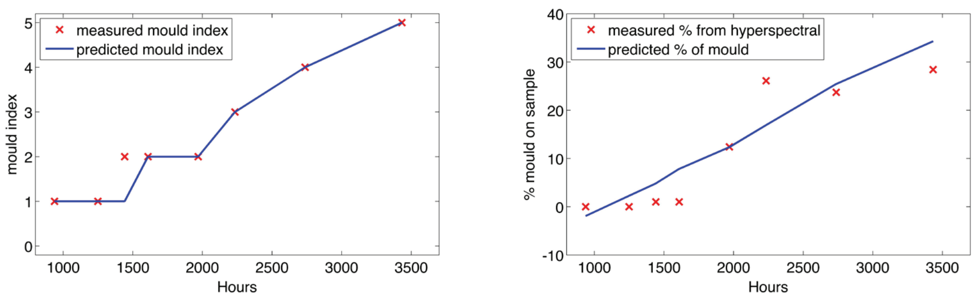


Figure 2: Measured versus predicted values for mould growth from the PLS regression of mould index (left panel) and % mould coverage (right panel).

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# Investigation of the resistance against soft rot of thermally modified bamboo (*Dendrocalamus barbatus*)

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**Keywords:** thermally modified bamboo, soft rot, resistance

Bamboo is one of the most used plants worldwide. Over one billion people are using it as construction material, especially in countries like Vietnam or India. The interest of bamboo as renewable resource increases on the world market, because of its magnificent mechanical properties. Therefore, it is well known as construction material in Asia for many centuries. In the last couple of years bamboo is also used as derived timber product, parquet floor or terrace material.

Despite its excellent mechanical properties, the use of bamboo is limited due to its susceptibility of wood-decay microorganisms. Especially in outdoor applications, bamboo is not protected against microbiological decay. One treatment of preservation is the thermally modification. Hereby, the physical, chemical and mechanical properties as well as the biological resistance of the modified material are changing.

The aim of this investigation was to evaluate the increase of the resistance against soft rot microbes related to the grade of thermal modification of the bamboo culms *(Dendrocalamus barbatus)*.The thermally modification of the bamboo was carried out at different temperatures (130 °C; 160 °C; 180 °C; 200 °C) over a time period of 5 h. Furthermore, chemical substances such as cellulose, hemicellulose and lignin were determined before and after the thermal modification.

The biological tests were conducted based on DIN CEN/TS 15083-2 (2005). The mass loss due to the fungal treatment was estimated and the soft rot decay was associated with the mass contents of bamboo main components, especially hemicelluloses content, in the different modification levels. The presented research confirms the effect of higher microbial resistance of thermally modified wooden materials. Especially for the bamboo specie *Dendrocalamus barbatus*, we were able to identify different parameters, which promote a betterment of biological durability.

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# Construction and material issues and usage prospects of antique wooden beam floors

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**Keywords:** antique wooden floors, usage requirements for wooden floors, mechanical, physical and chemical properties of wood

## 1. Usage requirements for wooden floors

Wooden floors are assessed in two aspects: visual - just after they are made, and quality - in a longer usage perspective. The main purpose of a floor is to transfer dynamic loads caused by the traffic taking place on its surface, and static loads of the objects placed on it; through the parquet, the subfloor and the insulation layer. The parquet (floor covering) is the top, wear layer and the external finishing element of the floor (PN-B-01023:1965). The parquet, and especially its wear layer, should be resistant to abrasion and humidity, warm to the touch, elastic, noise attenuating, resistant to light, resistant to indentations, electrical insulating or antielectrostatic, easy to keep clean, durable and aesthetic. The subfloor is an element of floor structure used to fix the parquet, which transfers static and dynamic live loads to building structures. Additionally, it also levels the support structure, provides thermal and acoustic insulation, and helps to maintain good microclimate conditions in the interior (improving the accumulation properties of the partition). The subfloor connected with the support structure must also have similar chemical properties, should be placed directly on the support structure, levelling it, adding height to it and acting as ballast (stabilisation of the position of joists supported only by recesses in the walls in accordance with PN-EN 13813:2003). The requirements for the subfloor depend largely on the type of parquet. Parquets made of hard materials resistant to compression and bending, such as boards, can be placed on a subfloor with much lower resistance properties. The insulation layers should consist of an anti-humidity layer placed below the structure on the ground and on the structure below the floor covering; a layer of thermal insulation and a layer of sound insulation.

## 2. Investigated material

The research covers antique parquets from 76 rooms in 21 sites dating from the 19th century and located in South-Eastern Poland. The parquets are located in the Łańcut Castle, in the Palaces in Kozłówka, Zarzecze and Przeworsk, in the Palace of the Bishops of Przemyśl in Krosno, Hunting Lodge in Julin, as well as in manor houses in: Bieździedza, Boguchwała, Dydnia, Falejówka, Hyżne, Kombornia, Kopytowa, Tarnowiec, Niwiski, Przewrotne, Uherce Mineralne, Witkowice, Wydrna and Żarnowiec, a staff outbuilding in Kolbuszowa and a vicarage in Ostrowy Tuszowskie.

## 3. Proposed assessment criteria

Antique wooden floors with beam structure had to support static and dynamic loads during usage (e.g. related with traffic or dance taking place on them). Even the static and dynamic loads that remain below the endurance limit cause elastic and plastic strains of wood that can disappear together with the force or can become fixed. They influence the force distribution inside the wood and can be combined with desorption stresses, intensifying deformations and cracks. Repetitive stress cycles result in material fatigue, which can damage its structure (Rozanska et al. 2011). In order to assess the usage prospects of antique wooden floors, we characterised the relations between mechanical, physical and chemical properties of wood and the changes of the structural and material properties of the floors made of it. We tested the resistance parameters of antique floors (especially their hardness (PN-EN 1534:2011), elasticity (PN-EN 408:2012), as well as surface properties: resistance to abrasion (PN-EN ISO 5470-1:2001) and resistance to scratches (PN-EN 438-2:2005) (Swaczyna et al. 2011). We analysed the strains caused by static and dynamic loads and tested dimension stability and deformations of panel elements and other structural layers of the floor. The capacity to transfer own and usage-related (live) loads was assessed through numerical calculations determining the stresses in floor elements, with the use of the finite element method (Rozanska et al. 2012b), while the capacity to transfer dynamic loads was checked through shock absorption tests in accordance with PN-EN 14808:2006 (Rozanska et al. 2013). The importance of given structural layers was compared by analysing the resistance of floors with continuous support (joists laying on a mineral base and joists placed in a layer of sand) and parquets with punctual support. We also compared the resistance of floors that had various variants of subfloor structure. The analysis of the influence of profiled woodwork joints used between panel elements on the character of their work and the loading degree were carried out with the use of a series of numerical analyses (Rozanska et al. 2012a). The input data for the analysis were determined on the basis of preliminary tests. We determined, among others, the density and static bending strength of individual parquet elements, which allowed us to determine the actual, current wood grade.

## 4. Conclusions

Some antique decorative wooden floors fulfil contemporary usage requirements, in spite of wood degradation caused by the passage of time and by the usage conditions. Their state of preservation permit the transfer of their own load (of the parquet layers) and of usage loads. In accordance to contemporary standards, concentrated usage loads in residential buildings amount to, as a minimum, $Q_k$=2 kN (for instance for a leg of a piece of furniture) or even 3 kN for a grand piano leg (PN-EN 1991-1-1). However, in case of antique parquets we are not able to obtain a “perfectly flat” surface that is preferred in contemporary parquets.

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# Monitoring of pressing process in advanced composite formwork panels - I.

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**Keywords:** composite formwork panels, pressing process, pressing temperature

The aim of this work was to optimize the pressing process of wood composites used for the production of formwork. The first stage of the research was aimed especially to the time optimization of the technological operation of pressing. The requirements for excellent hardening of the adhesive were considered.

For the needs of the experiment there were proposed and created four structures of three-layer composite formwork panels. Spruce slats were used in all structures as the core layer. Surface layers were formed by four alternatives: spruce slats (SPR), three-ply birch plywood with a thickness of 4 mm (PL 4), three-ply birch plywood with a thickness of 6 mm (PL 6) and OSB board (OSB). Moisture content of all materials during the time of experiment was w = 10 ± 1%.

Experimental composite structures were produced by pressing at the surface temperature of pressing plates $t_{LP}$ = 110 ± 2 °C instead of the usual temperature used in practice of 130 °C. Pressing time was in all cases τ = 540 s and the pressure was P = 6 MPa. These two parameters of pressing process are based on the conditions used in the production of similar composite formwork panels in practice (Barbu et al. 2013). All experimental samples were produced with dimensions of 500 × 470 mm. Size limitation follows from the size of the pressing plates of the laboratory press used.

Experimental research demonstrated that in the pressing process of three-layer composite formwork panels it is possible:

1. To reach the required temperature of 90 °C in bonded joint during the interval of minimally 90 s even when the pressing temperature of 110 °C is used (Fig. 1).

2. By optimizing of the pressing time to achieve the sufficient time and thus energy savings as well; the time achievable savings depending on the material used in the surface layers is at the level of 3.0 to 6.5 %.

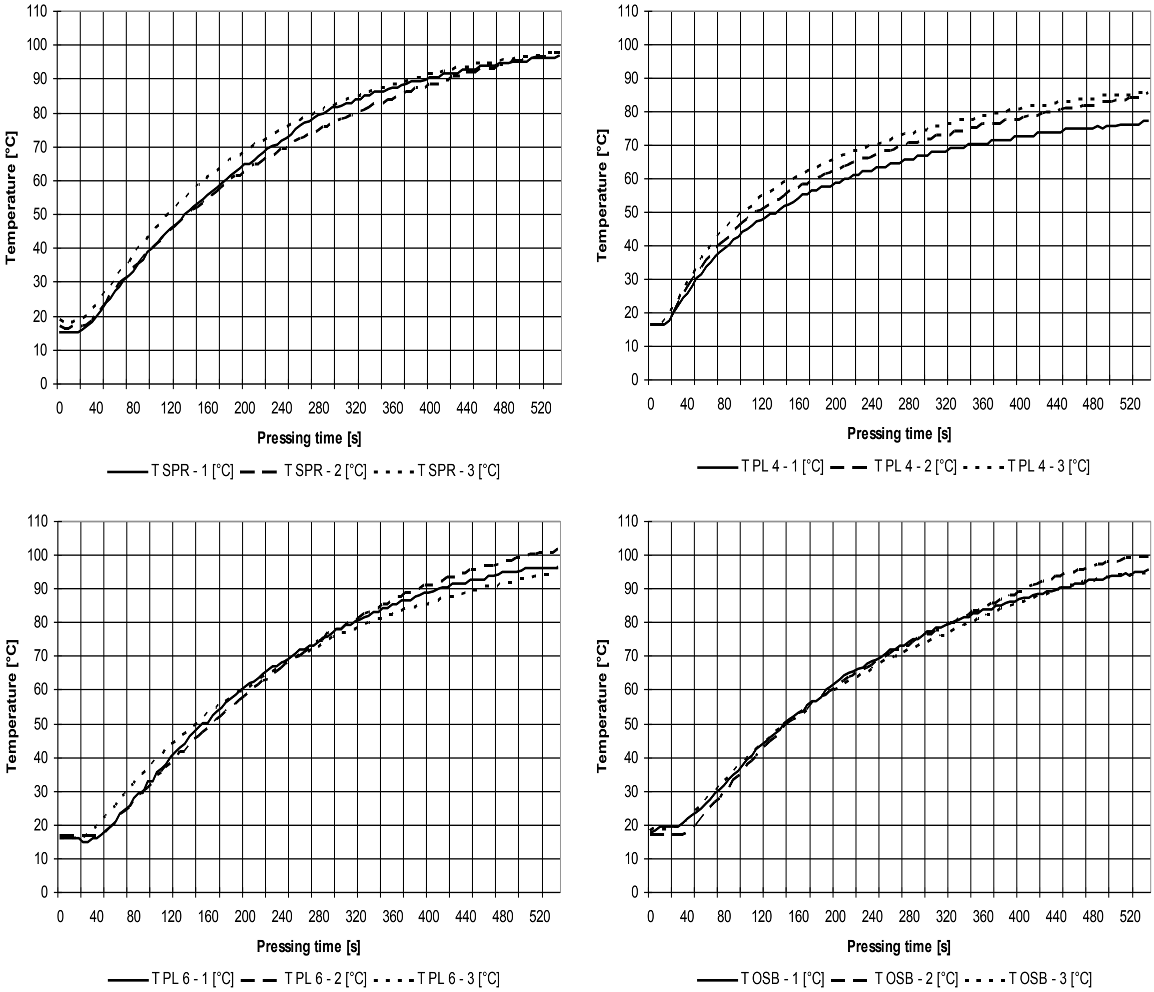


Figure 1: The temperature growth in the joint during the pressing of four formwork alternatives

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# Natural reinforcement of bent wooden elements

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**Keywords:** bamboo, reinforcement, bending, knots

Building industry is one of the most conservative branch of the economy. It is characterized by a reluctance to introduce new, untested in long-term use materials and design solutions. When comes to repair of existing engineering structures, the most common reinforcement technique used is simple replacement of overload element for a new one. But because of conservational restrictions the replacement method often cannot be allowed to use in case of historical structures.

One method which can be successfully used in historical structures is the introduction the reinforcing material inside the cross section of reinforced element. Significant advantage of this solution is the possibility to hide the reinforcement, which allows to keep the original aesthetic qualities. It is especially important for example in case of polychrome decorated ceiling beams.

Developed repair engineering method involves the use of bamboo plates. Bamboo is a material easy to processed and glued and it applies low values of additional loads. Because of its low specific gravity (density 900 $kg/m^3$) and high strength parameters (Young's modulus 16.9 GPa, tensile strength 260 MPa) bamboo provides many possibilities for designers, constructors and builders (Verma et al. 2012).

Tests were carried out using pine samples as a most common species used in construction works in Poland. Samples with dimensions of 20x40x800 mm were divided into 4 series:

a) sound wood, without any wood defects,
b) sound wood, weakened with single opening with diameter of 12.5 mm (simulation of the knot),
c) reinforced wood with bamboo plate 1.2 mm thick,
d) reinforced wood with bamboo plate 4 mm thick.

Semi-technical scale of samples was used in aim to determine the parameters of testing procedures for further research. Because of semi-technical scale, less variation of strength parameters was provided, in comparison to full-scale structural lumber. Additionally, since the samples were free of natural defects, determination of reinforcement influence on wood strength parameters was possible.

Strengthening technique assumed local application of D-shape reinforcement in form of bamboo plate (Fig. 1). Reinforcement was placed inside previously made grooves (Fig. 2) and glued with Havel Composites G60 epoxy glue. The D-shape of reinforcement was resulted from the technologically easiest shaping of the slot, that could be made using circular saw. Reinforcement procedure assumed strengthening the tension area of bended beams. Thus the height of the D-shape reinforcement was set at 25 mm, while the length was resulted from the diameter of the saw used (250 mm). Samples were tested in three point bending in accordance to EN-408:2012.

Figure 1: Shape of reinforcement

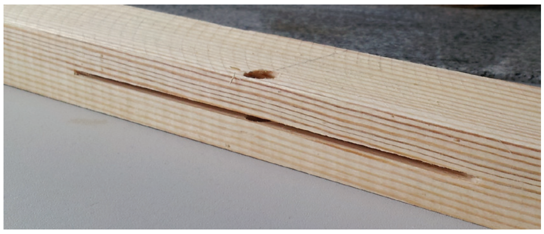

Figure 2: Preparation of material

On the basis of load and displacement values obtained during testing, MOR and MOE of each series of samples were determined (table 1).

Table 1: MOR and MOE values for A-D series

| **Series** | **MOR [N/mm$^2$]** | **Standard dev. [N/mm$^2$]** | **MOE [N/mm$^2$]** | **Standard dev. [N/mm$^2$]** |
|---|---|---|---|---|
| A | 80.2 | 9.0 | 13010.2 | 1063.2 |
| B | 49.6 | 7.1 | 11482.5 | 1375.0 |
| C | 53.3 | 6.0 | 10690.3 | 1259.4 |
| D | 57.5 | 6.1 | 11257.7 | 1220.7 |

Samples weakened with and opening showed 38% reduction in MOR and 12% drop of MOE in comparison to sound samples of A-series. In case of D-series testing showed statistically significant gain in MOR value (16%) in comparison to samples of B-series. Thickness of C-series reinforcement was not sufficient to provide a significant increase in MOR. Reinforcement (C-series, D-series) did not bring significant gain of MOE.

Basing on the studies it was confirmed that local bamboo D-shape reinforcement is purposeful in structural timber. It could be used especially in historical structures, where the issue of aesthetics is crucial. There is still a need to further analysis of the developed reinforcement technique in aim to optimize it both in terms of the shape, as well as the length of local reinforcement.

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# Gypsum-based bricks (WoodRub BRICKS) manufactured from recovered wood and rubber

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**Keywords:** residues, wood chips, rubber particles, construction materials, internal walls

Reuse of waste has become today one of the main human activities for preserving the environment. Nowadays, the countries of the European Union generate about 4 million waste tires and 30 million tons of wood waste. Both residues have a high recovery potential, as alternative materials or fuel, but currently the technology allows reusing them as advanced materials, extending their life and giving them new functions. The joint initiative WoodRub (20010-2014), funded by the European Commission through LIFE+ Programme, has manufactured various alternative composite products with greater added value made from wood waste and tire rubber for different specific uses, such as non-slip floors or acoustic panels.

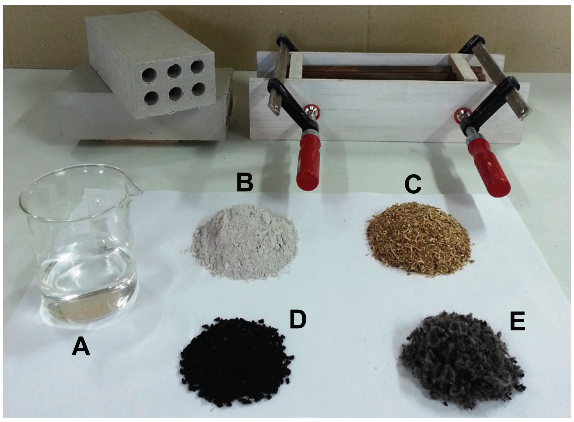


Figure 1: Water (A), gypsum (B), recovered wood (C) and rubber fractions (D), and reinforcement material (E) used for the manufacturing of WoodRub BRICKS

Bricks (WoodRub BRICKS) were manufactured by using the following raw materials and proportions per weight: (a) 15% of a medium-sized fraction (1-2 mm) of wood chips from particleboard production residues (b) 10% of a large fraction (2-4 mm) of rubber from waste tires (c) 5% rubber-textile (reduced rubber material containing textiles) as a reinforcement material (d)

70% gypsum-water (1:1.5) solution (Fig. 1). The mixing of materials took place in special rectangular moulds with the selected final brick standard dimensions of 8.5 × 5.5 × 18.5 $cm^3$ with six holes, thus fulfilling the purpose of the selected application (internal insulation wall). After mixing, the bricks were dried in an oven at 30-35°C. By weighting and calculating the volume of 20 orthogonal WoodRub BRICKS, it was found that their density was 0.580±0.023 $g/cm^3$. Taking into account that every brick has a stable void volume (holes represent 22.76% of the brick volume) of 196.05 $cm^3$, the density of the wood/rubber material used was 0.750±0.030 $g/cm^3$.

Compression testing of bricks was performed according to ASTM C39/C39M-12a standard with a Shimadzu testing machine. The bricks performed slightly better when loaded at the large surface of their lateral upper side than at the small surface. For both large and small surface loading, failures occurred towards the direction of load in the material under a hole or between the rows of holes. Strength in compression was almost doubled in the axial direction while the failures occurred were diverse (Table 1).

Table 1: Results of compression testing of WoodRub BRICKS

| Property | Lateral upper side | | Axial |
|---|---|---|---|
| | Surface 8.5 × 8.5 cm | Surface 5.5 × 8.5 cm | Surface 5.5 × 8.5 cm |
| Compression [$N/mm^2$] | 0.57±0.03 | 0.50±0.01 | 1.09±0.20 |

[a]*Mean values ± standard deviation*

The results of compressive strength of bricks were used for static calculations needed in 3 m internal wall constructions. According to the results of compression testing, one WoodRUB brick is able to bear the load of 35 or 55 bricks required for a single row when walls are constructed with bricks put in their small or large surface, respectively.

Thermal conductivity coefficient (k) of the WoodRub BRICKS was determined by the AnterUnitherm™ Model 2022, which uses the guarded heat flow meter method, at 25°C in accordance with the ASTM E1530-11 standard. It was calculated as 0.274 W/mK. The bricks showed a better thermal insulation than both the extruded and pressed house bricks with a thermal conductivity coefficient of 0.33-98 and 0.87-1.10 W/mK, respectively. However, the insulating bricks perform much better as they have a thermal conductivity coefficient of 0.15 W/mK. The sound absorption coefficient was determined by the impedance tube method according to ISO 10534-1 standard and showed that the maximum absorption coefficient was set to 1 kHz and decreased with increasing frequency. It was also implied that the resistance of bricks to air flow was high and that the bricks had a very low degree of porosity. Content of volatile organic compounds (VOC's) was measured on a surface of 0.25 $m^2$ manufactured from WoodRub BRICK's material according to UNI EN ISO 16000-9. The results showed low VOC's emissions of bricks. The overall results are promising for further investigating the manufacturing and properties of bio-based bricks and other building materials based on recovered wood and rubber.

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# In situ Evaluation of Historic Timber Structures with Non-destructive and Semi-destructive Test Techniques

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**Key words:** Nondestructive testing, in-situ evaluation, timber structures, acoustic methods, micromechanics

Timber has been a traditional structural material for centuries, and numerous examples throughout the world demonstrate its durability and satisfactory performance. Turkey possesses an extraordinarily long and well-documented history of wooden structures. The Northern part of Turkey exhibits excellent examples of well-preserved wooden structures, some of which are listed on the prestigious UNESCO World Heritage List. In historic structures, it is important to preserve the original state to the greatest extent possible. Wood deterioration is one of the most common damage mechanisms in historic timber structures and often inflicts damage internally. The deterioration of structural members results in changes in geometry and load-bearing capacity. Replacement of deteriorated members may not be an acceptable option for structures of historic significance, and redesign may be necessary to sustain the functionality of the structure. Preservation of the original structural state and the associated construction conserves the cultural significance of the building including architectural qualities and building techniques as well as the historic and socially important aspects associated with the structure. Determining an appropriate load rating for an existing timber structure and making rational rehabilitation, repair, or replacement decisions can be achieved only when a reliable and accurate assessment of its existing condition is made. Comprehensive planning and budgeting for a historic preservation project cannot commence without a detailed survey of a building's existing conditions. Knowledge of the condition of the structure can lead to savings in repair and replacement costs by minimizing labor and materials and extending its life. Nondestructive testing and evaluation (NDT&NDE) techniques provide a great opportunities to understand the physical condition and the load bearing capacity of the structural members of the existing constructions without causing any significant damage on the member.

NDE techniques allow in-situ evaluation and determination of the degree of degradation of built-in structural components. Such evaluation is needed to quantify the remaining strength of the members and to make statements about the reliability, safety and life expectancy of the structure. Several nondestructive and semi-destructive techniques can be used for assessing the condition and the remaining strength of the members. The aim of this study is to discuss recent advances in nondestructive and semi-destructive techniques that are used to evaluate the condition and mechanical properties of wood members in structures with an emphasis on historic buildings. It describes the principles, applications, and limitations of major evaluation techniques for in-situ assessment of timber structures.

# Adhesion promoters as a agents improving thermoresistance of glue lines

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**Keywords:** adhesion promoter, HM adhesive, exotic wood species, thermoresistance, loading

Progress in the field of bonding agents enabled new applications in the woodworking industry, especially in the furniture industry. Proper material selection and operational procedures within individual bonding processes has a significant impact on the quality of the resulting wood products. It should be noted that in recent years there has been a trend in the furniture industry and interior design to use the newer and newer materials, which on the one hand possess high aesthetic and decorative qualities, and on the other surfaces with limited bondability. These materials may include plastic materials characterized by interesting patterns simulating attractive species of wood which are used for wrapping and edge banding wood-based panels. Exotic wood is also becoming more and more popular in Europe, due to its unique grain structure, aesthetic, colour values and excellent physicomechanical properties. Exotic wood species are more complicated to bond than native species due to the wide variability in their properties. Resins, fats and extractive substances can migrate to the surface of bonded material and change their physicochemical state, what can cause many problems during edge banding of wood-based materials using hot melt (HM) adhesives (Bodig 1962, Freeman 1960, Gray 1962). Bearing in mind these, it is necessary to carry out processes that adequately prepare and increase the activity of the surface. The methods of material surface activation can be distinguished as either: chemical, physicochemical, radiation or electric. Some of these methods have been attempted with wood; the most important utilise adhesion promoters, commonly known as primers. Compared to other methods they stand out due to their high efficiency, universality, ease of application, and cost (Muszyńska et al. 2014). One of the most important criteria for assessing the quality and usefulness of HM adhesives is the thermoresistance of glue lines under loading (Taki et al 1998). The aim of this work was to determine suitable conditions for adhesion promoters based on organofunctional silanes, modified polyurethane and hot melt adhesives for bonding exotic wood species, with special emphasis on glue lines thermoresistance.

**Experiments**

In the experimental part 5 exotic wood species were used: acajou (*Khaya ivorensis*), American cherry (*Prunus serotina*), American walnut (*Juglans nigra*), sapele (*Entandrophragma cylindricum*) and, for comparison, European oak (*Quercus sp*) along with 3 HM adhesives (based on EVA and PO) and an adhesion promoter.

For the thermoresistance test samples with dimensions of 90x10x1 mm were prepared according to PN-EN/C-89353-2. After 24 h of air-conditioning samples were placed in a laboratory rack and loaded with 200 g weights. Then in laboratory racks with the samples placed in a laboratory drier at 50 °C for 1 h, after which they were removed and a visual assessment of the quality of glue lines were made. If during this time damage the glue lines did not occur, the temperature was increased by about 10 °C. The tests were carried out at increasing temperatures until the glue connection was destroyed.

**Results**

Table 1 summarizes the results of the thermoresistance of glue lines,

Table 1: Influence of the activation of wood surface with adhesion promoters upon thermoresistance of glue lines at loading 200 g

| Kind of wood species | Kind of adhesive | | |
|---|---|---|---|
| | filled EVA | unfilled EVA | PO |
| | Thermoresistance [°C] | | |
| without adhesion promoter | | | |
| acajou | 60 | 60 | 80 |
| American cherry | 60 | 50 | 70 |
| American walnut | 60 | 60 | 80 |
| sapele | 60 | 60 | 80 |
| European oak | 60 | 50 | 70 |
| with adhesion promoter | | | |
| acajou | 70 | 60 | 80 |
| American cherry | 70 | 60 | 80 |
| American walnut | 70 | 60 | 80 |
| sapele | 60 | 60 | 80 |
| European oak | 60 | 50 | 80 |

The overall analysis shows that this parameter varied by adhesive type. Glue lines from HM adhesive based on PO, obtained from all wood species were characterized by increased thermoresistance. Application of the primer usually resulted in thermoresistance increases of about 10°C. On the other hand, for systems with the filled EVA adhesive thermoresistance increased only for acajou, American cherry and American walnut. However, in systems with unfilled EVA adhesive using the primer, only American cherry demonstrated increased thermoresistance.

**Conclusions**

The highest thermoresistance of adhesive connections between veneers under loading were in systems based on the PO adhesive, whereas the lowest were based on unfilled EVA adhesive. Application of the adhesion promoter generally increased the thermoresistance of glue lines, but varied between systems.

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# Using wood based interior materials to promote human well-being: project Wood2New

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**Keywords:** Building, wood material, Wood2New, Woodwisdom-Net, human perception, health

This paper presents the main aims and first results of the transnational and multi-scientific project Wood2New, Competitive wood based interior materials and systems for modern wood construction. Key topics include the securing of a good indoor environment, human health and psychological well-being, the potential for multi-functional wood-based products and systems, and the development of solutions combining material properties of wood with high-quality design. The results aim at applicability for market segments selected based on research of consumer preferences and the business environment of wood based products.

We spend 90% of our lives inside buildings and this affects our physical and psychological well-being and comfort. Comfort is most widely associated with temperature, humidity, noise, light and smell and these factors are addressed by various regulations. However, the significance of well-being, particularly psychological well-being inside buildings, is poorly understood.

Increasing evidence shows that contact with nature is important for the overall well-being of the occupants of buildings. Studies have indicated that the occupants' response to natural materials such as wood is very positive with a strong preference shown for interior spaces containing high proportions of wood. Differences in wood ratios have also been shown to produce different physiological responses especially in autonomic nervous system activity.

The overarching aims for the development of our built environment and construction in general reflect the European 2020-targets and beyond, aiming at resource efficiency and significant reductions of, among others, carbon dioxide emissions and energy use. Wood is a renewable and sustainable resource when using raw material deriving from sustainably managed forests. As resources are becoming scarcer and the importance of a sustainable development increases, materials and products with environmentally, socially and economically sound values should have an advantage if they can deliver competitive performance. The competitiveness of wood based products and systems should be improved based on these values. Design has the potential to accelerate bringing the ideas to the market.

Materials should be chosen to be fit for purpose in terms of their location and their contribution to the risk of accidents. The safety implications of material selection are well documented with codes and regulations in place to ensure the safety of the public i.e. fire regulations, building regulations, and e.g. the Regulation (EU) No 305/2011 including requirements on hygiene, health and the environment, energy economy and heat retention, and the sustainable use of natural resources. Limitations for the use of wood in interiors need to be globally identified, including an overview of regulations, standards, and certifications.

Current knowledge on the health effects of wood-based emissions is sparse and inconsistent. A few studies have shown that wood-specific volatile organic compound (VOC) emissions could have positive vegetative effects, whilst others found no detrimental effect on human health, and in other cases they are claimed to be potentially harmful. The current project deals with long term emissions from wood in real life tests, coupled with toxicology, epidemiology and human perception. First results will be presented.

Other properties that affect human perception of materials and surfaces include colour, surface structure and surface temperature. Work in the project Wood2New will continue through a look into factors that influence the haptic properties of wood surfaces as to find measurable parameters to characterise them and investigate the potential of latent heat exchange to reduce energy consumption. Additionally, the potential for increasing the use of wood in interiors and the effects thereof will be studied through research by design.

Wood2New aims at tangible results promoting economically and ecologically sound living spaces supporting human well-being. Wood material has the potential to provide value-added products creating ‘more from less’ thus unlocking potential for new forest-based businesses. First results, and the roadmap forward are presented.

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# Technology and machinery for the manufacture of wooden houses from round wood in Bulgaria

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**Key words:** Houses built from machined round timber, Log home, machinery, technology

Wood is traditionally used in housing construction in Bulgaria. Houses built from machined round timber have entered into the market in the last 20 years. There are machines for turning wooden beams. A new machine was designed and its performance was examined. Both the performance and quality of the the machine as well as the produced wood elements were studied. Additionally, a new paste for filling the gaps between the beams was produced.

Industrial production of log homes (well known in North America and Canada) from machined milled components is a recent activity. The first houses were produced in the early 1990s, at the beginning of democratic changes. Their market share amounts at 2.1%, however owners are usually wealthier people. This construction segment often occurs in the winter resorts of Bulgaria as houses, cottages, saunas, catering and even hotels, and owning a log house remains a luxury.

This study describes the technology and machine for the production of machined milled logs needed for the construction of prefabricated log homes.

The work of the new Bulgarian machine OM-350 for production of round milled beams with 22 centimeter diameter from square wooden beams with sides 24 by 24 cm has been studied. We examined machine milling productivity of 60 square spruce beams (30 with a length of 4 m, and 30 with a length of 5 m) with an average moisture content of 24%.

Table 1: Average duration of individual operations are specified

| № | Average duration of operations | length of 4 m. | length of 5 m |
|---|---|---|---|
| 1. | Transporting square beam to machine with forklift [s] | 125 | |
| 2. | Beam alignment and adjustment of milling heads [s] | 158 | |
| 3. | Rounding of beam [s] | 312 | 382 |
| 4. | Stopping and adjusting of channel milling head - Circular Saw [s] | 172 | |
| 5. | Routing of semicircular longitudinal channel and simultaneous cutting of longitudinal compensation channel [s] | 312 | 382 |
| 6. | Stopping the machine and removing the finished round beam [s] | 118 | |

It has been concluded that the duration of operations No 3 and No 5 do not depend on the human factor, but depend only on the sharpness of the cutting blades. The other operations exclusively depend on the professional skills of the working team.

The average duration of rounding of a 4 m beam is 19 minutes and 57 seconds, and for a 5 m beam the duration is 22 minutes and 17 seconds. Over one 8-hour shift the machine produced 18 4 meter beams or 72 linear meters; in the process of rounding of 5 meter beams- the productivity is 16 beams or 80 linear meters.

The obtained result is:

- 72% coefficient of working time utilization;
- the price of one meter of impregnated spruce rounded beam: € 7.40 excluding VAT .

As an outcome of the study, the average prices for one square meter of a single floor building in 2014 in Bulgaria, depending on the total build-up area, were calculated to be between 380 and 440 Euro among prefabricated log homes manufacturers.

# Societal perceptions of the forest-based sector and its products towards a sustainable society: project W³B – Wood Believe

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**Keywords:** societal perceptions, forest-based sector, WoodWisdom-Net+

Over the last few decades, crucial changes have taken place in the views of, and demands on forests by society at large. The major factors driving these changes were increased environmental awareness and the recreational interests of society or the public's way of looking at the traditional role of forests as sources of raw materials. At the same time the urge to align societies towards "sustainable", "green" and/or "bio-based" economies results in higher demands for raw material, not only for increasingly sophisticated bio-based products, but also for providing renewable energy.

Unleashing the potential of the forest-based sector to take the lead in Europe's endeavour to develop a bio-based society will create new jobs and improve the livelihood for millions of citizens across Europe. The forest-based sector plays a pivotal role in society's battle against climate change. The sector's actual contribution, however, is dependent on policymakers as well as on European citizens and how they perceive, accept and promote forest-based products and the activities carried out to produce these products. The European forest based sector aims at significant contributions regarding the development of "bio-based economies". As shown in many studies (e.g., Amberla et al., 2010; Toppinen et al., 2013) public perception of the European forest-based sector is based on diverse sets of information, such as communication on global issues, while no comprehensive understanding on the forest sectorial state of the public perceptions exists. Furthermore, evidence from North America (Panwar et al., 2012) indicates a challenging gap between societal and industrial perceptions on sustainability. Particularly sectorial level sustainability assessments are rare in the literature. Therefore the forest-based sector provides an appropriate research platform for new contributions to sustainability.

The European forest-based sector consists of a complex stakeholder-system that interacts with all hierarchical levels of sustainability targeting issues of high social relevance, such as the impacts of climate change on forests, climate policy including forests and wood products in carbon accounting, wood products substituting more resource and climate intensive materials, uncertainty of user and producer acceptability of technologically new bio-based products, better understanding of supply and demand of new bio-based products in the emerging bio-economy, woody biomass becoming an important feedstock for bio-refineries and energy production and the increasing demand for wood stressing the issue of mobilisation from fragmented forest ownerships and sustainable harvesting.

In the light of these developments the overall objective of the W³B-project is: creating and demonstrating innovative cost-efficient ways for communicating to stakeholders the relevance of the European forest-based sector and its products for a sustainable bio-economy. The project will therefore investigate the state of attitude and societal perception in the forest-stakeholder system. Based on these investigations living labs and cognitive response experiments will be used to identify topics, develop stakeholder-oriented narratives and assess their efficiency towards comprehensive communication. The project will therefore also include topics relevant for other finished, on-going and starting Wood-Wisdom-projects and demonstrate at least four cases of practical implementation.

Based on these results the forest-based sector will be enabled to develop customized communication strategies to transport the relevant information, stimulate public discussion and achieve societal acceptance and support regarding its contribution towards a sustainable society. New topics in relation to public perceptions that have to be discussed are public perceptions on climate change impacts on risk management in forests, societal understanding of climate policies and awareness of new and innovative forest-based products, such as those that can replace petrochemical products like textiles, bio-plastics and natural fibre enforced composites, tall multi-storey wooden buildings.

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# COST FP 1303 Cooperative Performance Test - Status update

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**Keywords:** wood, performance, moisture content, degradation, round robin

COST Action FP 1303 "Performance of bio-based building materials" has successfully started in October 2013 and we are looking forward to an ambitious program during the next 3.5 years. COST Actions provide an excellent opportunity for collaborative research, e.g. in the frame of Round Robin tests. As we have learned from earlier actions it is valuable to start with such cooperative activities as early as possible in the life of the action. This allows harvesting results within the run-time of the action and will initiate lively discussions during the upcoming workshops and meetings.

The idea of this respective test is to distribute a fairly simple test set up among as many places in Europe as possible to collect performance data under the full range of climatic conditions to be expected. Furthermore we would like to consider performance in its manifold meaning, i.e. optical, aesthetical, moisture and functional performance and durability. In contrast to traditional Round Robin tests aiming on comparative evaluation and validation of results from different test labs, this initiative aims on collecting performance data under climatically different exposure conditions. Therefore it will be required to provide weather data from the respective test sites to allow establishing relationships between climate conditions and the following measured, which shall be evaluated regularly: decay, discoloration, development of mould and other staining fungi, corrosion, formation of cracks, moisture performance (if data logging device is included).

The idea of the Cooperative Performance Test, was presented and approved at the first Action workshop in Paris in winter 2014. Until the end of spring 2014, 27 partners confirmed their participation. A folding table with boards made from three different materials (i.e. Norway spruce, English oak and thermally modified spruce) serves as easy shippable and ready-to-use test object (**Error! Reference source not found.**). The boards are fixed with partly stainless and partly ordinary steel screws.

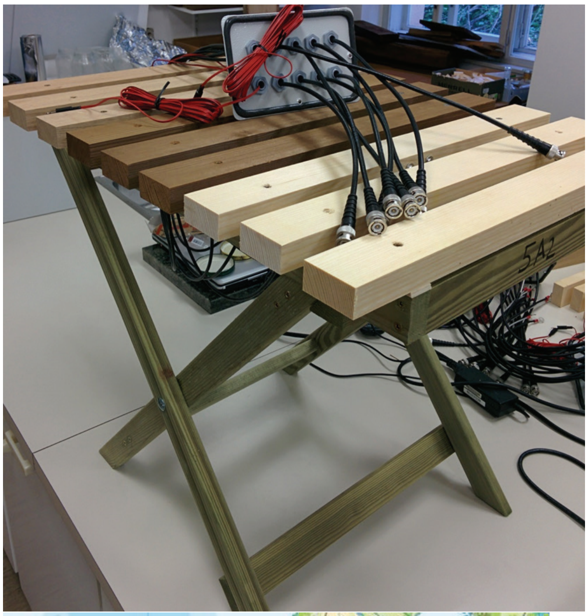


Figure 1: The design of the Performance table equipped with moisture and temperature logging sensors and distribution of the partners participating in the COST FP 1303 Cooperative Performance Test

In total 17 tables version A (Tables equipped with moisture logging sensors), 14 tables version B (Tables without moisture logging sensors) and 16 tables version C (blank rig) were manufactured. Scanntronik gigamodules are used for measuring and logging the electrical resistance and temperature of the wood. These data will be used for calculating the wood moisture content. Tables are distributed through all key European climatic zones (Fig. 1).

The exposure of the test tables started in September 2014. There are detailed guidelines for assessment prepared together with Excel forms that will enable easier comparison of the results. Data from the test will be available to the public, most likely through the IRG-WP Durability database. The results expected from this cooperative performance test will contribute to a better understanding of performance aspects of bio-based materials in the building sector under the influence of geographical and climatic differences. Furthermore it will enable the participants to estimate their own location in terms of exposure severity and performance to be expected.

**Acknowledgments**

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# A platform for exchange of performance data - the IRG-WP Durability Database

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**Keywords:** decay, field test, laboratory test, service life, wood protection

To deal with durability of timber and timber products is the core of the activities of the International Research Group on Wood Protection (IRG-WP). For more than four decades scientists from all parts of the world have come together every year to present results of their research and new developments and to share them with the scientific community. Determining the durability of the organic building material wood has turned out to be a major challenge. Wood is heterogeneous in terms of its anatomical and chemical constitution, its susceptibility to different decay organisms and degradation agents is very variable, and finally there exists a variety of measures to enhance the material-inherent resistance of wood. Consequently, numerous test methods using different decay organisms under laboratory and field conditions have been established in the past. It is worth stressing the point that that the results of such biological tests need to be interpreted carefully. Furthermore, it turned out that durability studies reported in literature often suffer from incomparability issues for several reasons. In addition to the heterogeneity of test methods, one will find that the results are mostly codified - sometimes in a cryptic way - or they are even incompletely published (Willeitner and Peek 1997, Brischke et al. 2012). Thus, the number of test results, which can be utilised for service life prediction of the material or component in question, is surprisingly few. However, in contrast to the fragmentary base of available data, there is an imminent need for service life related durability records.

The amount of worldwide existing data and test results must be a multiple of those available and published in a processable format. These data need to meet a number of requirements in terms of formatting, specificity, reliability and background information. For instance the use of durability classes, which usually indicate a full range of durability, appeared not to be precise enough for many natural scientific and engineering purposes.

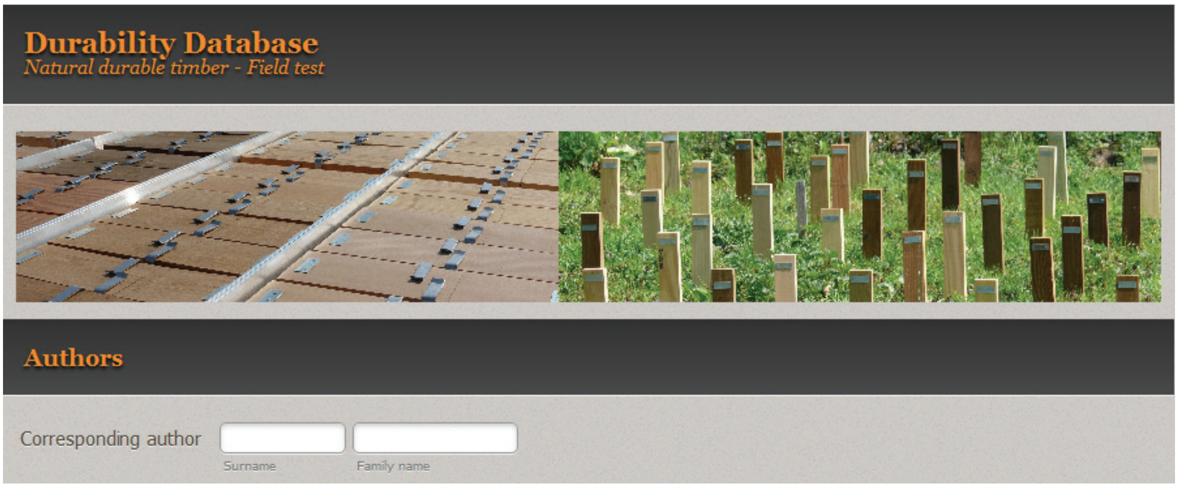


Figure 1: Online form for submission of durability data.

To increase the number and availability of useful data a suitable platform has been established on IRG-WP website in July 2013 (http://www.irg-wp.com/durability/index.html). The overall aim of this database is to facilitate the availability of wood durability test results for comparative studies and re-analyses. The database shall serve as data pool for service life prediction and modelling and will contribute to an enhanced understanding of wood durability. It is an open access web-based platform for scientific exchange in the field of wood durability and wood protection.

It is NOT the aim of the database to promote or denigrate any product or material. The database contains raw data only; no statistical evaluation is included. Thus it is the exclusive responsibility of the user to carefully interpret the test results published in the database. For each data set, the full range of information about the test method, the test material, and other relevant parameters, is required to guarantee reliability of the data. For this reason every data set submitted is reviewed and checked for completeness of all relevant data.

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# Development of the blue stain fungi on the façade of the model house in Ljubljana

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**Keywords:** wood, performance, moisture content, degradation, Norway spruce

A model house, made of 26 different bio based materials was constructed in the garden of the Department of Wood Science and Technology in Ljubljana. The house's timber frame based construction is made of Norway spruce wood, and outside insulated with low density wood fibre boards. The compartments in the timber frame construction are insulated with loose-fill cellulose fibres. The model is covered with a secondary water-shedding layer, namely a watertight and vapour–open membrane. The wooden façade applied on this object has protective and aesthetic roles. The façade on the model was finished in the mid of October 2013. The decking in front of the house is made of the same materials.

Figure 1: Model house on the garden of the Department of the Wood Science and Technology at University of Ljubljana

The façade and decking are made of 22 different wooden based materials (Table 1) of 2,5 cm × 5,0 cm cross-sections. Façade elements are positioned horizontally and screwed on the vertically positioned, copper-ethanolamine treated wood elements. Beside untreated control specimens, 4 different treatments were applied to the materials; copper-ethanolamine impregnation (Silvanolin®), montan wax impregnation (Silvacera®), acrylic surface coating (Silvanol® Lazura B), and thermal modification (Silvapro® Wood) (Table 1).

Table 1: Materials used in the façade and decking application on the model house

| Wood species | Treatment |
|---|---|
| Norway spruce | Untreated<br>Treated with montan wax<br>Surface coated with acrylic coating<br>Treated with copper-ethanolamine solution<br>Treated with copper-ethanolamine solution and montan wax<br>Thermally modified<br>Thermally modified and impregnated with montan wax<br>Thermally modified and impregnated with copper-ethanolamine<br>Thermally modified and coated with acrylic coating |
| European larch | Untreated<br>Thermally modified |
| Beech | Untreated<br>Thermally modified<br>Thermally modified and impregnated with montan wax |
| Sweet chestnut | Untreated |
| Scots pine sapwood | Untreated |
| Scots pine heartwood | Untreated |
| Black poplar | Untreated<br>Thermally modified |
| Ash | Untreated<br>Thermally modified |

Several parameters are monitored on this model house. There are 140 electrical resistance moisture monitoring sensors and 100 thermocouple temperature monitoring sensors. Measurements are performed and logged with 16 Scanntronik gigamodule (moisture) and Thermofox universal (temperature) devices. Furthermore, visual assessment of blue staining, degradation and fasteners corrosion is performed periodically. In order to elucidate weathering, colour is recorded using the CIELab system. This data is compared and linked to laboratory results. Therefore this house represents an excellent platform for students, researchers, wood industry and end-users.

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# Methodological Improvements in the Assessment of the Resistance against Moulds of Bio-based Insulation Materials

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**Keywords:** bio-based insulation materials, mould growth

Due to their positive environmental attributes, the use of bio-based insulation materials such as sheep's wool, straw, hemp, wood fibres, and cotton cellulose has been increasing in the construction industry across Europe. The performance of these materials is comparable to that of the synthetic materials commonly used in construction. However, they are potentially sensitive to biological degradation, such as that caused by mould fungi, which can restrict their use. To obtain technical approval from the French building research centre (CSTB), bio-based insulation materials must meet performance requirements based on the standards prEN15101 or NF EN 846. However, these standardized protocols focus only on assessing the inherent resistance of the tested materials against moulds, without taking into account their expected service life, their installation procedures, or their conditions of exposure to moisture in use. Moreover, the standardized criteria for determining their resistance against moulds are based only on visual inspection of samples exposed to spores under laboratory conditions. Microbiological methods developed by two French laboratories, FCBA and CSTB, based on quantitative criteria (counting fungal cells, measuring the amount of ergosterol) pointed out the weaknesses of the existing standards, whose criteria are not sensitive enough to detect early mould contamination. The results of durability tests performed on different bio-based insulation materials using different methods of mould growth quantification are presented here and the relevance of the test protocols are discussed. A harmonized methodology for the evaluation of bio-based insulation materials has been worked out based on this study and has been proposed as basis both for developing a specific French standard and improving the current European standards.

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# Effects of climate exposure on the (moisture) performance of structural details in timber bridges

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**Keywords:** decay, performance, service life, timber bridges

The service life of timber in outdoor applications can be limited by decay. Decay is a progressive process which effectively reduces the size and strength of a timber cross section and hence the capacity of the element. In load-bearing applications such as bridges, the absence of decay is crucial to ensure the safety of the structure. Models to predict the onset and rate of decay, e.g. dose-response models, are often expressed as functions of material climate i.e. moisture content and temperature (Brischke et al., 2006). In existing structures, an assessment of remaining service life can be based on measured material climate history and extrapolation. However, in design situations, a similar approach is feasible only if the material climate can be expressed as a function of parameters available in the design phase. Numerical models to predict material climate based on local climate are readily available but do not account for microclimatic effects i.e. moisture trapping, drying conditions and exposure to free water (Fortino et al., 2013). Knowledge about the amplitude of these effects is essential when assessing the service life of a structure or establishing an inspection plan. This study aims to rank timber bridge details with respect to moisture performance during natural climate exposure. The ranking is based on empirical data obtained from a test setup located in Lund, Sweden. The approach is similar to the categorization of fatigue classes in EN 1993-1-9 which also has a basis in empirical testing. Structural details typically found in timber bridges were designed and produced in collaboration with two Swedish timber bridge manufacturers: Moelven and Martinssons. The test specimens will be exposed to natural weather for one year from June 2014 and the moisture content is measured in selected points. The test specimens can be separated into two categories consisting of structural protection and moisture-traps. The first category is intended to rank the positive effect of protective measures and consist of a number of beams with various types of protective cover (see figure). Conversely, the second category intends to measure the adverse effect of moisture-traps and can be divided further into three types of details: Horizontal and vertical connections of timber beams, steel joints and column connection to concrete foundation. In addition to the previously mentioned test specimens, an unprotected 22x95 board of Norway spruce without moisture traps is used as reference. The reference also serves as a means of comparison to a previous study by Isaksson and Thelandersson (2013) in which a similar experiment on timber decking and cladding was carried out. Part of the test setup is displayed in figure 1.

Figure 1: Beam with structural protection and vertical/horizontal contact areas

Moisture content is measured hourly over the course of one year using conductive-type moisture meters. The conductivity in a plane between two penetrating pins on a depth of 15-20 mm from the surface is measured and a linear relationship between conductance and moisture content is used to derive the moisture content (William, 1988). In addition to the moisture content, the following quantities are recorded hourly: relative humidity and temperature of the ambient air, rain events (intensity and duration) and wind.

All test specimens are exposed to the same climate during the same time period. Consequently, a significant discrepancy in moisture content between test specimens must be attributed to detail design. This effect was first quantified by Isaksson and Thelandersson (2013) and referred to as the relative performance of the detail design. Relative performance is derived from empirical data and expresses the relative difference between a specific design and a reference design. A relative performance above 1 means that the detail is subjected to a more severe exposure (relative to the reference detail) due to either a moisture-trap, bad drying conditions or both.

Results from the initial test period are presented.

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# Moisture sorption in modified wood

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**Keywords:** Wood-moisture relations, wood modification, moisture sorption isotherm, glass transition

**Abstract**

Moisture is a key factor in the service life performance of natural fibre products, however, its exact role is still a subject of research. This is for a considerable part attributed to the poor understanding of moisture dependent behaviour of lignocellulose substance (Engelund et al. 2013). In previous work, moisture sorption has been considered as a statistical occupancy process of accessible sites in the fibre cell wall matrix (Willems 2014), successfully describing moisture sorption and hysteresis in glassy state of the matrix at sufficiently low ambient humidity. This work investigates the high-humidity moisture sorption behaviour, most relevant for the performance under exterior service conditions. Moisture adsorption beyond the cell wall softening point, is surprisingly intimately related to the low-humidity adsorption, via the study of the effects of various modification treatments of the cell wall. This result is of fundamental importance in the development of improved moisture sorption models for the analysis of experimental moisture sorption isotherms.

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# Effect of high pressurised water on wood surfaces

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**Keywords:** abrasion, high pressurised water, larch, black locust, kapur

Outdoor wood surfaces are exposed to degradation induced by weathering. The upper layer must be removed for renewal of the degraded surface. Grit blasting or high temperature washing are often used for cleaning outdoor wood surfaces. The technology of high temperature washing is really interesting, because nowadays the necessary equipment is available to households, so this method of cleaning can be carried out by the owners themselves.

Outdoor wood surfaces are generally protected by surface treatments in order to prolong their service life. After the aging/weathering of the protecting layer(s) the previously mentioned methods are used for cleaning the surfaces.

In our project we aimed to get information on the abrasive effect of highly pressurised water on the wood's surface and to show the protective effect of different surface treatments.

Three wood species were chosen for our project: larch (*Larix decidua*), black locust (*Robinia pseudoacacia*), and kapur (*Dryobalanops* spp.). The surface finishing materials were: Sadolin outdoor hardwood floor glazing, Woodex wood oil.

A universal and typical cleaning machine (type Kärcher K2.00 – available on the market) was used for the high-pressure water abrasion. The cleaning machine was set up with a Vario power spray lance, which ensured a constant shape of the water stream. The spray lance was positioned at a distance of 10 centimetres from the wood surface, and the angle was set to 70 degrees to the tested surface. With these settings n 42 mm wide abrasion area was achieved. During the tests 20 mm thick boards were eroded for determined time (larch – for 0,5, 1 and 2 minutes, black locust and kapur: for 2, 3 and 4 minutes). After abrasion procedure the wood samples (boards) were cut parallel to the abrasion line. The cross sections were than scanned digitally. The photos were than evaluated by image analysis software in order to determine the magnitude of the erosion in the cross section caused by the water jet.

In the case of larch the early wood was affected in a larger extent than the late wood. The consequence is a scattered, irregular surface (Figure 1.). The different surface treatments provided different protection against the high-pressure water jet. The untreated (not protected) surfaces suffered the most abrasion. The oil treatment penetrated the surface of the timber, but could not provide the protecting effect of the glazing, which proved to be the most effective protection against the water jet.

The magnitude of the erosion on the surfaces of Black locust and kapur boards was much lower compared to larch; however they showed similar character (Figure 2.). In the case of the hardwoods the water jet abraded the vessels and cells. If vessels formed a group, the water jet induced a deeper abrasion locally.

Figure 1: Surface of larch after abrasion by water jet

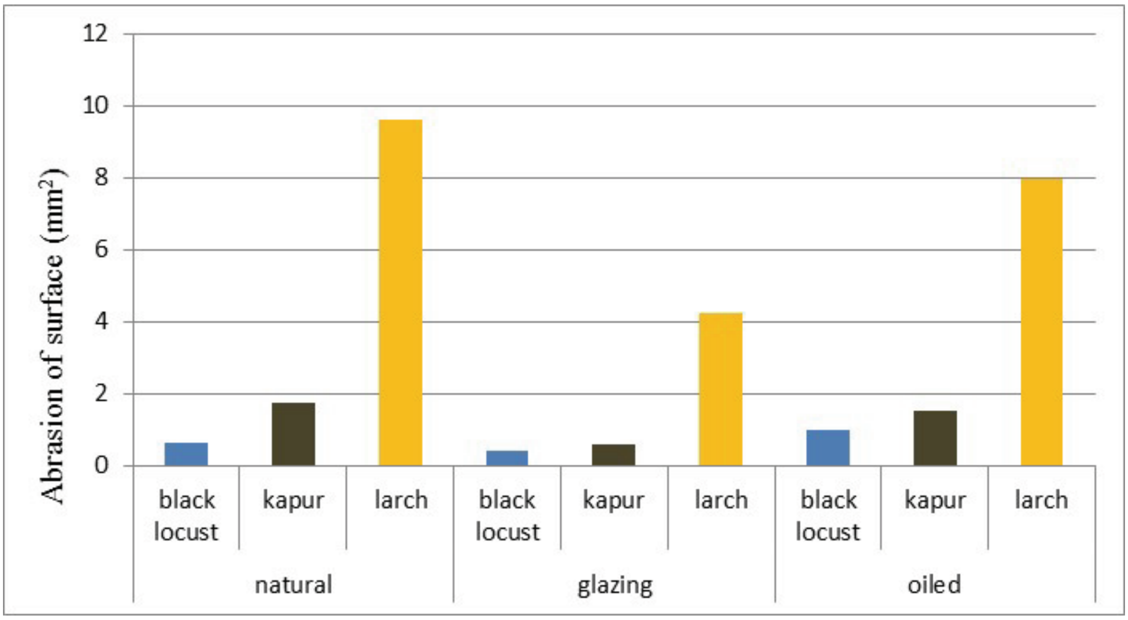


Figure 2: Surface abrasion after 2-minute-treatment, abraded surface pro 100mm length

## Acknowledgments


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# Time of Wetness (ToW) simulation based on testing moisture dynamics of wood

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**Keywords:** time of wetness, moisture dynamics, wood species, wood based panels, modified wood

Within the framework of CEN/TC 38 (European Committee for Standardization / Durability of wood and wood-based products) the WG 28 (Working Group Performance classification) have been established to harmonize, especially for use class 3 applications, views on durability aspects of wood species, preservative treated and modified wood. The related EU project PerformWood established the concept that natural durability and/or enhanced durability is not solely based on the presence of active ingredients having an impact on both fungi and insects. The material resistance complementary to this is also based on the time of wetness factor. Based on earlier results for plywood experiments were set up for solid wood. For plywood a simulation of time of wetness measured by continuous moisture measurements (CMM – Figure 1) (Van den Bulcke et al. 2009, 2011) was possible by using a floating test including wetting and drying components. For solid wood a soaking/submersion test procedure was added as a second test to distinguish between optimal design of a commodity and design including water trap. These methods have been used in a round robin and results were presented earlier by Brischke et al. (2014).

To complement this work some 52 wood species, 17 sets of modified wood and 8 wood based panels were assessed according this protocol soon to become a European standard test method. The method is based on one hand floating specimens with a face on water with edges sealed and on the other hand a submersion test with open end grain cross sections (Figure 2). The dimensions are aligned with common field test specimens. Results showed that absorption and desorption figures after 24 hours could differentiate wood species and still allowed to classify similar material in the same class. Based on curve fitting this approach can seemingly be improved and also parameters that explain better the water uptake rate and release rates next to total absorption and residual moisture content can be included. Data are presented using the unit g/m² for the floating test and kg/m³ for the submersion test but these values can easily be translated in percentages moisture content. The results as earlier presented by Van Acker et al. (2014) are now being compared with continuous moisture measurements to underpin the meaning of the critical parameters in relation to actual time of wetness.

Figure 1: Continuous Moisture Measurement (CMM) set up at UGent – Woodlab

Figure 2: Floating test (left) and submersion test (right)

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**Acknowledgments:**


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# LCA of an in-development ultralight particleboard

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**Keywords:** attributional LCA, decisional LCA, foam core, PLA, ultralight particleboard

*Introduction*: The particleboard (PB) industry has been striving to produce ultralight particleboards (ULPB) for several decades now. The main goal of decreasing the density of PB is to reduce the material intensity of such products, and, consequently, to decrease their production costs (Shalbafan et al. 2012). A side effect of this could be the reduction of environmental impacts throughout the whole life cycle of these products. Lighter products are advantageous in handling, they require less resources and hence less transport expenditures. With regard to todays harmonized standards in context with product environmental life cycle assessment EN 15804 and prEN 16485, these potential benefits can be explored based on a robust method with broad acceptance. This study presents the specific challenges of assessing the environmental impact of the life cycle of an in-development (research stage) ULPB, manufactured in an *in-line process* on a continuous press with a polylactic acid (PLA) foam core layer and using $CO_2$ as blowing agent. The aim is to identify environmental "hot spots" and to show the effect of core layer polymer substitution by comparing environmental impacts of the ultralight particleboard with a conventional particleboard.

*Method*: The analysis comprises all product stages from cradle-to-grave following the EN 15804 specification. The product is supposed to be produced in Switzerland in a conventional PB plant with a continuous press. For the use phase only the transport of the panels are considered. The end-of-life scenario considered is the incineration in a municipal plant (most realistic scenario in Switzerland). The functional unit is $1m^3$ panel (thickness 19 mm), raw, fulfilling technical requirements for indoor applications. The different panel formulations are compared over the same life span. The inventory for the conventional PB is taken from the Ecoinvent v2.2 database (Werner et al. 2007). Data concerning the formulation of the ULPB are derived from the last laboratory development. Several assumptions are done based on literature.

*Results:* The raw materials with the highest weights (polymers and wood) are the most influencing factors in the model (Fig 1.). Unexpectedly, no relevant effect could be observed due to the utilisation of a different blowing agent. Compared to conventional polymers, the utilization of a biopolymer in the considered formulation reduces the Global Warming Potential (GWP) slightly. From the viewpoint of ecological scarcity though, the agricultural processes are critical. The environmental benefits of reduced transports were assessed not to be relevant when compared to the impacts derived from different quantities and types of raw material chosen for the core layer.

Due to the ambiguous results related to the impacts of resources and by-products a simple decisional approach, based only on the primary fossil energy demand, comparing the ULPB with 100% PLA and the PB was conducted. The result show that the primary fossil energy demand obtained for the PB is five times higher than for the ULPB with 100% PLA core material. From both approaches there is a tendency (to be confirmed) that ULPB can have environmental benefits compared to conventional PB.

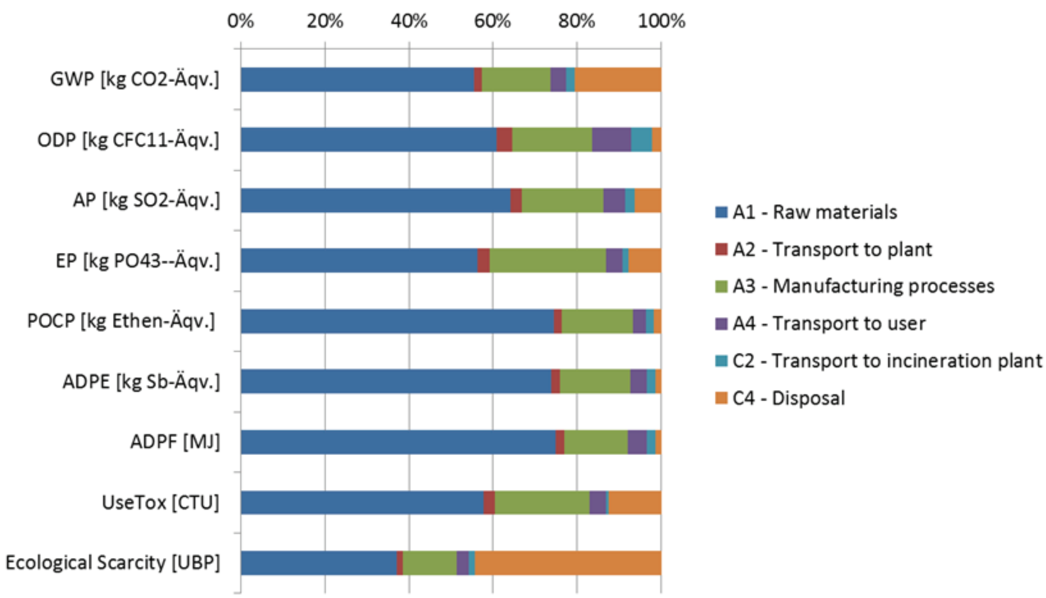


Figure 1: Relative environmental impact of the ULPB for each life cycle stage corresponding to EN 15804 modules.

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# Investigation on bonding properties of modified birch veneers using ABES machine

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**Keywords:** shear strength, wood modification, hot curing adhesive

This study tried to investigate the bonding properties of modified birch veneers (furfurylated, heat treated at 180°C and 220°C and melamine treated) with PF adhesive using automated bond evaluation system (ABES). The shear strength of glued strip samples was measured at different pressing and assembly times. Then as second goal, the feasibility of using ABES for evaluation of bonding characteristics of cold set adhesives (PVAc, EPI and $PU_{1k}$) was also examined (fig 1).

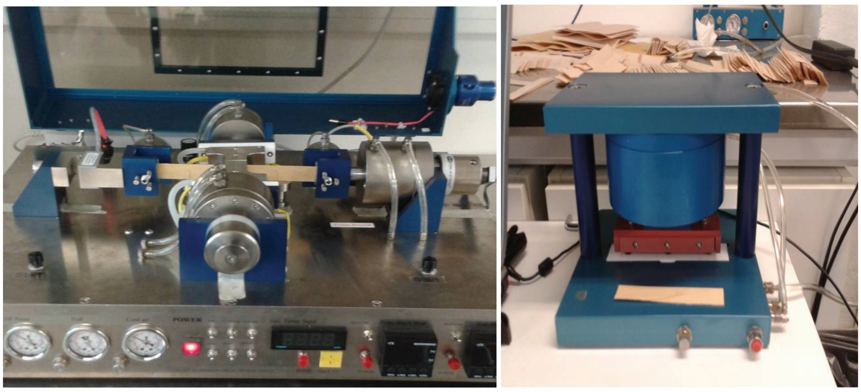

Figure 1: ABES testing machine (left) and the sample cutter device for cutting 20 mm x 115 mm strips (right)

Melamine treated and furfurylated samples glued with PF showed much lower shear strength after short pressing time (20 S) as compared to other wood types due to poor wetting of the surface after modification. Heat treated veneers (220°C) presented the highest value after 20 s pressing. Bonding properties did not change by increasing assembly time in all cases after short pressing.

Table 1: Testing parameters

| | Hot curing glue [PF] | Cold set glues |
|---|---|---|
| Measured value[MPa] | shear strength | shear strength |
| Applied pressure [N/mm$^2$] | 2 | 2 |
| Application amount of glue [g/m$^2$] | 100 | 200 |
| curing temperature [°C] | 130 | 20 |
| Bond area [mm$^2$] | 4 x 20 | 4 x 20 |
| Pressing time [s] | 20, 160 | 20, 90, 300 |
| Assembly time [s] | 20, 600 [=10 m] | 20 |

*For each case 9 replicates were tried*

After 160 S pressing, furfurylated samples assembled in 20 s showed the highest strength. Bonding strength decreased dramatically for furfurylated and melamine treated veneers by decreasing pressing time. Among cold set adhesives tried in this research, PU did not fit for studying with ABES due to increased pressing time (3-4 h), which is beyond the capability of the utilised testing device. It is possible to measure bonding properties of EPI and PVAc by ABES but a longer pressing time is required than hot curing glue.

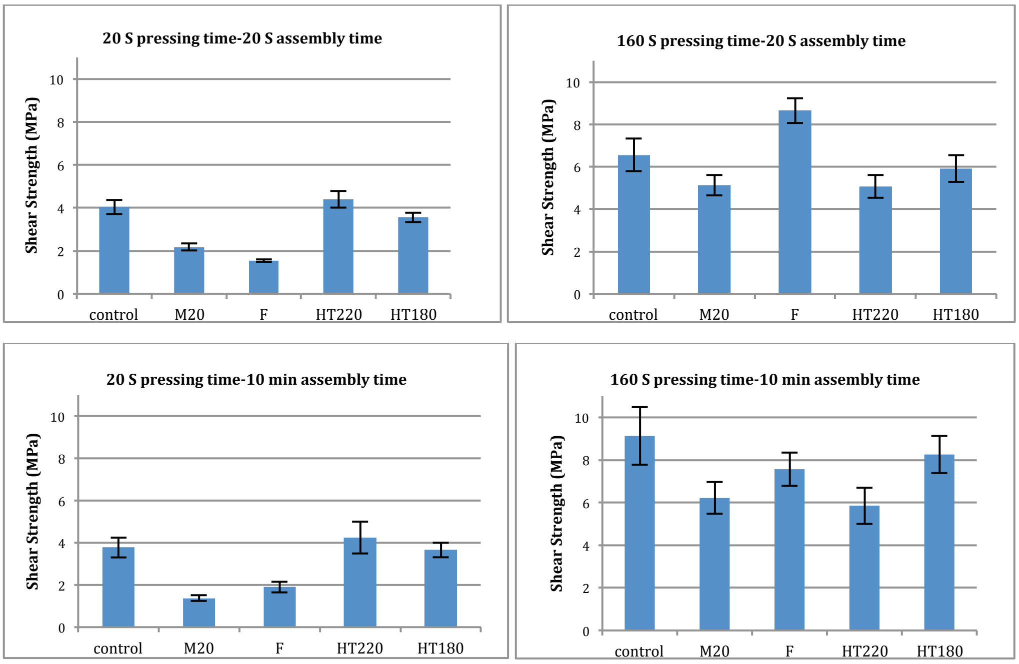


Figure 2: Obtained values for shear strength; control, melamine treated (M20), furfurylated (F) and heat treated samples at 180°C (HT180) and 220°C (HT220) glued with PF at 130°C.

**Acknowledgments:**

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# Bonding quality of laminated veneer lumber manufactured from densified poplar veneers – the effect of pressure level

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**Keywords:** Laminated veneer lumber, thermo-mechanical densification, pressure effect, bonding strength

Generally, low-density wood species such as poplar are not used in structural applications (e.g. laminated veneer lumber) because of their poor mechanical properties. Nowadays, great interest can be seen in compressive treatments in the transverse direction (i.e. densification) as a modification method to improve the poor mechanical properties of low-density wood species. Besides the change in density and mechanical properties, densification influences the morphology and surface roughness of densified wood. The changed structure of the densified wood affects adhesive penetration depth, adhesive distribution uniformity, and improves the bonding quality between veneer sheets (Kutnar et al. 2008, Bekhta et al. 2009, Candan et al. 2010). Therefore, the effect of pressure in the pressing process of laminated veneer lumber (LVL) manufacturing may influence the bonding strength. Hence, the aim of this work is to evaluate the effect of pressing pressure on the bonding strength of LVL manufactured from densified poplar veneers.

In this study, poplar veneers *(Populus Euramericana I-214)* 3, 3.5, and 4 mm thick were used to produce LVL. The veneers were first compressed in the transverse direction of the surface to 2 mm and densified 50%, 78% and 104%, respectively. The densification was carried out in a hydraulic press with cooling equipment by the thermo-mechanical (TM) method at 170°C and 2.1 MPa. After densification, the veneers were conditioned at 20°C and 65% relative humidity, then 4 veneer sheets were bonded with urea-formaldehyde (UF) or polyvinyl acetate (PVAc) adhesives and assembled into panels and pressed under 0.25, 0.50 and 0.75 MPa pressure. Additionally, control samples were produced from 2 mm thick undensified poplar veneers. Specimens were then cut from these and their bonding strength was determined according to EN 314-1.

The observed densification rates were 47% for 3 mm veneers, 70% for 3.5 mm and 76% for 4 mm veneer; 3%, 5% and 17% thicker than the expected thickness, respectively. The observed densification rate of 4 mm veneers was not significantly different from specimens with an initial thickness of 3.5 mm. The reason for this may be the instant spring-back effect of compressive deformation after opening the press.

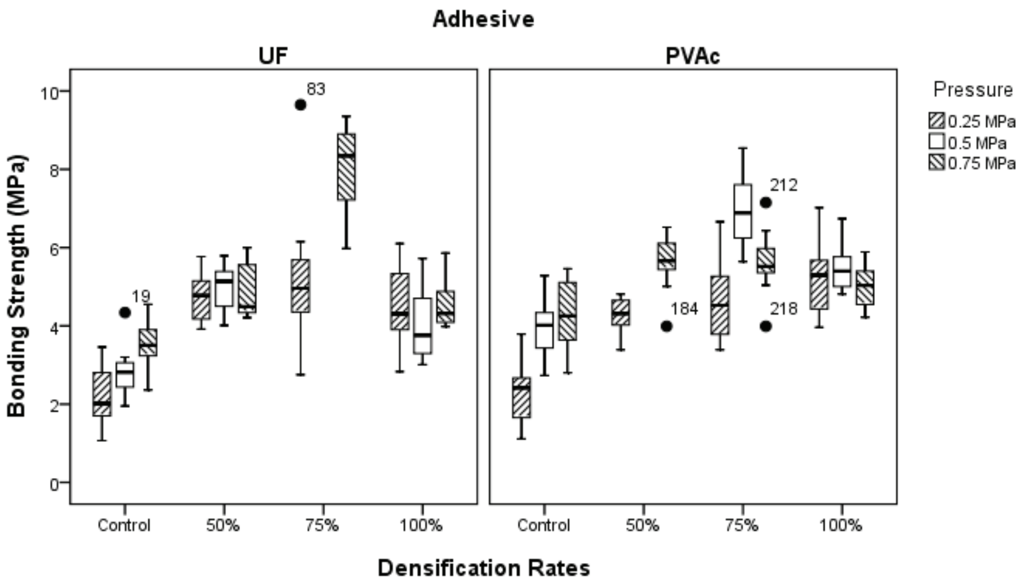


Figure 1 Average bonding strength of LVL sampler according to EN 314-1

The results of this study are shown in Fig. 1. The bonding strength of LVLs manufactured from densified poplar veneers was significantly higher than the control samples. The highest bonding strength value was measured in LVLs manufactured from 75% densified veneers (3.5 mm original thickness). In the UF group, significantly increased bonding strength was observed when pressing pressure was increased from 0.25 MPa to 0.75 MPa for control samples and LVLs manufactured from 75% densified veneers. There was no significant effect of pressing pressure on bonding strength of LVLs manufactured 50% and 100% densified veneers in the UF group. In the PVAc group, significantly increased bonding strength was observed when pressing pressures higher than 0.25 MPa were used for control samples and LVLs manufactured from 50% and 75% densified veneers. Pressure had no significant effect on bonding strength of LVLs manufactured from 100% densified veneers. In conclusion, higher bonding strengths might be obtained when 75% densified veneers and pressures greater than 0.25 MPa are used in LVL manufacturing.

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# Investigating Views of Naturalness Across Europe

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**Keywords:** building materials, restorative environmental design, biophilia

Natural elements are thought to provide positive health impacts to building occupants including reduced psychophysiological stress (Fell 2010, Ulrich 1991), improved post-operation recovery (Ulrich 1984) and improved attention restoration (Kaplan 1995). Determining which materials are considered natural will aid designers attempting to include natural elements in building design.

A survey asking individuals to rate the naturalness of 22 building material specimens was conducted in Espoo, Finland (n=42) and two Slovenian cities: Koper (n=43) and Ljubljana (n=46). This survey builds on the work of Nyrud et al. (2011) examining user views of building material naturalness, originally conducted in Oslo, Norway. Respondents were asked to visually examine each 100 mm x 100 mm specimen and subjectively characterise its naturalness on three scales: natural and not natural; a naturalness scale from 1-7; and an ordered ranking of all specimens. Samples were convenience samples of students, faculty and staff at three universities (Aalto University in Espoo, the University of Primorska in Koper and the University of Ljubljana in Ljubljana). The sample in Koper also included the members of a local sports club.

The five untreated solid wood specimens in addition to the untreated stone tile specimen were considered natural by more than 89% of all respondents (Fig. 1). The steel specimens, ceramic tile, woven fabric, and polished plastic were considered natural by fewer than 13% of all respondents. Both Kendall's tau and Spearman's rho rank correlation coefficients (range -1 to 1) both indicated strong correlations between groups, suggesting general consensus despite some apparent regional differences. The comparison between Koper and Ljubljana results in: tau = 0.781 and rho = 0.915; and Slovenia compared to Espoo: tau = 0.758 and rho = 0.905.

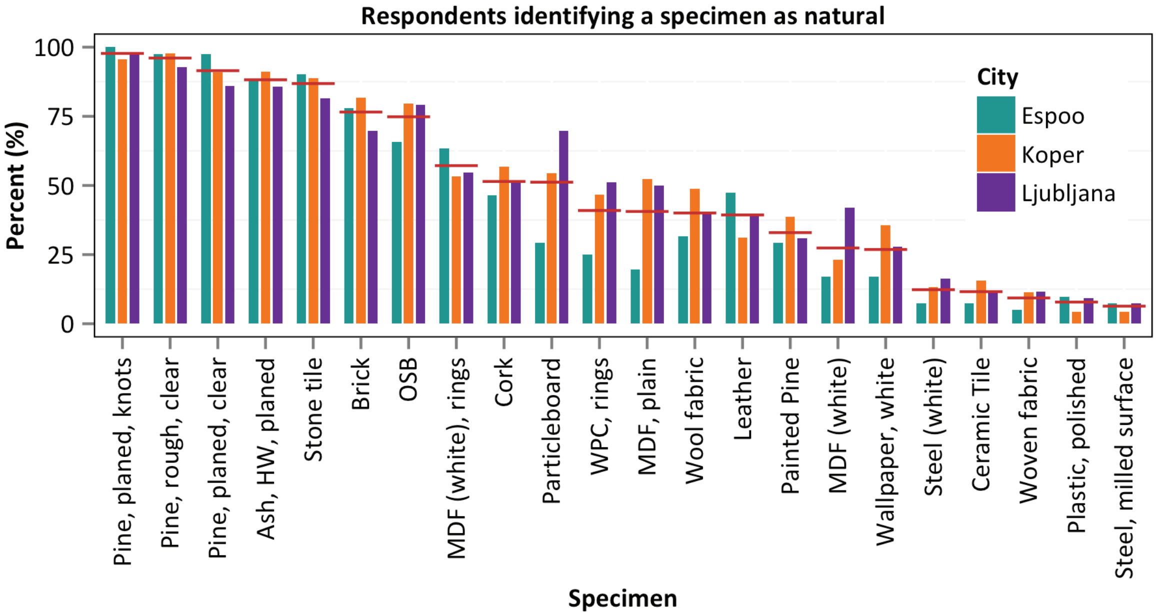


Figure 2: Percent of each group identifying specimens as natural. Red bars are average of all responses for a given specimen.

Overall, respondents tended to agree when identifying the naturalness of the 22 building materials presented. However, the differences that do exist suggest designers should consider material choices carefully when attempting to bring nature indoors through building material selection and use. Additionally, respondents from Espoo, Ljubljana, and Koper appear to be in general agreement with respondents from the study conducted in Norway by Nyrud et al. (2011).

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# Evaluation of fungal infestation, decay and evaluation methods in a simulated use class 3 situation (block test) after some years of exposure

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**Keywords:** block test, fungal decay, MOE dynamic

The so called "block test" was designed as part of the assessment methodology for testing the behaviour of natural and modified wood used under use class 3.2 (EN 335) conditions. The test was developed to expose the wood close to the ground to an environment with high humidity and high biological activity, but not in soil contact.

The present study describes the evaluation of fungal infestation and decay of untreated samples in different blocks depending on their exposure time, positioning within the block and wood species. The decay of the samples was assessed with the so called pick-test and the determination of the Modulus of Elasticity (dynamic MOE). Furthermore the influence of wood moisture content on the accuracy of the measurements was investigated.

After 4 years outside exposure, samples showed visible signs of decay. The highest rate of decay was visible in the middle layers of the block. After 7 and 8 years outside exposure, samples of all layers were infested with a similar intensity of different types of decay. The results have shown that in the bottom layer close to ground the major type of decay is white rot as well as white rot in combination with soft rot. In contrast, samples from the middle layers and top layer were infested mainly by brown and white rot but also soft rot was observed (Table 1).

The observed decay of the untreated samples indicated good conditions for fungal growth within the block test setup. The results displayed no significantly differences in type of decay between hard-and softwood species. Hard- and softwood were infested by white as well as brown rot (Table 1).

Table 1: Type of decay in different layers

| Block no. | Top layer | Middle layers | Bottom layer |
|---|---|---|---|
| 1 | S[2] | B[3], W[3], S[3] | W[1] |
| 2 | B[5], W[5] | B[4], W[4] | W[4] |
| 3 | B[3], S[3] | B[3], S[3] | W[1], S[1] |
| 4 | W[1], S[1] | W[3], S[3] | W[3], S[3] |
| 5 | W[3] | B[4], W[4] | B[3], W[3], S[3] |
| 6 | B[1], S[1] | B[2], W[2] | W[3], S[3] |
| 7 | B[1], W[1] | B[2], W[2] | B[2], W[2] |
| 8 | B[3], W[3] | B[5] | B[5] |
| 9 | W[3] | W[5], S[5] | W[5] |
| 10 | B[1], W[1] | B[2] | W[1], S[1] |

B – *Brown rot*
W – *White rot*
S – *Soft rot*

[1] *Scots pine sapwood*
[2] *Scots pine heartwood*
[3] *Spruce*
[4] *Oak heartwood*
[5] *Beech*

The test setup is according the definition of use classes a method for use class 3.2 applications because the samples are out of ground contact. But because the infestation of samples in all layers by soft rot can occur, this should make part of a proper test design.

In general, MOE-measurements showed deterioration at earlier stages than both visual assessments of the samples and the evaluation with the pick-test and provides additional information. However, the evaluation of MOE needs more sophisticated equipment and experienced staff to perform the measurements. Nevertheless, the determination of loss in elastic properties is a good addition to the pick test and visual assessments of wood particularly in early stages of decay. In order to minimize the influence of the variety of wood moisture content, the specimens have to be either climatized before measurement of MOEdyn or the wood moisture content has to exceed fibre saturation point. Storing specimens in water, thus using (wet specimens) saves time during field tests. The experience during the long time exposition showed, that there is no indication for a reduction of fungal vitality caused by the soaking of specimen. The result showed that after 24h of water storage, the wood moisture content was above fibre saturation.

Based on these results the following requirements should be fulfilled for a MOEdyn measurement applied in field tests:

- Use of either climatized or water stored specimens for assessing MOEdyn; water storage is less time consuming during field tests; water storage for a minimum of 24h is mandatory to guarantee wood moisture contents above fiber saturation.
- No vacuum-pressure impregnation is recommended, to avoid the potential risk of destroying fungal hyphae within the wood tissue to be deteriorated during field tests

# Performance of thermally modified timber in use class 3.2

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**Keywords:** thermal modification, cracks, decking, pre-drying, sorting, wood anatomy

It is commonly known that wood properties like biological durability, hygroscopicity and dimensional stability are improved by thermal modification (Scheiding and Direske 2014). Therefore TMT (thermally modified timber) is often used for decking boards and cladding components in outside exposure. Both applications, decking and cladding, represent high climatic and mechanical stresses for the material. Normally they comply with use class 3.2 respectively 3.1 according to EN 335:2013 and DIN 68800-1:2011 (Flade 2011).

The reduced swelling and shrinking of TMT could lead to the assumption that the crack formation of TMT is also reduced. However, several cases of damage can be observed - mainly on decking but also on cladding. The damage mostly was not caused by fungal degradation but by high brittleness and strong crack formation as investigations of damage carried out by IHD show.

### Experimental work/investigations

For a deeper investigation of the causes and mechanisms of crack formation a research project about crack formation in TMT was initiated. TMT was produced on laboratory scale and industrially, different wood species (beech, spruce, ash, birch) were used, specimens (500 x 120 x 25 mm³) with different annual ring orientations (lying/diagonal/standing rings) and different wood characteristics (compression wood resp. facultatively coloured heartwood) were sized and planed. For weathering, specimens were exposed on field test site according to use class 3.2 similar to decking (unprotected, horizontally laid, south-oriented). Crack formation was monitored and assessed in different intervals. Additionally, further cases of damage with strong cracks were investigated due to physical-mechanical properties, wood selection and cracking manners.

### Results

In the paper previous experiences and preliminary findings on crack formation are presented. In accordance with the modified wood properties of TMT it was observed that the cracking manner also differs from that of untreated wood. That is reflected in typical crack phenomena of TMT such as:

- tangential delaminations on conifer wood, esp. in plain sawn boards, mainly on inside face (Fig. 1);
- deep radial surface cracks, esp. in beech wood;
- very long and traversing end cracks;
- radial internal cracks, deciduous wood species with higher density (ash, beech) are esp. susceptible (Fig. 2);
- tangential cracks in ash TMT.

Figure 1: Tangential delaminations, facade cladding, spruce TMT

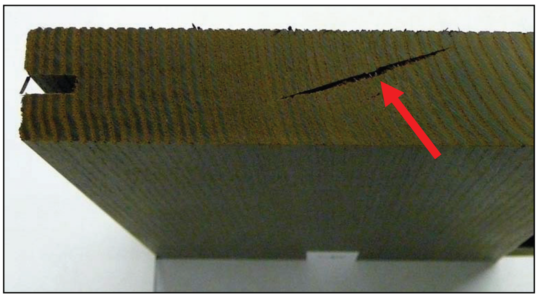

Figure 2: Radial internal cracks, cross section, decking board, ash TMT

It became apparent that crack formation is not only affected by thermal treatment, but there is a wide range of factors in different steps in the chain of custody of components like decking, that have an influence on the kind and dimension of crack formation: starting with the selection of wood species (specific features, wood anatomy), sorting (annual ring orientation, presence/absence of certain wood characteristics), pre-drying operation (internal tensions, drying defects), intensity of heat treatment, wood processing through to mounting (Fachregeln des Zimmererhandwerks 02 2007) and caring of decking in service. Such influencing factors will be illustrated in detail.

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# Diversity of wood decay fungi in test fields across Europe

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**Keywords:** wood decay fungi, molecular analysis, DNA

In contrast to the extensively studied wood decay fungi in the interior of buildings, the significant higher fungal diversity on weathered timber in use has been investigated to a much lesser extent. Therefore, the IHD initiated a research project comprising the analysis of the fungal spectrum and the intensity of degradation of wood in ground contact at five European sites (Bordeaux, Hamburg, Udine, Dresden, Poznań) using conventional and molecular methods. Beech and scots pine specimens were exposed according to EN 252. The fungal decay was studied over a period of three years. Every six month a set of three specimens per wood species were removed from test sites. These stakes were analyzed at IHD using surface and interior samples from three ranges of each specimen: above ground, earth/air passage area and in ground (Fig. 1). Conventional diagnostics were done by macroscopic and microscopic investigations of local areas with visible infestation at magnifications of 7.5...110-fold (reflected-light microscope) and up to 750-fold (transmission light microscope). The further molecular diagnostics include sequencing of the nrDNA-ITS region (internal transcribed spacer of the nuclear ribosomal DNA) and comparison with sequence databases as well as melting curve and restriction analysis of amplified ITS regions.

As a result, more than 300 ITS sequences were generated and analyzed, assigned to 98 different species and 77 genera of fungi mainly belonging to the *Basidiomycota*. Thereby, about 25 fungi were detected per test site. As expected, soft rot infestation was found frequently. Nevertheless, due to mixed DNA samples and a lack of reference sequences in databases the corresponding fungal species (*Ascomycota*) could be identified only to a small extent.

For each site a specific spectrum of fungi was detected, whereby some of the predominantly occurring species are not yet known as typical destroyers of used wood such as *Hypholoma fasciculare* (massive infestation in Hamburg and Poznań), *Cyathus striatus* and *Cyathus stercoreus* (dominant fungi in Dresden, Hamburg and Udine) or *Scopuloides hydnoides* (frequently occurring fungus in Hamburg). The morphological and genetic characteristics of dominant fungal species at each test site were documented. White rot occurred generally in a significantly higher level than brown rot at all test sites with exception of Bordeaux. A general increase of the detected fungal spectrum with increasing exposure time was surprisingly not found. In particular, the dominant fungi were detectable over the entire exposure time.

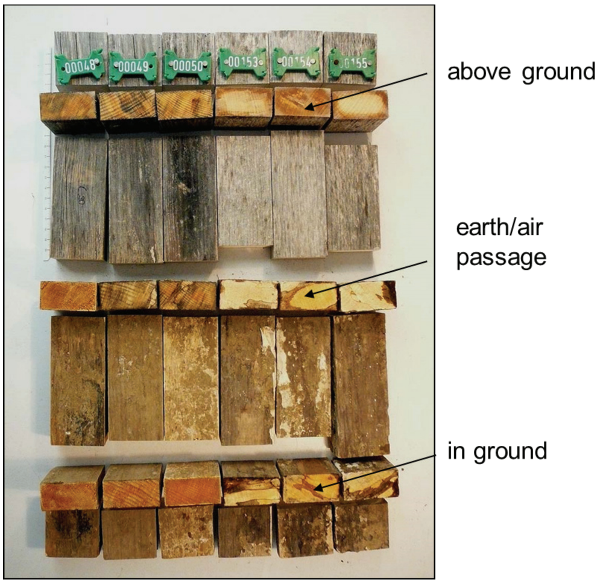


Figure 1: Sampling from different regions of specimens

The findings of fungal diversity were related to test field characteristics such as climate and soil parameters and to the rating of decay of the specimens according to EN 252. A clear correlation of site-specific activity, fungal community and theoretical infestation potential (derived from field and climate characteristics) was not depicted due to a lack of data for a comprehensive weighting of the different influencing parameters.

Further investigation is necessary to detect the less known soft rot fungi. Therefore appropriate molecular methods have to be established and a sufficient amount of reference data must be provided.

**References:**

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# Weathering test of furfurylated wood decks in a 3-year exposure in Greece

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**Keywords:** furfurylated wood, wood decks, weathering test, Kebony wood

Furfurylation is a modification process commercially carried out in order to improve biological resistance and water-repellence of wood (Lande et al. 2004, Westin and Alfredsen 2007, Lande et al. 2008). In terms of weathering performance, Temiz et al. (2007) reported that furfurylated wood (FF) showed only slightly higher resistance to accelerated weathering than untreated wood. For the purposes of this work, a 3-year outdoor weathering test of furfurylated wood decks was carried out. The following wood materials were used: (i) a deck of furfurylated Radiata pine *(Pinus radiata)* wood, (ii) a deck of furfurylated Maple *(Acer spp.)* wood, both delivered to Greece by Kebony AS (Skien, Norway), and (iii) a deck of Ipê *(Handroanthus* spp*.)* wood that was used for comparative reasons as control deck. All decks had surface dimensions of 80 x 120 cm and thickness of ca. 22 mm and were exposed outdoors without any protection or finishing.

Furfurylation treatment was carried out by Kebony AS applying a commercially implemented process based on a full cell (vacuum/pressure) impregnation with a aqueous polymerisable mixture of furfuryl alcohol, buffering agents, maleic anhydride and other catalysts (Larsson-Brelid 2013) followed by an intermediate vacuum drying step before steam curing and drying (post curing). The decks were exposed outdoors for 36 months in Karditsa, Greece, in order to evaluate physical and structural properties such as colour, staining, distortions, surface cracking and end-splitting. Colour changes were determined according to CIELAB colour system using a BYK Gardner tristimulus colourimeter. Twelve colour measurements were carried out for each deck. Evaluation of staining was made macroscopically. Each deck was carefully examined for staining and other discolourations. The distortions in wood decks were measured with a dial gauge adjusted on a custom-made reference guide. All properties were determined prior to weathering and also after 6, 12, 24 and 36 months. Cracking and splitting were assessed by taking and analysing photos of all surfaces using a reference ruler for comparison purposes.

The conclusions drawn can be summarised as follows (Table 1; Figure 1 and 2): (a) all tested decks showed colour changes that were perceptible by naked eye and were relatively much higher during the first twelve months and much lower during the following ones; (b) the furfurylated decks showed smaller colour changes compared to the control deck of Ipê wood; (c) concerning surface cracking, furfurylated Radiata pine wood generally showed minor surface cracks and furfurylated Maple wood deck presented the lowest degree of surface and edge cracking; (d) the wood decks tested along with the control Ipê wood deck have showed no macroscopic signs of black staining and no decay after three years of outdoor exposure in Karditsa, Greece.

Table 1: Mean values of the determined colour coordinates and total colour changes of furfurylated and control wood deck throughout the 3-year weathering period

| Property | Deck type | Months of weathering | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 6 | 12 | 24 | 36 |
| Mean L* | Ipê (control) | 40.59 | 49.68 | 48.51 | 47.05 | 51.64 |
| | FF Radiata pine | 33.95 | 43.17 | 43.96 | 43.94 | 45.42 |
| | FF Maple | 39.54 | 49.18 | 41.31 | 43.55 | 47.04 |
| Mean a* | Ipê (control) | 9.61 | 7.81 | 2.19 | -1.15 | 1.71 |
| | FF Radiata pine | 9.01 | 6.76 | 2.01 | 1.39 | 2.27 |
| | FF Maple | 9.80 | 5.60 | 1.89 | 1.59 | 2.66 |
| Mean b* | Ipê (control) | 16.47 | 12.98 | 7.20 | 8.03 | 6.50 |
| | FF Radiata pine | 15.23 | 11.63 | 7.52 | 6.96 | 8.88 |
| | FF Maple | 19.05 | 11.44 | 6.34 | 6.26 | 10.09 |
| ΔE* | Ipê (control) | --- | 10.53 | 15.41 | 16.43 | 17.69 |
| | FF Radiata pine | --- | 10.99 | 14.89 | 15.46 | 15.19 |
| | FF Maple | --- | 13.98 | 15.73 | 16.28 | 14.02 |


Figure 1: Furfurylated Radiata pine wood deck: (left) as in May 2011 and in May 2014 (right)

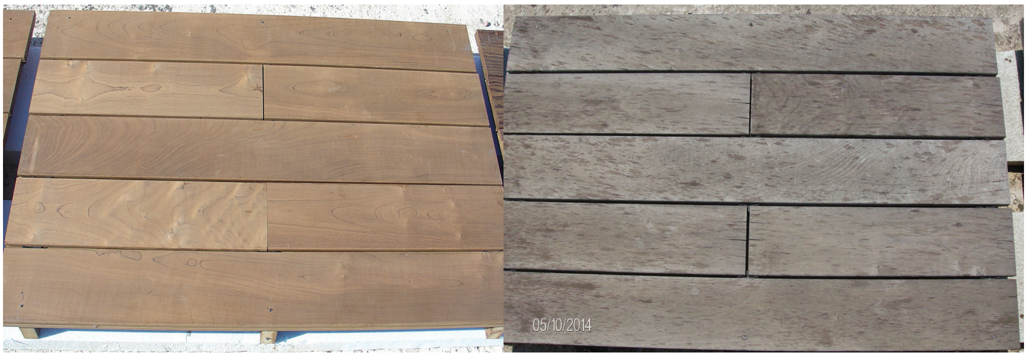


Figure 2: Furfurylated Maple wood deck: (left) as in May 2011 and in May 2014 (right)

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# Durability and service class of CLT. The case of Spain.

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**Keywords:** Service class, durability, construction, sustainability, wood.

In the current situation of the construction sector, and taking into account the sustainability policies focused on energy efficiency and life cycle assessment, the crucial role of wood as building material is analysed. While wood is definitely consolidated as building material in other countries of the European Union, we can clearly observe that in Spain wood reintroduction is proceeding fairly slowly. This may be due to the lack of rules regarding this building material in Spain in addition to the taboos and lack of knowledge of specifiers and architects about it.

New products are being introduced in the market of building materials as wood based products, such as CLT (Cross Laminated Timber), which have a technical capacity that makes them competitive with other building materials such as steel and concrete, and with exceptional environmental credentials because of its base/raw material.

In addition to the handicaps mentioned above, it can be seen that according to the current regulations, CLT is suitable for use in service class 1 and 2, but not in performance class 3. Moreover, it should be mentioned that this product obtained the CE rated by ETA, carried out through the CUAP procedure, which implies that there is not specific regulations for it.

Considering these points, and taking into account that the majority of CLT is made with species such as fir (not suitable for chemical treatment in depth) and that the characterisation tests have not yet been done with an harmonized standard, specifically developed to assess the product, it raised the question of whether a material such as CLT manufactured with other species such as pine, with its corresponding treatment and with a suitable glue for exterior use, could be used in service class 3, especially in harsh climates for glue laminated products such as in Spain. All these points bring up an investigation to study the possibilities of the use of CLT in service class 3, which also consider all the environmental aspects involved using life cycle assessment method. To study the ageing patterns of CLT, and its durability, two types of tests are considered:

**Laboratory tests**

These tests will be carried out in cube shaped test specimens, whose size will be determined by the ageing chamber where the tests will take place. These test tubes will be shaped based on panels of CLT made with wood species of impregnable conifers, treated for external use, and with glues suitable for this use. Several configuration prototypes of the CLT board will be made, and three types of climates represented in Spain will be simulated. The most suitable prototype will be used again in a larger size in field tests.

**Field tests**

These tests will last two years, and will include placement in three exterior locations but lifted more than 30 cm over the ground, of three cube shaped test tubes, made from CLT panels. The cubes will incorporate temperature and humidity dataloggers, which will produce the evolution of the “climate of the material” (temperature and humidity content). The experimental devices will be visited regularly for assessment of other types of data (degradation, deformation, cracking…) that cannot be measured through these devices. The cubes will be located in three different geographical areas with representative climates of Spain. These test tubes will be built with a size enough to be able to eliminate the edge effect that occurs in wood with moisture penetration.

With the obtained results of both tests, CLT ageing patterns will be achieved, and could reveal its durability and its applicability in class service 3. A life cycle assessment of the CLT panels will be pursued in parallel with the durability study and connections between performance and the life cycle assessments will be examined.

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# A case study: evaluation of state of conservation of wood panels and beams of a CLT kindergarten.
# Proposal of a diagnostic approach and realization of an Italian register of service life condition of recent wooden buildings.

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**Keywords:** Cross-laminated timber (CLT), fungal decay, diagnosis

Cross-laminated timber structures are becoming more and more popular in Italy especially for new public buildings. Tuscany has been really active in the construction of public buildings with a principal timber structure during the last ten years and also in spreading the relevant knowledge as specific guidelines (Linee guida per l'edilizia in legno in Toscana- Guidelines for wooden building in Tuscany , AA VV, 2009).

Panels and beams are generally of Austrian – German production and are made of Norway spruce (*Picea abies*) without any treatment to artificially improve their durability because their use is previewed in class 2 according to the standard EN 335: 2013. Indeed, being within normal houses, theoretically they shouldn't suffer from fungal attack, but any house could have hidden, dangerous moisture traps.

Moreover, being box-framed houses, they do not have a principal frame to concentrate on during diagnosis, because both floors and walls as a whole are structural principal elements.

Both situations make it necessary to establish specific diagnostic, monitoring and control procedures.

The presentation shows a diagnosis performed on a public, box-framed building (Fig. 1). After only two years of service life a diagnosis showed some severe fungal attack on both CLT panels and roof beams (Fig. 2). The aims of this case study are to understand the cause of early severe decay and to propose a method of diagnosis.

Figure 1: The panels and beams of a CLT building used as kindergarten

Figure 2: The beams on the roof of building after the opening of the sheath.

The roof of the kindergarten is made of principal horizontal CLT panels, supported at the two ends by glulam transverse elements (Figure1). The CLT elements support small section beams (Figure 2) to create an insulating volume, covered with OSB panels and sweating sheets and, finally, by a plastic impermeable layer

It is important to remark that to understand and define a right approach to a long lasting wooden structure in a building different competences are needed, such as architects, civil engineers, wood technologist, biologists.

The most important things to evaluate are the accuracy of project details and their adequacies to the service condition on the basis of climatic parameters (rainfall, average seasonal T, sunlight exposition, principal winds, etc.) and biological hazards. Additionally, confirmation that procedures to maintain dry and below 20% moisture content of the wood during the building site phase must be attained, or in case of no possibility to reach this control measure, assuring that before enclosing the wood structure inside the envelope, the moisture content was below 20%.

Inspections for the presence of moisture during the service life should be accommodated through some type of window directly to the plasterboard. These windows could be positioned in critical points on the building, e.g. the bathroom, or kitchen, etc. This precaution would permit early detection of high wood moisture content and allow avoiding the development of decay. Further, another important aspect is avoiding entrapping moisture during construction.

The aim of this research is to investigate the state of conservation of recent timber building in Italy in order to establish a database regarding the state of conservation and the most frequently occurring decay types. The latter aspect is important because Italy is in the temperate zone, but due to its varied topography, it is characterised by several climate zones. 35% of its territory is mountainous, while 42% is hilly and only 23% is on plains (mainly the northern great Po valley); 7456 km of coastline is developed. Significantly different climates are encountered in the north, attached to the European continent, than in the south south, surrounded by the Mediterranean Sea. Overall, 6 different climate zones can be distinguished.

The high variability of the climate conditions affects the biological hazard to which the timber is exposed in use or when stored, however, all the wood decay organisms are present in Italy, including fungi, insects (Coleoptera and Termites), bacteria and marine borers (Conti and Palanti 2010).

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# Biological performance of zinc borate-incorporated particleboard: Effects of leaching on efficacy

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**Keywords:** environmental degradation, leaching, zinc borate, particleboard

Wood-based composites have been increasingly produced over the past few decades due to a number of factors, including depletion of high-quality wood, development of new composite materials and widespread acceptance of wood composites for construction applications. Wood-based composites, however, require protection from the effects of moisture, weather, biological agents (decay, wood-destroying insects, and marine borers) and fire when used in exposed outdoor environments. Inorganic borate systems, particularly zinc borate, have an established commercial track record due to their low cost, efficacy against fungi and insects, low mammalian toxicity, minimal environmental impact, high compatibility with most manufacturing processes and fire retardancy at higher retentions (Eaton and Hale 1993, Gardner *et. al*. 2003, Tsunoda *et.al*. 2002, Wu *et.al*. 2003). The aim of the current investigation was to examine the feasibility of zinc borate incorporation in particleboard preservation and determine the effectiveness of zinc borate retention levels against decay and termite attack in laboratory conditions. Changes in mechanical properties due to biocide addition were monitored. In addition, the effects of a robust leaching procedure were tested to determine the efficacy of biocide against fungal and termiticidal activity.

Particleboards (300 x 300 x 15mm) prepared from particles of mixed wood species generated from demolished construction materials were incorporated with zinc borate at target retentions of 0, 1, 1.5 and 2% of the particle weight. An in-line treatment method was utilized to introduce the powdered chemical during the blending stage. The static bending properties, modulus of rupture (MOR) and modulus of elasticity (MOE) of the boards were evaluated according to the Japanese Industrial Standard (JIS) for particleboards. Decay and termite tests were conducted according to the Japanese Industrial Standard with a minor modification of the specimen size. Table 1 shows the mechanical properties (modulus of rupture and modulus of elasticity), air-dried densities and moisture contents (MC, at the time of testing) of boards prepared for this investigation. These results clearly demonstrated that the addition of zinc borate did not appear to have a negative effect on the mechanical properties within the range of the retentions tested.

Table 1. Mechanical properties of particleboards incorporated with zinc borate (mean of 9 specimens - values in parentheses are standard deviations)

| ZnB content [%] | Air-dried density [g/cm3] | MC [%] | MOR [MPa] | MOE [MPa] |
|---|---|---|---|---|
| 0.00 | 0.59 | 6.05 | 18.38 (3.43) | 2435 (387) |
| 1.00 | 0.62 | 5.87 | 18.61 (3.18) | 2460 (373) |
| 1.50 | 0.63 | 5.72 | 19.11 (4.16) | 2459 (451) |
| 2.00 | 0.62 | 5.80 | 19.21 (3.78) | 2549 (455) |

As shown in Table 2, zinc borate contents of above 1.5 % boric acid equivalent protected particleboards from fungal attacks under both unleached and leached conditions. In order to suppress the termiticidal mass loss to less than 3 %, a minimum of a 2 % BAE threshold value needs to be implemented in treated particleboards.

Table 2. Mean mass loss [ML (%)], mortality [M (%)] and consumption rate [CR (μg/termite/day)] of zinc borate-incorporated particleboards after exposure to *Coptotermes formosanus* for 3 weeks (mean of 5 specimens - data in parentheses are standard deviations)

| ZnB content (%) | Characteristics of termite attack | Unleached | Leached |
|---|---|---|---|
| 0.00 | ML [%] | 8.7 (0.82) | 8.6 (1.59) |
| | M [%] | 34.5 (2.92) | 20.9 (1.02) |
| | CR [μg/termite/day] | 91.1 (5.02) | 87.4 (15.18) |
| 1.00 | ML [%] | 4.3 (0.85)* | 5.1 (0.55)* |
| | M [%] | 52.1 (15.57)* | 26.0 (1.33)* |
| | CR [μg/termite/day] | 52.5 (4.72)* | 49.4 (3.92)* |
| 1.50 | ML [%] | 3.3 (0.47)* | 3.9 (0.24)* |
| | M [%] | 85.1 (5.35)* | 31.1 (4.07)* |
| | CR [μg/termite/day] | 49.6 (5.21)* | 38.9 (1.74)* |
| 2.00 | ML [%] | 2.6 (0.31)* | 3.2 (0.43)* |
| | M [%] | 92.5 (1.19)* | 30.9 (1.68)* |
| | CR [μg/termite/day] | 44.1 (3.70)* | 34.0 (2.54)* |

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# Use of wood waste as a resource for structural wood-concrete compounds

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**Keywords:** wood-concrete compound, structural properties, wood waste valorization

**Wood-concrete compounds as structural materials**

Construction and building operation has an important environmental impact. Today the most widely used construction material is concrete; which is heavy, has rather high embedded energy, strongly draws upon non-renewable resources, is challenging to re-use, and exhibits rather poor properties with regard to thermal insulation and storage capacity, and acoustic insulation. Last but not least, the concrete types used today in mid-size building construction are essentially far too good from a structural point of view.

Mixes of concrete with wood components, so-called wood-concrete compounds (WCC), may be one of the answers to the challenge of a more sustainable evolution of concrete-based construction.

The first WCC materials were developed at the beginning of the 20th century. Until today, they have mainly been used as *non-structural* finishing layers where their good fire resistance, thermic and acoustic insulation properties are combined with a relatively low and thus, beneficial density. From a structural point of view, the main impact of this new material is the potential for creating very light-weight *pourable* concrete; but, due to their current applications, their mechanical properties are not well known or optimized, respectively.

**Mechanical properties of WCC**

Sawdust and mineralized wood fiber concrete compositions were analyzed, including a commercially available product (Agreslith®). Different binders (standard Portland cement and aluminate cement) and wood/cement ratios (t/c) were considered. To improve the compatibility of Portland cement and wooden aggregates, active charcoal has been added to certain recipes, see Table 1.

**Use in hybrid composite Timber-WCC construction**

WCCs alone, as non-reinforced concrete, have little potential for load-bearing elements. To overcome the lack in tensile strength, tensile reinforcement is needed. Different timber-concrete composite systems can be adapted to the new structural material. Currently under development are multilayer sections with glulam tension layers and either directly a Compression layer of WCC or a shear layer of WCC plus a thin compression layer made out of highly resistant WCC (or alternatively out of traditional structural concrete) (Macchi, 2014).

Table 1: Recipe and average material properties of WCC

| Recipe | t/c | Humid density [a] COV in brackets | Compressive strength [b] COV in brackets | Tensile strength [c] COV in brackets |
|---|---|---|---|---|
| 1: Sawdust, Portland cement | **0.33** | **1125 kg/m$^3$ (0.4%)** | **2.1 MPa (0.3%)** | **0.3 MPa (7.0%)** |
| 2: Sawdust, Portland cement, active charcoal | **0.33** | **1209 kg/m$^3$ (1.1%)** | **3.3 MPa (4.5%)** | **0.4 MPa (4.0%)** |
| 3:Sawdust, aluminate cement | **0.33** | **1184 kg/m$^3$ (0.6%)** | **1.0 MPa (18%)** | **0.1 MPa (15%)** |
| 4: Sawdust, Portland cement (70%), aluminate cement (30%) | **0.33** | **989 kg/m$^3$ (5.7%)** | **0.2 MPa (4.5%)** | |
| 5: Sawdust, Portland cement | **0.2** | **1149 kg/m$^3$ (0.4%)** | **4.9 MPa (6.4%)** | **0.5 MPa (5%)** |
| 6: Sawdust, Portland cement, active charcoal | **0.2** | **1324 kg/m$^3$ (1.1%)** | **6.8 MPa (5.5%)** | **0.8 MPa (2.0%)** |
| 7: Sawdust, aluminate cement | **0.2** | **1233 kg/m$^3$ (1.4%)** | **1.2 MPa (3.1%)** | **0.2 MPa (1.0%)** |
| 8: Mineralized fibers, Portland cement | | **1385 kg/m$^3$ (2.5%)** | **4.9 MPa (20%)** | **0.8 MPa (12%)** |

[a] *The humid densities of the tested WCC compositions roughly are between 1000 to 1400 kg/m$^3$. Dry densities are considerably lower (450 to 1100 kg/m3) depending on the content of organic material.*
[b] *Tested according to SN EN SN EN 12 390-3 on cylinders with 150 mm diameter and 300 mm height*
[c] *Tested in indirect double punch test proposed by Chen (1972)*

By using a composite layered structure we can benefit of the numerous secondary benefits of this material, mainly:

- **WCCs are fire resistant.**
- **WCCs are good thermal and acoustic insulators.**
- **Pourable WCC can be used as active thermal inertia volume.**
- **Timber-WCC composite structures are light-weight.**
- **Timber-WCC can be burned to valorize the calorific energy contained.**

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# A reflection on the possibility of modelling and predicting decay in structural wooden components through the use of real building performance data

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**Keywords:** wood, fungal attack, crack, shrinkage, discoloration, service life condition.

The Ecole Supérieure du Bois (ESB) moved from Paris to Nantes in 1993. Local governments provided a beautiful building of wood and concrete to hold the 150 students expected at that time. As courses have developed the number of students studying wood science and technology, from pre-university to PhD level, grew to 350. Consequently, the town and local governments agreed to finance an extension to the original building in order to provide more teaching space.

The extension is an innovative wooden structure that makes use of outdoor asymmetric columns, box and cantilever beams. Such a design is heavily reliant on calculation and computer modelling. Discussion of the design prompted the suggestion that sensors should be fitted to the building in order to monitor its movement and behaviour during use. The data from these sensors can then be compared to the predictions made by the initial calculations and models. Thus providing the opportunity to verify the models, optimise them and future designs.

Building the glue-lam timber extension started in 2011 and was put in service in July 2012. Most of the monitoring work has focused on the mechanical behaviour of the building and for this reason 32 extensometers were installed at the beginning of the service life and data from them has been recorded every 2 hours. These sensors were put on indoor glue-lam beams and also on the external columns and beams. In the external elements, three strain gauge rosettes were glued to the inclined column surfaces, while longitudinal strain gauges were installed on north/south surfaces of vertical columns and on the main beams. 13 Temperature (C°) and Relative Humidity (RH %) sensors were also installed later and at the same locations as the strain gauges, consequently, data from these has only been recorded since July 2013.

Another extension is being built at the ESB that will provide a second workshop by autumn 2014. It is intended to monitor the performance of this second extension too. It is hoped that by analysing the data obtained from the first extension it will be possible to place the sensors for the second extension in strategically important places, i.e. where conditions might arise to support fungal decay.

The evaluation of the performance of the existent building will be based on visual observation, crack and wood moisture content measurements.

Figure 1 The outdoor glulam beams and columns

Figure 2 The outdoor glulam columns of extension 2

The two extensions will experience the same weather conditions as they are only a few metres apart. Therefore there is the possibility that data from one extension can be used to predict the performance of the other and the data from the other can be used to verify the predictions.

Data from the first extension has already provided some data on building movement, which seems to follow some trends. The work now is to create a model that mimics these trends as atmospheric and loading conditions change. In addition to the mechanical behaviour is a prediction of the onset and development of decay. This is relatively new and novel in building modelling. Of course, there is plenty of information on the development of decay on various wood products. These data, however, are often derived from standard tests which generally use constant temperatures and humidities.

The 2$^{nd}$ extension has some columns that will be fully exposed to the outside elements (see Figure Figure **Error! Reference source not found.**). These will be in danger of biodegradation unless protected in some way. This provides another opportunity to use different finishes on the different columns in order to assess the ability of different systems to keep the moisture content of exposed wood below the degrade threshold over a long period of time.

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# Emissions from wood, treated with copper-amine based wood preservatives – a two years exposure study of semi-field test

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**Keywords:** leaching, emissions, semi-field-test, copper, boron

Emissions of active ingredients from wood, treated with copper-amine based wood preservatives and partly additionally treated with a hydrophobic timber treatment were examined in a realistic semi-field test (Fig.1) for two years. Results of the semi-field test showed copper emissions of 3,8 % and 2,9 % respectively and boron emissions of 23,2 %. A clear positive effect was shown with the additional hydrophobic timber treatment, causing a circa 75 % reduction of the copper leaching.

A comparative laboratory test according to CEN/TS 15119-1 was performed and results of the 19 days of laboratory test were extrapolated for a period of two years. The extrapolation of the laboratory test showed slightly lower copper emissions for the samples treated with the copper-amine based wood preservatives only and slightly higher ones for the samples with the additional hydrophobic timber treatment compared to the semi-field test. The extrapolation of the laboratory test overestimates the boron emissions clearly, exceeding 100 % boron loss in the first year of field-exposure already.

Figure 1: Noise barrier elements exposed at the test field of Holzforschung Austria with leachate collection system

## References


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# Applying the grid method to investigate crack appearance and propagation in notched wood beams used in individual houses in Europe

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**Keywords:** Notched beam, full-field measurements, grid method, performance modelling

## Introduction

Standardized lattice timber beams appear as an efficient solution for economical, ecological and mechanical aspects (see Fig. 1 (a)). Many applications of this type of structure can be found in the field of industrial buildings as well as in small and collective houses (see Fig. 1 (b)). However, in wood structures, shear and tension perpendicular to grain induce brittle fracture if they are not controlled. This is particularly the case in the joining zones and even more when the beam elements are thin (Fournely et al. 2012). This study focuses on the strain distribution in notched beams specimens cut in chord elements of a timber truss beam.

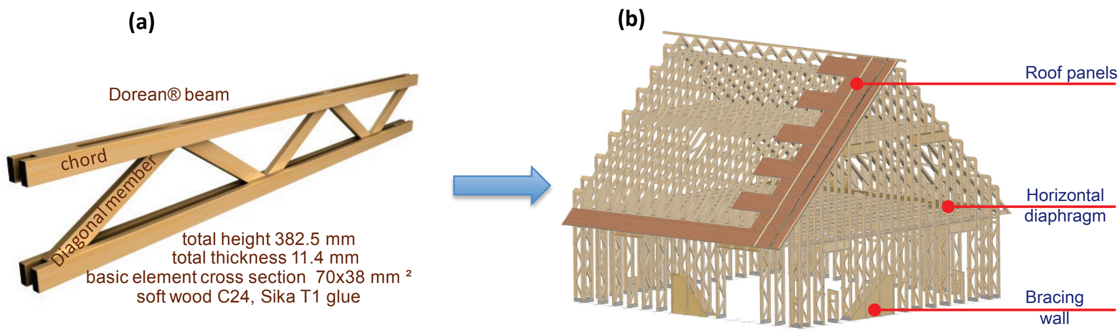


Figure 1: DOREAN's lattice beam (a) used in collective house (b)

## Material and methods

Fig. 2 presents the experimental device employed during the tests. The wood specimen under three-point bending can be seen as well as the load sensor and the supports of a classic 200 kN testing machine (see Fig. 2(b)). The wood specimen dimensions, machined with DOREAN's beam of Fig. 1(a), and the different orientations of the annual rings are presented in Fig. 2(a). The experimental device and the grid deposited near the notch can be seen in Fig. 2(b). The analytical approach based on the notched effect proposed by Eurocode 5 (AFNOR 2005) requirements is also applied in order to calculate the shear stress at the support levels.

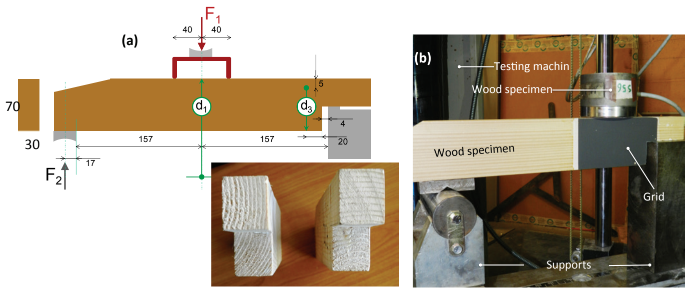


Figure 2: Dorean beam (a) used in collective house (b)

**Results and discussion**

Fig. 3 shows experimental results of shear strains maps for 2 images for one specimen. They are obtained by a suitable grid image processing presented in (Badulescu et al. 2009). At this level of applied load, it can be seen on the $\varepsilon_{xy}$ map that the maximum of the shear strain is located between the edge of the support and the right angle of the notch. Two other zones of high level of shear strain can be observed, one is located in a horizontal zone located at the front of the notch and another one behind the effective support (see Fig. 2(a)). Various videos showing the strain map evolution in this zone at crack appearance and during crack propagation will be shown during the presentation. They will be compared to their counterparts obtained by FE calculation.

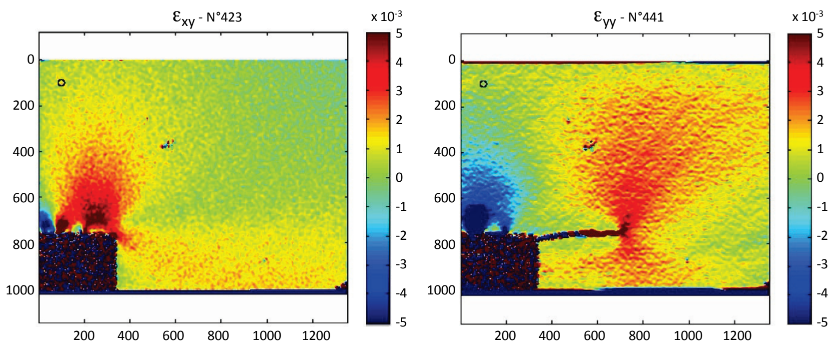


Figure 3: Strain maps for images N° 423 and 441

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# Technology to use the biomass of meadow plants as thermal insulation material and their thermal properties

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**Keywords:** meadow plants, thermal insulation material, thermal resistance, ecological building

The presentation is based on research examining the thermal properties of meadow plants (38 species), growing on temporarily unused agriculture areas in Estonia and that are supported by Estonian Agricultural Registers and Information Board (ARIB) to prevent afforesting (Veri, Teppand 2014). Conversely, this activity also contains a dangerous environmental problem, because the unused biomass has started to decay and has a big influence on $CO_2$ emissions.

The purpose of the experiments was to determine the technology needed to implement this type of biomass as bio-based thermal insulation without harmful impact to the building structures at least in rural and agricultural buildings. After use as bio-based thermal insulation the materials present less risk of environmental harm.

A number of experiments were carried out to examine the best structure of biomass, composed of single species or multiple species, both loose and with adhesive additives, fixing the structure to avoid settling inside the building structure. Tests were made both with natural and synthetic fillers. During the studies of test specimens the thermal conductivity was measured. Thermal conductivity behaviour depended on moisture content inside the specimen and changes in temperature. It became obvious that the thermal conductivity of the meadow plant biomass depends neither on the plants habitat nor the specific gravity of the heat insulation. As an insulation material, the test specimen without additives had similar properties to mediocre industrial insulation materials. It is not rational to use clay and cement because of the huge water requirements. The demand of lime usage to influence thermal conductivity was not proved. Possible additives are quickly solidifying glues, including plant liquids whose usage must not require too much water. The best results were attained with a low concentration of polyvinyl acetate hydrosol. The structure of the specimen was stable and flexible, ensuring it cannot settle inside the building structure (Fig1).

The thermal resistance of the specimen was $\lambda_D$ = 0,04-0,09 W/(m·K) with densities between 70 and 90 kg/m$^3$. (Veri, Teppand 2014)


Figure 1: Specimen Nr 13 with with low concentrate of polyvinyl acetate hydrosol (photo of Veri V.)

In the future field tests will investigate the next properties of heating insulation of meadow plants, such as stability over time, the behaviour during different weather conditions, sound insulation qualities, the material's biological resistance, expansion and contraction with changes in temperature and humidity conditions.

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# Thermal modification of reed (*Phragmites communis*)

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**Keywords:** Anti-Swelling Efficiency (ASE), conservation, heat treatment, high-energy multiple impact (HEMI) test, thatched roofs

Reed (*Phragmites communis*) has been used as roof thatching for centuries especially in coastal areas, where plenty of it was available. Therefore, thatched roofs are affecting the appearance of many regions in Europe. Besides the conservation of historical buildings, reed is an appreciated material for modern buildings for various reasons and nowadays used for thatching walls and roofs. Besides being a renewable resource reed is characterized by its outstanding thermal insulation. It is an appealing and very traditional material with known performance when applied as house roofing.

However, during the last decades a significant number of prematurely failing thatched roof structures became known (Haslam 1989, Anthony 1999). Research on agents that might have affected the roofs and led to short service lives (partly below 10 years) has been established and various potential causes have been identified. For instance an increased number of warm roofs with insulated attics, an increased amount of imported reed from outside Europe, newly introduced pests, disadvantageous conditions for harvesting and storage, or increased emissions from cattle-breeding farms have been discussed in this respect, but no causal relationship has been clearly identified.

This study aimed to investigate methods for improving the durability of reed and thus prolonging the service life of thatched roofs. Therefore thermal modification, which has been successfully applied on wood and bamboo, was considered in the first instance. Thermal modification is known to increase dimensional stability and the durability of lignocellulose, but leads to reduced strength and stiffness as well. Furthermore the colour of thermally modified lignocellulose turns generally to dark brown. Therefore in this study reed, which can be considered as lignocellulose as well, was heat treated at different intensities under exclusion of oxygen. The effect of the heat treatment on fungal resistance, equilibrium moisture content, dimensional stability, colour, and structural integrity of reed was examined.

Native reed showed a higher susceptibility to white rot fungi compared to brown rot fungi. Preliminary decay tests with thermally modified reed showed no clear tendency, because mass loss varied drastically even in untreated material. Long incubation times (> 12 weeks) seem advisable even though test specimens have been very small compared to wood mini block tests.

As with wood and bamboo, the heat treatment led to a darkening of reed and reduced sorption properties. An anti-swelling efficiency (ASE) based on maximum swelling of the reed culms of up to 90 % was reached, but was clearly depended on the treatment intensity. Furthermore a clear correlation was obtained between CIE L*a*b* colour values and the equilibrium moisture content at different given relative humidity.

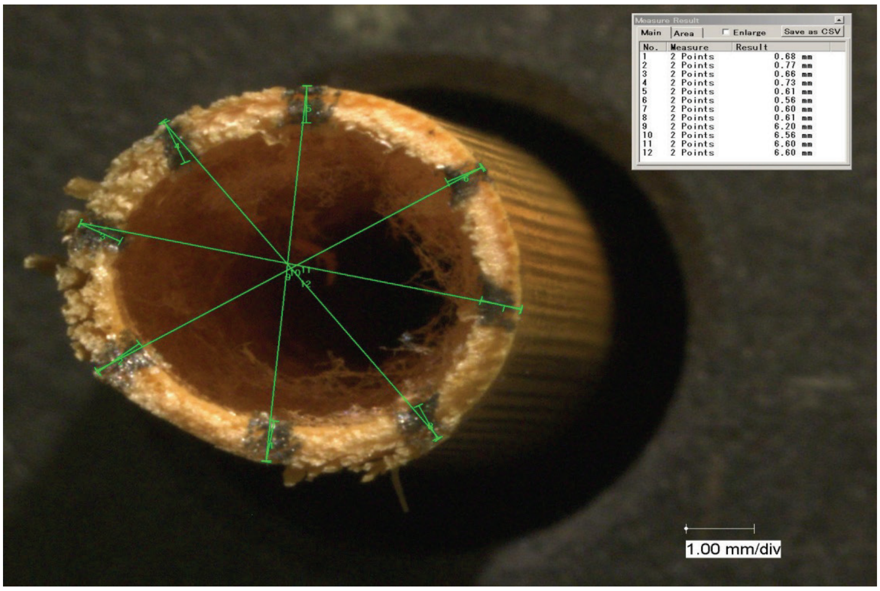


Figure 1: Multi-point measurement of culm wall thickness after swelling.

The structural integrity as an indicator for brittleness and strength of the reed culms was determined in High-energy multiple impact (HEMI) tests. As expected the structural integrity of reed decreased with increasing treatment intensity. The most severe treatment (decrease in mass by heat = 11 %) led to reduction of the resistance to impact milling by 31 %. At the same time the equilibrium moisture content was reduced by 50 %, and the ASE was 90 %.

Thermal modification was found to be generally applicable on reed. Several analogies were found between thermal modification of wood and reed, but the latter showed also some peculiarities that need further consideration. In particular, the suitability of thermally modified reed for thatching, which is basically skilled manual work and requires robustness of the processed material, will be of interest.

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## About the cover photo
## THALASSO Spa Lepa Vida at Piran Saltpans

*Coexistence of architecture and the cultural landscape*

The cover photo was provided by the innovative and multigenerational architectural team from PIA studio d.o.o., Portorož. The photo shows one of their projects, the THALASSO Spa Lepa Vida at the Piran Saltpans, which they did in collaboration with Sečovlje Salina Nature Park. The spa is located in one the few remaining traditional saltpans still active along the Adriatic coast.

The business idea of setting up a small spa center based on the by-products of salt (brine, the salt-pan mud), was born more than a decade ago. The conceptual design is in line with the geometry of the pans, while the building design was inspired by the small wooden houses used for storing tools in the saltpans, where salt production takes place. Wood was chosen as the main construction material because of its ecological value and aesthetics. The edge area is constructed from hundreds of wooden piles, which restrict the spa and separate the ground from the water, but do not impede the view of the surrounding landscape. The thermal center is made of wooden paths that connect the individual houses of simple shapes. The houses each serve special purposes at the spa such as reception, a cloakroom, toilets, a bar, lifeguard room, medical facilities, the pump room and other technical facilities. The entrance to the spa is located in the central part of the complex, where sea access and land access meet. The central area has a swimming pool with seawater, Kneipp therapy pools and a smaller pool for brine therapy. At the edge of the center are canopies and platforms for massage and mud therapy.

| | |
|---|---|
| Designer | PIA studio d.o.o. Portorož |
| Authors | Stanislava Pustoslemšek, Adriano Coren, Pascal Fusil, Uršula Koren |
| Photography | Pascal Fusil |
| | |
| Statics | Bartole Consulting s.p. |
| Electro installations | LIZ-PROEL d.o.o. |
| Machine installation | NOM BIRO, projektiranje in svetovanje d.o.o. |
| | |
| Investor | Soline, pridelava soli d.o.o. |
| | |
| Conceptual design | 2003 and 2007 |
| Construction | 2011-2013 |