# Integrating sustainability and health in buildings through renewable materials

InnoRenew CoE International Conference
2020

**InnoRenew CoE**
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**INNORENEW.EU**

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EVROPSKA UNIJA
EVROPSKI SKLAD ZA REGIONALNI RAZVOJ

# Welcome


As we open the second InnoRenew CoE International Conference, it's hard not to think of all that has changed in the year and a half that has passed since our debut conference.

Although the pandemic has dramatically changed our day-to-day lives, it has not changed society's need to address the rapidly changing climate, reconsider our economic priorities, and refocus our attention on important social issues. Buildings remain part of the solution to many problems, and I think it is becoming clear that we need to consider much more about buildings than the basics of shelter.

As the pandemic kept us indoors, many of us may have realised that our indoor environment plays an even more important role in our well-being and happiness than we previously acknowledged. Likewise, we may have considered more carefully how buildings affect the well-being of those who live in different circumstances. Access to safe, comfortable, and healthy living and working spaces is (and should be) a priority in a just society.

Another major change that will affect our work in the years to come is the introduction of the European Green Deal, which will be a major driver of sustainable development in Europe. The European Green Deal prioritises investment and innovation in building renovation solutions for energy performance and attempts to ensure these solutions reach all members of society. The European Green Deal recognizes the need to establish high-performance housing for all and will support renovation in social housing, schools, and other facilities that are often left behind. This is a step in the right direction for inclusive, high-performing buildings.

I rarely find proclamations of success convincing when it comes to sustainability – especially about buildings. We must continue to drive change through research, development, and innovation to make our built environment a beacon of sustainable development. We cannot be satisfied with the environmental performance of our products or buildings; we cannot allow people to be excluded from our advancements; and we cannot forget that buildings impact the well-being and happiness of their occupants.

At this year's InnoRenew CoE International Conference, we wanted to showcase how renewable materials play an integral role in sustainable construction by highlighting environmental performance, safety, and health as well as the economic, digital, and social links that bind us to the materials in the built environment. Conference presenters will discuss advances in design, material development, health research, retrofitting, environmental assessment, and many other topics that increase the efficiency and performance of the building and renewable materials sectors.

Carlo Battisti, President of Living Future Europe, will weave together these complementary threads in his keynote address, "Healthy, living transparent. The quiet revolution of materials". He works to push for change and supports researchers, architects, engineers, and other construction professionals to achieve it. His efforts have expanded knowledge and acceptance of restorative sustainability and regenerative design within Europe's construction community. We are excited and grateful for his participation in our conference.

Together, the contributions paint a hopeful picture. But we must continue to push the science forward, embed these innovations in normal construction practices, and ensure inclusion of all who can benefit from our hard work.

While I wish these matters could have been discussed in person in Izola, we must embrace new options for discourse on these topics. I hope the conference inspires you to reach out to one another and continue sharing, collaborating, and building communities that embrace the challenge of creating a sustainable and just built environment. You may also consider our new open access and peer-reviewed journal, *Interdisciplinary Perspectives on the Built Environment*, as a place to share the insights your work provides.

Thank you,

Dr Michael Burnard
Deputy Director, InnoRenew CoE
Assist. Prof., University of Primorska

# Schedule at a Glance

## MORNING

**Welcome**
9:00–9:05

**Keynote**
9:05–9:35

**Flash Talks**
9:35–10:35

**Coffee Break**
10:35–11:00

**Human Health in the Built Environment**
11:00–12:30

**Lunch**
12:30–14:00

## AFTERNOON

**Complementary Topics**
14:00–15:30

**Coffee Break**
15:30–15:55

**Sustainable Construction with Renewable Materials**
15:55–17:25

**Closing**
17:25–17:30

# Keynote Address

**Carlo Battisti**
**President, Living Future Europe**

*Healthy, living, transparent.*
*The quiet revolution of materials.*

Carlo Battisti has a degree in civil engineering from the Politecnico of Milan, nearly twenty years of experience in construction companies and a master's in management and organizational development from MIP International Business School. His certifications include Certified Project Manager IPMA®; LEED®, Living Future and WELL Accredited Professional; GBC Home AP, GBC Historic Building AP; USGBC® and WELL Faculty™.

Since 2009, he has been working with IDM South Tyrol (Italy) as an innovation manager in the Business Development department, Construction. From 2010 to 2011, he worked with the Energy and Environment Cluster of Trentino as manager of the business unit for sustainable products. From 2015 to 2016, he was the co-owner of a startup focused on LEED consulting. In 2015, he co-founded the Living Future Italy Collaborative.

Since 2017, he has been working with Eurac Research as Chair and Project Manager of COST Action 16114 RESTORE (REthinking Sustainability TOwards a Regenerative Economy). The RESTORE COST Action (2017-2021) will affect a paradigm shift towards restorative sustainability for new and existing buildings and space design across Europe through the collaboration of 160+ researchers from 40 European countries.

Since 2018, he is European Executive Director for the International Living Future Institute and current President of Living Future Europe. The Institute's mission will hasten the change and provide needed direction towards a regenerative design transition in Europe. It is actively pursuing European market alignment and adaptations of the Living Building Challenge (LBC).

# Agenda

## Welcome | 9:00-9:05
Dr Michael Burnard, InnoRenew CoE

## Keynote | 9:05-9:35
Carlo Battisti, Living Future Europe

## Flash Talks | 9:35-10:35



## Coffee Break | 10:35-11:00

*Unable to present

## Human Health in the Built Environment | 11:00-12:30



## Lunch | 12:30-14:00

## Complementary Topics | 14:00-15:30



## Coffee Break | 15:30-15:55

IRIC2020 AGENDA CONTINUES ON THE NEXT PAGE

# Agenda

## Sustainable Construction with Renewable Materials | 15:55-17:25



## Closing | 17:25-17:30

## THANK YOU FOR ATTENDING IRIC2020!

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# *Flash Talks*

## *Using discrete optimization methods in decision support for structural design*

Balázs Dávid

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Structural design is a complex process of several stages that is used for the design and development structural plans. The stages of this of this process (planning, design and detailing) have to be performed sequentially, each stage using the output of the previous one as its input. As these stages are complex, even separately, efficient solution methods can be useful to aid the decision-making processes of civil engineers. Early decisions in the design process (such as topology and material combination choices) affect the future steps and overall performance (such as energy demand or costs). These effects are not known in advance and can only be estimated. Providing multiple possible design suggestions by quick heuristic algorithms can help with quantifying the effects of these early decisions.

In this presentation, we will introduce heuristic optimization methods for the design stage of the above process. These methods use preliminary designs as their input and aim to improve their quality through several local transformation steps. Different constraints are considered during this process, and the solution is optimized by taking multiple different cost objectives into account. As each local transformation step shifts from a feasible solution into another one, multiple possible solutions are visited in the solution space. The best ones are saved and presented by the system as possible suggestions.

To measure the quality of these resulting suggestions, we also develop a mathematical model that is able to calculate the costwise optimal solution. The quality of our suggestions will also be compared to this solution.

**Keywords:** structural design, local search, mathematical model, decision support

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# *Office Building Optimisation Using the Energia Design Synthesis Method*

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Office buildings represent one of the most common public building with extremely high cooling energy demand and corresponding negative environmental impact in Central Europe. Due to the high wall-window ratio of this building type, the indoor thermal and visual comfort suffers, as a consequence of characteristic summer overheating and winter heat loss.

The current office building design method develops a sole plan, based on experience, without any type of optimisation in connection with the complete building and its most important space organisation and building body shaping design possibilities. On the other hand, multiple studies deal with improvement and optimisation of comfort and energy performance concentrating only on subsystems for instance, façade, glazing, shading or HVAC systems.

The heuristic Energia Design method creates multiple design versions and assess comfort and energy performance by applying high-tech building physics simulations. The results support decision making in design concepts. However, this method is limited to some numbers of considered concepts, therefore the optimal office building case is not ensured.

This research integrates a self-developed synthesis step in form of the Energia Design Synthesis method as the only technology for the generation of optimal office buildings in energy and comfort. The P-graph methodology serves as an important inspiration for the Energia Design Synthesis that applies mathematical modelling and combinatorial optimisation, in the field of architectural design. Due to the fact that almost 80% energy saving can be achieved by passive strategies, the current study focuses on space organisation optimisation in a generic office design. A series of rules were defined using a modular geometry system to model all potential office geometries. A back-tracking algorithm generates all office building geometries satisfying the rules. In a dynamic thermal simulation framework building physics performance is calculated to generate a ranking in thermal comfort, daylighting, indoor air quality and energy performance.

**Keywords:** optimisation, residential building, synthesis, active design strategy

# *Developing temporary housing solutions for displaced persons A study of user needs*

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Temporary housing solutions are needed in civil protection for offering shelter to people in disaster-affected areas and other displaced persons. Often, shipping containers are used for this purpose, and while some studies highlighted the positive aspects (Zhang and Elmpt, 2014; Hong 2017) and their sustainability (Islam et al., 2016), others have pointed out the need for better and more sustainable solutions (Perruci et al., 2016). In this paper, we identify different types of temporary housing according to two main distinct categories of temporary dwellings (Abulnour, 2013): temporary shelter and temporary house. We study them from the functional and technical perspective, their sustainability aspects, use of bio-based materials and reuse at the end of their life cycle. The aim of this paper is to give further recommendations for the construction of environmentally and socially sustainable temporary dwellings. Sustainable shelter design is of major importance, particularly for European regions, since laws for public procurement follow rules of green purchasing. We identify desired characteristics of temporary dwellings based on twelve in-depth interviews with those that received refugee status in Slovenia, six of Syrian and six of Eritrean nationality. Participants were asked to describe their dwellings in their home country, their accommodations on the journey to Slovenia and their current accommodation. In addition, they were asked for feedback on a draft building plan to develop an adaptable and modifiable modular wooden building that could be used as a temporary dwelling. Dwelling features that the interviewees valued most were having private bathrooms and kitchens and being settled in cities, close to necessary infrastructure and integrated with the local population. They did not show strong preferences toward any construction materials, but some of them showed some concerns regarding the use of wood, especially those from Eritrea having less experience with wood as a construction material.

**Keywords:** temporary housing, sustainable design, user needs, refugees, interviews

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# *Evaluation of Biofinish for Wood Protection*

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Wood is a versatile, natural and environmentally friendly material that has attracted attention for sustainable building for many years. However, wood is susceptible to deterioration during weathering and biological attacks, and, therefore, wood products require protective measures to extend their service life in outdoor applications. For sustainable use, the environmental impact of such protective treatments should be as low as possible. Biofinish is a fungal-based wood treatment with protective functionalities and self-repairing properties. This environmentally friendly treatment has several advantages compared to traditional wood surface protection methods due to its self-repairing property, low maintenance cost and absence of harmful chemicals (Peeters et al., 2018). The objective of this study was to evaluate the interaction of biofilm that is built up by *Aureobasidium pullulans* with wood materials and its subsequent ability to protect the wood substrate against photodegradation. Growth of fungal hyphae over time and deposition of extracellular substances on the wood surface was investigated microscopically. Biofinish-treated wood was also exposed to artificial weathering cycles that included UV irradiation and water soaking. Protection of the wood by Biofinish treatment against photodegradation was assessed by micro-tensile tests combined with FT-IR spectroscopy. Furthermore, cellular-level chemical changes in the wood substrate below the Biofinish layer were analysed by confocal Raman microscopy. The outcome of this study may be utilized to improve and further control Biofinish treatment with stable characteristics under service life conditions.

**Keywords:** Biofinish, photodegradation, micro-tensile testing, vibrational spectroscopy

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# *HUNGARIAN NEST+*
# *New type energy spaces in the sustainable architecture*

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The biggest stress on the sustainability of our environment is caused by the construction industry. More than 30% of the global pollution emissions are caused by the development of the built environment without ecological awareness. It is time for the conscious design process, to shape our built environment in a sustainable and humane way, in accordance with nature. The creative students and educators from University of Pécs, in association with University of Miskolc and University of Blida, set the goal of creating a new Hungarian energy project, the HUNGARIAN NEST+ PROGRAM, at this year's Solar Decathlon Europe competition. The international consortium was established as a concentration of multidisciplinary researchers from many disciplines. Nowadays, architecture and automation represent an almost inseparable combination, which creates innovations that promote the revolution of the entire construction industry. The international innovative house-building competition, Solar Decathlon Europe 2019, focused on addressing the social challenges of an inherited built environment. In Hungary, 800.000 outdated, physically amortised "Cube-houses" are waiting to make them meet the challenges of the 21st century. HUNGARIAN NEST+ is an innovative example to provide quality guidelines for sustainable development of inherited architectural environments and for defining new architectural directions! An experiment to turn into positive the energy efficiency of built environments. The project is based on a combination of simple, consistent ingenuity of vernacular Hungarian architecture, the natural confidence of environmentally conscious thinking, the purity of low-budget solutions, and the high-tech applications of energy design. We have developed many variations and technological innovations throughout the project, enabling HUNGARIAN NEST+ to combine energy conscious solutions with humane living without ecological footprint, both in the renovation of existing buildings and in the realization of new buildings. And the next phase of the project is just coming!

**Keywords:** Solar Decathlon Europe, new type energy spaces, HUNGARIAN NEST+, environmentally positive architecture, Cube-house, recycling

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A „kevesebb" a jövő megoldása! – low-tech épületek high-tech tervezéssel, https://energiaoldal.hu/a-kevesebb-a-jovo-megoldasa-low-tech-epuletek-high-tech-tervezessel/

Manfred Hegger, Caroline Fafflok, Johannes Hegger, Isabell Passig: Aktivhaus The Reference Work, From Passivhaus to Energy-Plus House, 2016, Verlag D. W. Callwey GmbH & Co. KG, Munich. Genehmigte Lizenzausgabe für Birkhäuser Verlag GmbH., pp. 48.-49., ISBN 978-3- 03821-643-8

# *Testing the Thermal Properties of Loose-Fill Straw Insulation*

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Current research suggests that natural materials such as straw can be a suitable insulation alternative to reduce energy demands in the construction and building industry, particularly during service due to its excellent thermal properties, low embodied energy, carbon storage, and acceptable mechanical properties (Chaussinand, Scartezzini, Nik, & Nik, 2015; Maraldi, Molari, Molari, & Regazzi, 2018; Mattila, Grönroos, Judl, & Korhonen, 2012; Sabapathy & Gedupudi, 2019). Traditional construction with straw utilises the material for insulation in the form of straw bales. The objective of this research was to test the thermal properties of straw as loose-fill insulation in traditional wall construction to validate if its thermal performance is competitive against readily available synthetic insulation batts.

A commercially available synthetic batt (15 kg/m3) and three straw samples of densities 31 kg/m3, 54 kg/m3, and 69 kg/m3 were tested between two chambers fitted with thermocouples to measure the increase in heat from a heated chamber to the adjacent chamber over a set time. The results aligned with the literature, noting the insulation properties of the straw were dependent on density; even the sample with the lowest density (31 kg/m3) acted as an insulator to the adjacent chamber. The highest density sample (69 kg/m3) resulted in the lowest temperature increase of 0,95°C (20,7°C to 21,65°C) compared to the synthetic batt, which prevented any increase in temperature of the adjacent chamber. This study suggests that the use of straw presents a plausible future application in the construction industry as a natural material for insulation in buildings. When sourced locally, it has low environmental impact and lower costs associated with transportation. However, future research and development is required to determine a standardised building material for its use in build-ings.

**Keywords:** straw, insulation, loose-fill, energy efficiency

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# *Thermo-Hydro-Mechanical Treatment of Australian Sawlog and Pulplog Hardwood Resources*

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Australian sawn-board product is regulated by timber's physical and mechanical properties to ensure safe operating performances in context specific applications. Contemporary and emerging timber resources, however, are lacking the traditional properties of commercially sawn products, namely density. One technique used to improve timber properties is densification through thermo-hydro-mechanical (THM) treatments (Rautkari et al., 2010; Sandberg et al., 2013; 2007). The objective of this study was to assess the change in timber properties of several Australian wood species densified using a THM treatment to identify if these modified species could be utilised in regulated building applications. Three hardwood species from different forest management schemes were tested in this study: *Eucalptus obliqua*, *E. nitens*, and *E. globulus*. *E. obliqua* was sourced from regrowth sawlog (60 year-old), *E. nitens* from plantation sawlog (26 year-old) and plantation pulplog (16 year-old) and *E. globulus* from plantation pulplog (26 year-old). Australian Standard (AS) 3959:2018—Construction of buildings in bushfire-prone areas—states *E. obliqua* and *E. globulus* are suitable for general construction with a density ≥750kg/m3 and *E. nitens* is suitable for window and door joinery with a density ≥650kg/m3. Air-dry densities measured from each species, according to their respective forest management scheme, suggest sawn-board products from these resources are lower in density than required for use in building construction in bushfire prone areas; *E. obliqua* ~595 kg/m3, *E. nitens* (sawlog) ~560 kg/m3, *E. nitens* ~525 kg/m3 and *E. globulus* ~520 kg/m3. By using THM treatment, samples were densified to 67% and 53% of their original thickness (15mm) to demonstrate modified sawn-board can meet AS for use in construction and joinery; *E. obliqua* ~875 kg/m3 and ~980 kg/m3, *E. nitens* (sawlog) ~775 kg/m3 and ~1015 kg/m3, *E. nitens* ~680 kg/m3 and ~940 kg/m3 and *E. globulus* ~775 kg/m3 and ~870 kg/m3 at 67% and 53%, respectively.

**Keywords:** hardwood, sawlog, pulplog, sensification

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## *VOC-emission optimized Cross Laminated Timber*

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Cross laminated timber (CLT) is one of the most popular engineered wood products. The main species used for this product is spruce. To respond to the strongly increasing demand of CLT, it will become necessary to also investigate additional raw material resources for its production. Pine – having in mind its availability, mechanical properties and ability to grow even in regions with poor growth conditions – could offer a high potential to serve as a new material for CLT in the future.

The first phase of the study comprises the characterization and quantitative evaluation of VOC emissions from spruce and pine in order to draw conclusions about the variability of VOC emissions. A comparison of kiln-dried and green wood provided a sound basis for further investigations. Furthermore, different CLT variants were tested in order to compare their emission levels.

The second phase covers the optimization of the CLT manufacturing process regarding VOC emissions. Based on findings from the first phase, process parameters such as drying and gluing as well as storage time were modified.

In the final project phase, long-term tests in model rooms constructed of different types of CLT are being carried out, enabling evaluation of the influence of various building materials regarding indoor air quality in reality-close scenarios.

Results showed a significant influence of drying temperature and drying time on VOC-emission from pine. Additionally, the gluing step in CLT production as well as a combination of wood species (pine, spruce) used resulted in a considerable VOC-reduction in the final product.

**Keywords:** cross-laminated timber, process parameters, VOC, pine wood, model room, indoor air quality

# *Sustainability, health, and renewable materials Trends in scientific publications*

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Building practices can have a large impact on human health and the environment, so it is crucial to strive towards sustainability and use of renewable materials in all stages of the construction process. As academic research accumulates, detecting trends can illuminate current developments in both research and practice.

Our aim was to explore recent trends in scientific publications in five topics: "digital solutions in renewable materials", "enhancing renewable materials with modification", "developments in renewable material composites", "advancing human health in the built environment", and "design and engineering solutions for sustainable buildings". We used a Natural Language Processing based toolkit (Zdravevski et al., 2019) to perform an automatic quantitative analysis of scientific articles' titles and abstracts published in English. The search was performed in October 2019, and it included three databases (i.e., PubMed, IEEE Xplore, and Springer). In total, 2036 publications were identified and analysed based on the inclusion of specific keywords (e.g., "biophilic design", "timber", "circular economy") from three areas: health, renewable materials, and sustainability.

The largest number of articles was found in the topic "digital solutions in renewable materials", followed by "enhancing renewable materials with modification", and "design and engineering solutions for sustainable buildings". The number of publications peaked in 2015 and 2016, but after a slight decrease in popularity in 2017, the topic has again started to gain interest. The most common keywords in the included articles were related to the topic of sustainability, ahead of keywords related to the topics of health and renewable materials. The most frequently mentioned specific keywords were "human well-being", "sustainable architecture and design", and "human health".

**Keywords:** sustainability, health, renewable materials, buildings

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# *The Influence of Four Commercial Wood-surface Treatments on Mould-fungi Growth in a Pure Culture*

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The increased concern regarding mould on wood-based building materials has raised demand for sustainable biocidal treatments to protect early contamination during the construction stage of timber buildings. Providing surface protection for all types of wood-based construction elements already at the construction site will reduce the mould-associated risk for not only the construction elements but also for the indoor climate and dwellers at the use-stage of the building. The purpose was to test the protective effect of commercial water-based treatments containing different biocides on single mould fungi growth in pure culture.

Small specimens of Scots pine, sapwood and heartwood, and Norway spruce were treated with four treatments, and a fungal test was performed in 90 mm Petri plates. Two samples (treated and untreated control) placed on the plate with a distance between each other, and between, a fungal inoculum placed. Five pure cultures of fungi species used in the study: *Aureobasidium* sp., *Trichoderma* sp., *Aspergillus* sp., *Cladosporium* sp., *Penicillium* sp. The specimens were exposed at the temperature of 24°C and relative humidity of 90%.

The treatments contained biocides, i.e.: treatment 1: tetramethylol acetylenediurea and io-dopropynyl butyl carbamate (IPBC); treatment 2: mixture of several biocides (IPBC, benzisothiazolinone [BIT], methylisothiazolinone [MIT] and 5-chloro-2-methyl-1,2-thiazol-3-one [CMIT/MIT mixture]); treatment 3: IPBC; and treatment 4: mixture of propiconazole and IPBC.

The fungal growth was observed in the untreated samples after four days of incubation; the specimens with treatment 4 attacked after eight days while treatment 1 and 3 had free from fungal mycelia inhibition zone after 22 days of incubation. The moisture content after the test was similar for treated samples in plates with *Aureobasidium* sp., *Aspergillus* sp., *Cladosporium* sp., *Penicillium* sp. but was significantly higher for *Trichoderma* sp. The type of wood did not influence fungal growth in comparison to the type of treatment.

**Keywords:** biocide, wood, surface treatment, fungi, mould

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# *Improving hydrophobicity and thermal stability of wood by esterification with fatty acids*

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The hydrophilic nature of wood is based on its structural anisotropy and strong affinity to hydroxyl functional groups (mainly due to the polysaccharides present in its structure), making wood very reactive with water. The environmental factors can cause instability to the wood matrix and its deterioration; thus, several wood modification techniques have been developed to ensure its long-term durability and focus on specific applications (Gérardin, 2016). The natural fats are an interesting alternative for wood protection when converting them into fatty acid chlorides (Jebrane and Sebe, 2008). Acid chlorides containing long hydrophobic chains can provide a water-repellent effect and thermal stability when reacting with the wood matrix (Hon, 2017). In this study, samples of Monterey Pine (*Pinus radiata*) were used for the esterification process; firstly, by removing its polar extractives (toluene:ethanol (2:1) extraction), then, kept under vacuum atmosphere to improve the esterification. Three different reagent were used for modification process: hexanoyl chloride (C6), lauroyl chloride (C12) and steaoryl chloride (C18) at [0.1M; 0.5M; 1M]. Pyridine (10%) was used as a catalyst, and the byproducts of the reaction were removed by adding triethylamine. The reaction was conducted for 3h at 100ºC (C6, C12) or at 80ºC (C18). Finally, the modified wood was washed with dietylether and ethanol. After modification, the WPG and density were increased proportionally to the reactive concentration [0.1M to 1 M]. The hydrophobicity and surface energy were changed, with a higher hydrophobic behaviour after the esterification reactions. Moreover, a thermal analysis (carried out by TGA under an oxidative environment) to emulate the typical conditions of a fire combustion was performed, confirming that the resistance to thermal degradation at higher temperatures (above 500ºC) increased. It was particularly enhanced by the esterification treatments with short alkyl chain.

**Keywords:** wood modification, esterification process, fatty acids, hydrophobicity, thermal resistance

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# *Aspects of Residential Environment Included in Residential Satisfaction Questionnaires: A Systematic Review*

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Residential satisfaction is a frequently studied topic in recent decades as it can offer important insights into the quality of residential environment, beneficial both from theoretical perspective as well as for practical purposes. One of the most prominently used methods of measuring residential satisfaction is the use of self-assessment questionnaires measuring satisfaction by assessing satisfaction with individual aspects of the residential environment. Developmental process of these questionnaires often takes an ad hoc approach, especially in terms of the selection of aspects to be included in questionnaire items, i.e., for the purposes of the study at hand, often without providing a solid rationale for the selection of these aspects. To authors' best knowledge, there are no established criteria and justifications for including specific aspects of the residential environment in the measurement of satisfaction and also no reviews of these aspects to date. Therefore, the aim of the present study is to provide a systematic review of aspects of residential environment (on dwelling with building and neighbourhood levels), included in the residential satisfaction questionnaires. Since these include a great variability of aspects on many levels of specificity, the additional aim of the study is to categorize these aspects to possibly arrive at a comprehensive list of included aspects of environment in residential satisfaction questionnaires while also recognizing the most prominent categories used in the reviewed questionnaires.

**Keywords:** residential satisfaction, questionnaires, aspects of residential environment, systematic review

# *Molecular Dynamics Investigation of Capturing Paracrystalline Cellulose Phase from Mixed Crystalline and Amorphous Cellulose Under Constant Load*

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Cellulose is one of the major abundant biopolymers on earth, roughly half of all plants are constituted from it. It is composed of linearly dispersed glucose polymers that are strongly bonded through hydrogen bonds. Two distinct phases of cellulose can be seen in a typical wood, namely crystalline and amorphous region. The ratio of crystalline and amorphous region controls the typical properties such as rigidity and flexibility of the cellulose fibers. The mechanical properties of the cellulose depend on the amount of crystallinity and organization of both phases. Moreover, combined crystalline and amorphous have not been analyzed in detail and no systematic study exists on the investigation of paracrystalline phase formation under constant load conditions. The investigation of paracrystalline's structural morphology, hydrogen bond information and mechanical properties are thus necessary for understanding microfibril at molecular level. To address these issues, we employ molecular dynamics simulations to study of the formation of paracrystalline states under constant load. GROMACS was used for all MD simulations with GROMOS 53a6 force field. The system is composed of a mixture of crystalline cellulose plates and amorphous cellulose. Each crystalline cellulose plate is comprised of 30 glucose chains, with each chain containing 18 glucose units and each amorphous contains four glucose chains with 518 units. The amorphous region is confined between two plates. The upper crystalline plate is fixed, and the bottom plate is loading with different forces, for instance, 1000, 3000, 5000, 7000 kJ mol-1 nm-2. The radial distribution function (RDF) demonstrates that the obtained long range ordering for paracrystalline lies between that of corresponding amorphous and crystalline peaks (Kulasinski et al., 2014). The RDF peak intensity increases at increasing load. Therefore, paracrystalline state is predominant and also inevitable at the crystal and amorphous interphase.

**Keywords:** molecular dynamics, cellulose, paracrystalline state, constant load, amorphous

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## *Practical education of Smart Home Systems emphasizing sustainability*

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Smart home systems can make living more comfortable. Moreover, they may provide ways to save energy; thus, they can help to achieve sustainable buildings. The possibilities are wide and the energy savings can be as high as 45%. To achieve such high values, the capabilities of the smart home system must be known to the person using it. The Department of Technology possesses a working smart home model. Our students can try its operation, and they are also introduced to the various ways to program it. The different approaches of saving energy are presented during the education process, too.

**Keywords:** energy, smart home, programming, education

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# INNORENEW COE COMPLEX

SEPTEMBER 2021

The InnoRenew CoE complex will be Slovenia's largest wooden building and home to the InnoRenew CoE research institute.

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Rendering of InnoRenew CoE complex (top) and its roof terraces (bottom) in Izola, Slovenia. Image: InnoRenew CoE

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### INNORENEW PROJECT

InnoRenew CoE is funded through the InnoRenew project, which involves nine Slovenian partners and one German partner: University of Primorska, Fraunhofer Institute for Wood Research WKI, University of Maribor, Institute for the Protection of Cultural Heritage of Slovenia, Slovenian National Building and Civil Engineering Institute, Pulp and Paper Institute, Zavod eOblak National Institute of Public Health, Regional Development Agency of the Ljubljana Urban Region and InnoRenew CoE.

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# *Human Health in the Built Environment*

# *Development of outdoor environment in schools with natural materials A response of future users*

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In this article, we present a concept of an outdoor natural thematic path to be installed in a school's environment in order to influence children's physical and psychical development. The path is designed with wood and other natural materials. Design of the natural path was prepared in cooperation with interdisciplinary experts and discusses the importance of precisely focused practices for physical development, sensory stimulation, development of concentration, orientation in space, overcoming one's own boundaries and gaining self-esteem, development of synaptic connections in the brain, visual memory, stimulation of social and moral development, development of motivation, teamwork, sense of belonging, interdisci-plinary work and ecological awareness.

In this paper, we will discuss the response of future users and change of the school's learning processes, which until now have been designed for the needs of a frontal learning system and, therefore, unfriendly to users. By communicating the reasons why learning processes need to be placed as much as possible in the natural environment, and the solution given, we want to suggest crucial changes for the future development of schoolyards for more socially and environmentally sustainable development of education.

**Keywords:** thematic path, wood, nature integration, school environment, cognitive development, sustainable development, motor skills, sensory stimuli, cross-curricular integration, change of learning environment, architectural planning of outdoor space

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# *Ensuring the health of users with the integrated approach to the renovation of school buildings*

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INTRODUCTION. It is important how we design, maintain and renovate school environments as they are designed for children, who are the most vulnerable population, and they spend in school on average around eight hours per day. Quality school environment influences different dimensions of health. Through the entire life cycle of the building, the following parameters have to be considered: noise, lightening, space distribution and orientation, thermal comfort, air quality, furnishing, etc. Usually, users' experience is not important when starting renovation process and also some of the health parameters are not paying enough attention. Through the comprehensive design process of the school environment, there is both interdisciplinary collaboration between different experts and a big need for users' participation in the renovation process.
AIM. To define the health parameters that should be addressed when renovating school buildings. In this research, we will create the strategy how to involve users into the renovation process of school buildings, focused on the design of healthy school environment from public health and architecture prospective. Research is base for the project "Evaluating user experience after building renovation: development of a new methodological approach", where we will develop a new methodological approach for assesing user experience after the renovation of the building and prepare a new tool for assessing user experience after building renovation.
METHODS. We conducted comprehensive literature review (integrated approach towards design and renovation of school buildings, evaluation process of existing school buildings, etc.), research on health parameters, and development of new strategy model.
RESULTS AND DISCUSSSION. When designing/renovating healthy school environment different elements should be considered: health parameters, users experience, integrated approach, interdisciplinary collaboration, etc.
CONCLUSION. To conclude, a comprehensive approach is needed in the planning process of healthy school buildings, which is based on interdisciplinary collaboration between different stakeholders, from planners to users.

**Keywords:** healthy school environment, health parameters, users experience, renovation, primary schools, interdisciplinary collaboration, public health

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## *Bioinspired building materials – lesson from nature*

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Plants evolved during 460 million years to a constantly changing environment and became well adapted to different climatic conditions (Koch and Barthlott, 2009). Due to their immobility as individuals, plants are an excellent biological material for detecting climate phenomena. Living organisms use smart, optimized and elegant solutions to survive, thanks to continuous selection and mutation processes. Consequently, plants developed tissue with barrier properties while they faced a number of existence challenges (water loss, extreme temperatures, UV radiation, etc.).

Systems found in nature are a valuable source of inspiration for several applications. Scientists and researchers from different fields (structural engineering, robotics, medicine, materials science) use the concepts of biomimicking and bioinspiration. In the last years, the possibility to benefit from solutions developed by nature also became more interesting for sustainable architecture. Comprehensive analysis and evaluation of plants' adaptation strategies (both static strategies and dynamic mechanisms) to their environment in different climate zones is indispensable to transfer concepts from biology to architecture. Consequently, specific adaptation solutions might be implemented in new materials that will be used for building envelopes erected in the same climatic zones. Integrating length scales and mixing biological, chemical and physical concepts for tailoring materials properties during preparation should allow better designing of future smart materials. The optimization process should lead to development of active biomaterials performing as interfaces between outdoor conditions and internal comfort; they should be able to regulate humidity, temperature, CO2 and light as well as capture and filter pollutants and be self-assembling, self-cleaning, grafting and self-healing. This contribution provides several examples representing plants' adaptation to various environments that are analysed and presented with the scope to inspire future researchers to implement them into building materials.

**Keywords:** biomimicking, bioinspiration, climate adaptations, building façades

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# *Psychophysiological and attention restoration in a wooden office: A pilot study*

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It has been shown that certain indicators of human stress can improve in interior spaces with visible wood (e.g., Burnard and Kutnar, 2019). Due to the scarcity of studies, additional research is needed to confirm and clarify current findings. Ideally, human stress responses in indoor environments should be captured by combining measures of physiological arousal, affective states, and cognitive performance (Parsons and Tassinary, 2002). However, it is challenging to reliably elicit a stress response in humans and select appropriate measures and timing of their administration. Additionally, because small effect sizes are expected, appropriate experimental design and sample sizes are required.

The primary aim of this pilot study was to examine if a mental arithmetic task performed before an evaluative audience can lead to a stress response and recovery that is reflected in the selected measures of affective states (i.e., pleasure and arousal single-item scales), cognitive performance (Attention Network Test; Weaver, Bédard, and McAuliffe, 2013), and electrodermal and cardiovascular activity.

A convenience sample of 20 participants completed the study. After stress was induced in subjects (five minutes), half of them relocated to a desk made of light wood and the other half moved to a desk covered with a plain white cloth, where they rested for 10 minutes before completing the cognitive task (five minutes). The physiological activity of the subjects was measured continuously throughout the entire study protocol, while the affective states were assessed twice, immediately after the stress-inducing activity and directly before completing the cognitive task. The analysis of the results examines the suitability of the study protocol together with the selected stress-inducing activity and measures capturing physiological, affective, and cognitive performance outcomes. Recommendations for future studies are discussed based on the findings.

**Keywords:** wood, restoration, cognitive performance, physiological arousal, affective states

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# *School Furniture as a Risk Factor for Musculoskeletal Pain Among Slovenian Students*

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The very first environment where a human is exposed to long-term sitting is school environment. School furniture could be one of the external risk factors for musculoskeletal pain among students. The aim of this study was to evaluate school furniture as a risk factor for musculoskeletal pain among Slovenian students. The study was divided into two parts. Firstly, a review regarding the student-furniture mismatch was conducted. Secondly, student-furniture mismatch in Slovenian schools was calculated and correlation between the mismatch and musculoskeletal pain was evaluated. Students from primary and secondary school, and from higher educational programs, were included in the study. To calculate the mismatch, eight anthropometric measures (popliteal height, knee height, thigh thickness, elbow height sitting, shoulder height sitting, sub-scapular height, hip width, buttock-popliteal length) and six furniture dimensions (seat height, seat depth, seat width, seat inclination, upper edge of backrest, sitting desk clearance) were measured. Additionally, students completed the Nordic Musculoskeletal Questionnaire. The results of the literature review indicate a high student-furniture mismatch among the existing studies, ranging from 30% to 90 % (Batistão et al., 2012; van Niekerk et al., 2013). Similarly, the high mismatch was found among Slovenian students at all educational levels. Further on, ergonomically designed school furniture was proposed based on the anthropometric data of the students. The high mismatch between the furniture and students' anthropometry indicates that there is a need to ergonomically redesign school furniture in Slovenian schools at all levels. Furthermore, the data obtained could be considered when designing new school furniture in Slovenia. Studies with larger sample sizes assessing multiple age groups are desired to better understand the student-furniture mismatch.

**Keywords:** ergonomics, design, school-furniture mismatch

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# *Appreciation/acceptance of traditional and modern appearance of materials and products by users*

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This paper deals with phenomena of taste for modern or traditional approach by creating built environment and its elements with particular surfaces. It is related to the research project Identity- SK- common platform of design, architecture and social sciences, where it is a main goal to explore regional identity within socio-cultural sustainability and well-being and the possibilities of its transformation and interpretation in a modern society with its built environment. Local identity can be understood as the essence of a cultural heritage and genius loci and plays a very important part in self-identification. Although there exist many research studies in field of ethnography, cultural anthropology, history and archaeology, they are very rarely available and understandable for architects, designers, investors, producers and services providers directly in the regions. Solution can be found in form of regional concepts for products and services, coming from interdisciplinary literature and field research and storytelling. First of all, it is necessary to research about it, respect it, having a lot of respect and empathy by adding something new, use it with the context and telling stories, not to embed in misinterpretation and be stranded in many form of kitsch.

In the research, we are setting hypothesis that facing the elements having marks of regional identity create positive reaction by users - measurable with objective physiological parameters, observations and mapping and subjectively through interviews and questionnaires. The objects that are being developed in the workshop will be further explored and tested regarding the preferences of respondents. The measure of decorativeness or simplicity is one crucial issue. Also the topic of physiological reactions with EEG sensors of respondents while facing elements with local identity and built environment that has marks of local identity through environmental simulations is being now further explored and will be presented.

**Keywords:** regional identity, tradition, modern, well-being, built-environment

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# *Complementary Topics*

# *Continuous densification of solid wood The band press approach*

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The densification, i.e. transverse compression of solid wood can lead to improvements in the mechanical properties, and this opens up new applications for low-density wood species, in particular. For the past one hundred years, many efforts have been made to mass produce densified wood products, but despite being available on the market, they still are niche products with annual production volumes of about 2000 m3 in Europe.

Hitherto, all commercially available densified wood products have been produced in a batch-type process, which limits the achievable process speed and integration into the largely continuous wood processing chain. In two previous studies, we explored a continuous surface densification approach using roller pressing equipment. Desired density profiles with a pronounced peak close to the surface could be obtained at process speeds of up to 20 m min-1. However, the short contact time between the wood and the rollers makes it virtually impossible to integrate a cooling stage and treatments to reduce the set-recovery into the process.

For these reasons, we propose the use of a band (belt) press. Such a machine will be installed in the Wood Science and Engineering division at Luleå University of Technology in the first quarter of 2020, and will function as a research and process development platform. The press is dimensioned for the densification of full-sized floor boards of up to 250 mm in width and 100 mm in thickness, at a processing speed of up to 60 m min-1. It is equipped with sensors to measure the pressing forces, moments, and temperature, and its design allows for digital image correlation analysis of the densification process. We hope that the new band press will push densified wood products closer to large-scale industrial implementation and foster new collaborations with other research groups in the field of wood densification

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**Keywords:** wood compression, densification process, belt press, process development

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# *A Review of Wood Modification globally Findings from COST FP1407 and 2019 updates*

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Wood modification (chemical, thermal, impregnation) represents an assortment of innovative processes continually being adopted in the wood protection sector. COST Action FP1407 (Understanding wood modification through an integrated scientific and environmental impact approach – ModWoodLife) was initiated in 2015, with its 4-year programme aiming to investigate modification processing and products design with emphasis on their environmental impacts. Among the final tasks within COST FP1407 was to reevaluate the current status of wood modification across the member countries, which resulted in a meeting in Florence, Italy, where the national status of wood modifications in 18 different European countries was presented.

However, it became clear that activities in other European countries needed to be addressed, and as a result, a more extensive evaluation of wood modification processes across Europe was undertaken, as well as determining the activities globally. As a result, it became clear that the original figures quoted at the time of the COST FP1407 meeting in Florence were considerably lower than actual production levels, which are reported herein, along with those from evaluating the overall global position. These figures suggest that wood modification is undergoing a significant increase in production due to demand, with levels of recent growth seemingly suggesting this will continue for the coming years.

**Keywords:** wood modification, Europe, COST, production

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# *Optical and abrasion properties of plasma treated and UV LED printed wood samples*

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UV LED printing technology can be used for printing directly on wood, which enables new options for unique printed wooden elements in the interior and exterior design. With appropriate design and processing technology, all kinds of wood samples and end products (doors, furniture elements) can be enriched and their added value can be raised. Depending on the application's end use, a pre- or post-treatment may be required to improve ink adhesion and durability. Plasma treatments are a common procedure to improve the performance of coatings and adhesives on various substrate materials. Particularly on wood, air plasma treatments are known to improve adhesion strength and durability of many types of lacquers and varnishes (Žigon et al., 2018). In some cases, air plasmas were even found to be a suitable replacement for parts of the conventional pretreatments, such as the last step of sanding before applying the coating (Wolkenhauer et al., 2009). In other cases, chemical primers could be excluded altogether on plasma pretreated substrates (Viöl et al., 2012).

In this research, Common beech (Fagus sylvatica L.) wood samples were printed using flatbed UV LED inkjet system (Apex 1610) with Nazdar UV inks. Half of the specimens were pretreated using a dielectric barrier discharge (DBD) plasma in atmospheric air (Žigon et al., 2019). To determine the influence of the DBD pretreatment print gloss, print sharpness and abrasion resistance of the printed samples were measured. Print gloss was measured on the 100 % covered printed black area with Novo Gloss Trigloss Gloss Meter (RHOPOINT) at 20, 65 and 85 ° gloss angles. The results indicate no significant changes regarding specular reflections after the DBD pretreatment. Print sharpness as a surface quality factor was determined with modulation transfer function (MTF) using ImageJ, an open source image processing program. The results of abrasion resistance obtained with Taber Abraser didn't show significant difference, either. Based on these results, it can be concluded that DBD pretreatment did not have a significant impact on printing properties of Common beech wood samples printed with UV inkjet.

**Keywords:** UV LED, printing, plasma treatment, gloss, abrasion resistance

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# *Towards Smart Textiles for Civil Engineering Application*

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Integration of sensors or any other diagnostic technology directly into a material or structure is a way to increase the safety level of the construction and provide other features as online diagnostics, predictive maintenance or a functionality of early warning in case of component failure. Many of the available embedded sensor technologies suffer from limited lifetime or necessity to have a battery power or influence the structure integrity. Technologies with lower impact on the structure, as integration of Fiber Bragg Grattings sensors, require expensive sensitive equipment to evaluate signals. Application of sensitive coatings on the textiles for reinforcement purpose is a novel and innovative approach. Using textile for the reinforcement of concrete and composites allows subtile and still high-performance structures to be built. The textile itself can be used as substrate for layers providing sensing functionality to measure moisture, strain, load or to detect cracks in the material. The main advantage is the direct contact of these additional layers with the measured material, in situ measurement, as well as protection of the sensitive textile against ambient environmental conditions.

This paper will introduce flax textile reinforcement as sustainable alternative to synthetic reinforcement material, coated with carbon-filled epoxy resin. The carbon provides conductivity properties to the textile. Graphite and bio-carbon will be studied in this work. A detailed study of textile conductivity properties with respect to the carbon concentration in epoxy will be presented in the full paper. The promising results obtained with textile coated by epoxy filled with graphite shows suitable conductivity levels for embedded strain/load measurement in civil engineering. The results of epoxy-graphite and epoxy bio-carbon mixtures will be shown together with the coated textile conductivity study. The potential for applications in moisture detection in timber constructions such as CLT or GLT will be discussed in the full paper as well.

**Keywords:** smart textile, embedded sensing, renewable materials

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# *Application of Cross Laminated Timber furniture as Earthquake Shelter. A public domain release of the Lifeshell concept.*

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Earthquake is an unpredictable and potentially deadly phenomena. Building with anti-seismic technology can effectively reduce the risk of injuries; however, the adoption of this technology on a large scale is difficult because of funds, logistics and bureaucracy. As a result, there are critical seismic zones where residential and non-residential buildings are not safe. The concept of wooden-based furniture used as an anti-seismic shelter is here released under the Creative Commons licence: a low-cost, natural-based, open-source, copyright-free solution. The so-called "Lifeshell" concept has been independently funded and developed, and it is here presented in its engineering characteristics. "Life in Shell" depicts an alive human being protected by wood during an earthquake. Lifeshell is a furniture in the shape of school desk, wardrobe, table or bed made of cross laminated timber panels. A school desk prototype was tested. The desk was to resist a total impact energy of 40,000 Joule without collapsing. Lifeshell concept comprehends various types, sizes, weights, finishing and accessories. Cost effective solutions are foreseen for being assembled and finished by the final user: they also include a basic survival kit. On the other end, top-range versions can be aesthetically pleasant and enriched with high-end accessories. Lifeshell concept is ready to be adopted by the industry for a further development. By this publication, authors release this potential life-saving technology using the Creative Commons CC BY 4.0 License (public domain), which allows the engineering, production and selling of this furniture without any royalty fee for the authors.

**Keywords:** anti-seismic, furniture, cross laminated timber, shelter, creative commons

**Acknowledgements:** Authors gratefully acknowledges Silvio Pedrotti and the ESSEPI Srl for the prototype and idea development, Jakub Sandak and Martino Negri for inspiration.

## *Distributed Ledgers and Decentralized WoT Architectures*

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Collecting sensor data in buildings raises several challenges, such as handling sensor hardware and platform heterogeneity, the distributed nature of sensors, network vulnerability to disconnections, and optimization of resource usage (network, processing power, etc.).

Typical solutions rely on container management tools like Docker (Anderson, 2015) to abstract the heterogeneity of IoT devices and run applications on the edge, harvesting the processing power that recent sensors and middleware devices offer. In such a distributed setup, optimization of device usage becomes a major concern. Existing solutions use orchestration tools like Kubernetes (Hightower, 2017) to allocate applications to the most relevant device on the network. However, these orchestrated solutions remain centralized, which means that they create a single point of failure (SPOF), thus reducing the reliability and security of the whole architecture.

In our work, we designed a fully decentralized architecture that features choreography (Peltz, 2003), rather than orchestration, capabilities while remaining free from SPOF. To do so, we jointly exploit the advantages of consensus algorithms, distributed ledgers, and the Docker API to implement a choreographed solution. Our experiments have demonstrated the effectiveness of optimizing computing resources on the edge. Using a distributed ledger presents the advantage to make the choreography verifiable, which means that anyone can go back in time and observe that the behavior of the solution was optimal.

We validated and evaluated our solution with a proof-of-concept implementation in a national cultural heritage building. Our prototype provides optimal application migration at run-time and tolerates device disconnection. These advances open research opportunities to improve fault tolerance in a distributed system.

**Keywords:** edge computing, distributed ledger, consensus algorithms, sensor networks

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# *Numerical simulation of moisture transport in thermally modified wood exposed to rain*

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Renewable wooden products exposed to continuously variable outdoor climates are strongly affected by the moisture levels in the material. High moisture contents accumulated in wood during long periods, in combination with favorable temperatures, represent a risk for the durability of thermally modified wood products because of decay development. In this context, numerical simulations can quickly predict the high levels of moisture as well as the related risk of decay in decking products for buildings. This information can help to optimize the product maintenance, for example, suggesting the use of appropriate coatings. Earlier studies by the first author have shown that the single-phase finite element modelling of moisture diffusion in untreated wood is an efficient tool to simulate the moisture transport in wooden components of buildings sheltered from rain (Fragiacomo et al. 2011). An extension of this approach, which takes into account the effect of rain in thermally modified products, is proposed in the present paper. The sorption isotherms used in the model are measured at different temperatures above zero degrees Celsius within this research. In addition, the diffusion coefficient includes the contribution of free water in wood above the fiber saturation point. A case study of thermally modified wood is numerically analyzed, and the results in terms of moisture content are compared with data taken from previous research (Metsä-Korteläinen et al. 2011). In future work, the proposed moisture transport model will be combined with well-assessed models for wood decay (Brischke and Meyer-Veltrup 2016).

**Keywords:** thermally modified wood, moisture transport, rain effect

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# *Sustainable Construction with Renewable Materials*

# *A European reference house for Life Cycle Assessment of wooden residential buildings*

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The construction industry accounts for 15 % of all greenhouse gas emissions. During their use phase, buildings use 40 % of the total energy consumption, which contributes significantly to air pollution and other environmental impacts. While the energy consumption during the use phase is predicted to decrease as efficient buildings, like zero and near zero energy buildings, become more common, climate change and other environmental problems from the production or raw materials, construction and end of life remain serious concerns that need to be solved urgently.

Life cycle assessment (LCA) and the EU-recommended Environmental Footprint (EF) are well known and accepted tools to measure a comprehensive set of environmental impacts throughout a products life cycle. However, to assess how good (or bad) a wooden building performs environmentally is still a challenge. In the EU Environmental Footprint pilot phase from 2013 – 2018, an average benchmark for the different product groups was found to be very useful. Based upon the recommendations for a benchmark of all kinds of European dwellings, we developed a scenario of a single-family house nearly zero energy building. This scenario results cover 16 recommended LCA impact indicators and can be normalised and weighted into one single point for easy and quick comparisons. The results are presented as the average impact per one square metre (m2) of floor area over one year.

The developed benchmark for wooden buildings is a suitable comparison point for new wooden building designs. The benchmark can be used by architects and designers early in the planning stages when changes still can be made to improve the environmental performance of wooden buildings or to improve the communication and interpretation of the LCA results for customers and other stakeholders. This presentation will discuss the methodology, results and compare the results of the wooden building with the benchmark of average European dwellings made of different materials.

**Keywords:** life cycle assessment, Environmental Footprint, buildings, benchmark, wood

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# *HYGROSCOPIC COFFER. Digital parametrization and realization of timber bilayer compo-sites for passive dehumidification in built environments*

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The issue of sustainability in the building sector is particularly current: green buildings involve environmental, social and economic benefits (Ragheb et al., 2016). The integration between renewable materials and passive design strategies for the improvement of the built environment comfort (Omrany and Marsono, 2016) leads to a reduction in energy consumptions and in the use of active HAVC systems (Rodriguez-Ubinas et al., 2014). Sustainability concerns the materials employed, but also their performance: natural materials with embedded responsive properties respond to specific external stimuli, changing some of their physical or chemical properties and this represents an additional and innovative advantage in built environments. As biomimicry suggests (Benyus, 1997; Pawlyn, 2011), it is possible to take advantage of the embedded hygroscopic behaviour of wood in order to create a hygromorphic composite material that passively reacts to relative humidity variations of the environment (Ugolev, 2014). These composites are realized with a cross-grained double-layered structure, joining a thicker veneer (active layer) and a thinner one (passive layer), in order to reproduce the principles that make pine cones scales bending after exposure to humidity variations (Menges and Reichert, 2012; Reichert et al., 2015; Holstov et al., 2015; Wood et al., 2018).

The double-layered panels, called "unplywood" (Bianconi and Filippucci, 2019), can be digitally parametrized and used as a false ceiling for the passive dehumidification of an indoor environment, using only the convective motion of the humid air and the stack effect. This is particularly useful when the relative humidity excessively increases, exceeding the comfort levels (Wolkoff and Kjærgaard, 2007).

The result is a passive dehumidification system where the timber panels act as sensors and as decorative architectural elements at the same time and contribute to improve the indoor environment from a hygrometric point of view as well as from a perceptive one.

**Keywords:** passive hygrometric control, timber composite, natural ventilation, digital parametrization, hygromorphic bilayers

# *Residential Building Optimisation Using Passive Design Strategies*

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A fundamental problem of the sustainable built environment development represents the poor optimisation content in the design process. While first studies focus on algorithms for only one particular subsystem (e.g., insulation, shading, heating generation, etc.), the overall complete building optimisation is still missing. Though the patented Energia Design Method applies sophisticated energy, climate, comfort, lighting, aerodynamics, life cycle assessment simulation techniques as a heuristic support for overall building optimisation, all possible design cases and, therefore, the optimum is still not guaranteed.

To overcome these shortcomings, a previous study integrated a synthesis step to generate all feasible and possible building cases considering the most decisive passive design elements. A specific building design problem demonstrates the method in form of a simple residential building. With simulation-based assessment of comfort and energy performance, an order including the n-best solutions could be achieved, and the passive exemplary modelling of Energia Design Systhesis was proven.

The current research proposes the extension of the optimisation process with active system configurations. The gained optimal design cases serve as initial models to be equipped with all residential housing related heat transfer, heat generation, as well as energy supply systems, including mechanical and natural ventilation strategies. Lighting and operation control complete the active-hybrid modelling. All reasonable system combinations are created and assessed by complex building physics simulations. Evaluation of the thermal and visual comfort and energy results were processed by predefined user specific weighting system(s) to elaborate a final order with the guaranteed optimal overall building solution. This active system optimisation modelling completed the successful validation of the Energia Design Synthesis method. After the passive and active optimisation process, a series of interrelations and affecting factors were analysed and primary correlations defined as basis for an automated algorithm system that is able to absolve the complete optimisation process.

**Keywords:** optimisation, residential building, synthesis, active design strategy

# *Energy Efficient Retrofitting: A comparative analysis of implemented strategies in Bosnia-Herzegovina and Slovenia*

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Sustainable approaches in retrofitting buildings for energy efficiency are becoming inevitable in the time of global climate change. Retrofitting existing building stock can be effective in reducing global energy consumption and decreasing resource overexploitation. However, less developed EU member states and neighbouring developing countries show reluctance towards healthy and renewable materials and their use in the building recovery process. This can be explained by different influences – a chain effect that goes from legislation and lack of effective strategic programs and action plans to consumers who prefer materials that are more affordable, regardless of their environmental or health impact. This process directly reflects on an industry incapable or not interested enough to produce equally priced materials from sustainable resources. Global issues primarily reflect on developing countries, such as Bosnia-Herzegovina, that cannot afford better or more innovative energy recovery systems. This research aims to display analysis of documents and legislation regarding retrofitting of residential buildings in Bosnia-Herzegovina and Slovenia. To address this broad problem, analysis of differences between good practice environments and environments where resistance towards sustainable retrofitting is present was performed. The analysis tackled indirect causes, studied legal foundations (rulebooks and official gazettes) and examined strategic frameworks (energy strategies, action plans), providing concise insight thereof and pointing out potential barriers to implementation of recommended retrofitting solutions based on renewable materials. Furthermore, this research sets a good platform for further similar analyses of other countries in the region.

**Keywords:** legal framework, action plans, developing countries, energy efficiency, renewable materials

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