Co-funded by the Eco-innovation
Initiative of the European Union

CelluWood

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Laminated Strong Eco-Material for Building Contruction Made of Cellulose-Strengthened Wood

SEPTEMBER 2014

The project was co-funded by the Eco-innovation Initiative of the European Union.

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Summary

Illustrations. PHOTOS: AIDIMA, InnovaWood

CELLUWOOD project aimed at developing a new range of structural elements for construction made of wood by introducing innovative technologies. The project developed the fit for purposes nanocellulose and lignin-based bioresins and their novel applications in the laminated wood production (glulam products) instead of synthetic resins made from petrochemicals.

The ultimate outcomes are new glulam re-engineered construction elements, namely eco-beams and eco-columns, manufactured with more natural based and eco-friendly adhesives in comparison with the conventional laminated beams and columns. These innovative building products and the inclusion of new technologies are expected to provide environmental benefits.

A significant impact on the glulam market is expected leading to higher demand for glulam products when carbon neutral building solutions are sought.

The challenges:

Why CELLUWOOD?

Glulam is one of the fastest growing structural materials of the last few decades. It is a type of structural engineered timber product comprising a number of layers of dimensioned timber bonded together with durable, moisture-resistant structural adhesives.

The advantages of glulam towards conventional structural wooden elements may include the availability of standard components, versatility, no need for cladding, large spans, good strength-weight ratio, superior fire performances and corrosion resistance. Compared to steel construction elements, glulam is the least CO_2 emission technology and has six times less embodied energy used.

The adhesive is probably the single most important parameter in glulam production. The adhesives used today for the production of laminated wood products are still mostly based on synthetic resins, which are in fact under increasing restrictions due to the tightening environmental and health protection regulations. The idea of obtaining glulam adhesives from renewable raw materials is becoming a topic of considerable interest. Moving away from synthetic resins made from petrochemicals has become realistic and it is predicted that in the next 10 years the impact of the so-called bioresins will be well noticed on the global adhesive market. A new adhesive system in which all or part of the petrochemical component is replaced by a bio-derived material is an attractive concept and represents a real challenge. At the same time it offers an opportunity for both wood products industries and adhesive manufacturers. The objective is to deliver an environmentally improved gluing system without sacrificing high durability or bonding quality. A range of adhesives have already been derived from natural and vegetable oils or other bio components.

Illustration. PHOTO: InnovaWood

Cost was and still is a determining factor in the development of renewable materials. However, industrial production has become viable as technologies evolve.

A new demand for bio-derived products, including adhesives, is primarily driven by consumer demand as well as environmental considerations. Consumer demand has been generated by a growing awareness of environmental and health issues. This has led to public opinion deeming petroleum-based products being harmful to the environment. The construction sector also suffered new regulations concerning human health and safety and the environmental impacts of construction materials. These regulations promote indoor air quality improvement and the use of eco-materials developed without using petrochemical agents. In particular, this refers to decreasing or even completely avoiding the formaldehyde presence in adhesives. The reduction of formaldehyde emission has been a major subject of research within the wood-based panel industry over the past decades. However, it is important to note that any product incorporating wood will release formaldehyde or other volatile organic compounds to some degree, given their natural presence in wood.

The work within CELLUWOOD project has been driven by this increasing need for the use of bio-based resins as natural and sustainable alternatives to traditional petro-chemical formaldehyde adhesive materials, and by the possibility of transferring and modifying already existing technologies from other sectors to the bioresin production sector.

CELLUWOOD objectives

The main objective of CELLUWOOD is to develop a new range of low carbon, reliably strong building construction materials made of wood and based on innovative technology applications (eco-beam and eco-column). This objective is achieved through:

- introduction of (new) technologies from other sectors (e.g. cellulose velvet, bio-composite reinforcement and bioresin) for innovative uses in the lamination, defect repairing and board reinforcement to get a strengthened board for glulam production;
- innovation in the use of nano/micro cellulose and bioresin technologies in timber re-engineering;
- development, testing and demonstration of the novel products.

The specific objectives of the project are:

- to develop bioresins for glulam timber production based on higher percentage of natural components without sacrificing durability or easy bonding. The new bioresins are used to repair, joint and strengthen sawn lumber in producing strong building components for construction purposes;
- to promote the utilisation of small diameter and underutilised European grown timber as raw material for glulam products.

Illustration. Lignin glue testing. Knot reparation. PHOTOS: RGBSTOCK, CHIMAR

Project innovation

During the CELLUWOOD project, different adhesion systems based on raw materials from natural resources have been studied on their suitability for the production of the CELLUWOOD new glulam beams and columns.

Three of these natural based adhesion systems were selected for the final experimental phase:

- lignin reinforced PF (phenol-formaldehyde resin) adhesive;
- nanocellulose reinforced epoxy;
- nanocellulose reinforced casein resin.

Significant development of beams and columns by using the developed natural based resins has been carried out. Hence, more sustainable and environmental friendly structural beams and columns, namely 'eco-beams' and 'eco-columns', have been generated.

Illustration. PHOTOS: RGBSTOCK

Lignin reinforced PF adhesive

The objective was to develop an adhesive with a "greener" character capable of setting in cold pressing in order to be used as a binder for the production of glulam building materials in small and medium sized companies. CHIMAR HELLAS SA. (Greece) developed and tested various binders based on natural raw materials so as to find the most promising one for the development of a cold-setting system suitable for the requirements of the CELLUWOOD products. The various adhesion systems were evaluated at lab scale in accordance with relevant EN standards. It was found that a lignin-based adhesive system comprising resin and hardener was the most satisfactory one and could fulfil the standard requirements for the glulam application.

This adhesive resin is of phenol–formaldehyde type resin where 50% of phenol has been replaced by lignin. This new lignin-based gluing system cures at room temperature within only a few hours and can be effectively used in the production of glulam beams and columns with a performance comparable to the products produced with conventional gluing systems.

The resin and the hardener are used in a so-called "honeymoon" gluing system. The process for the preparation of a gluing system comprises:

- a bio-based phenol-formaldehyde polymer where up to 50% of phenol can be replaced by lignin;
- a hardener to promote the cold-setting of this polymer.

Nano cellulose epoxy and nanocellulose casein resins

Nanocellulose-based resins have been relatively new ways of naturally sourced based formulations. In general, nanocellulose-based materials have high strength and low weight.

Cellulose macro- and nanofibers could be used as reinforcement or/and highly functional components in composites or other material systems, e.g. resins. The potential of nanocellulose is that it achieves strong and reliable bonds derived from the very high surface area of the nano-particles relative to their size. Two techniques of using nanocellulose as functional components have been developed at Brunel University. The first one used an epoxy glue as base and the second used a casein-based resin, both functionalised with nanocellulose components.

In case of the nanocellulose epoxy glue, the shear strength of the new system was about 50% higher than conventional epoxy gluing systems, when its addition was 1%. The dosage of nanocellulose used during the testing was in a range of 1-5%.

From many tests it was concluded that low addition of nanoncellulose (in nanoncellulose epoxy 1-5%, and nanocellulose casein <10%) could significantly increase the bonding performance of both glues, but specific concentrations depend on the requirements of the end products.

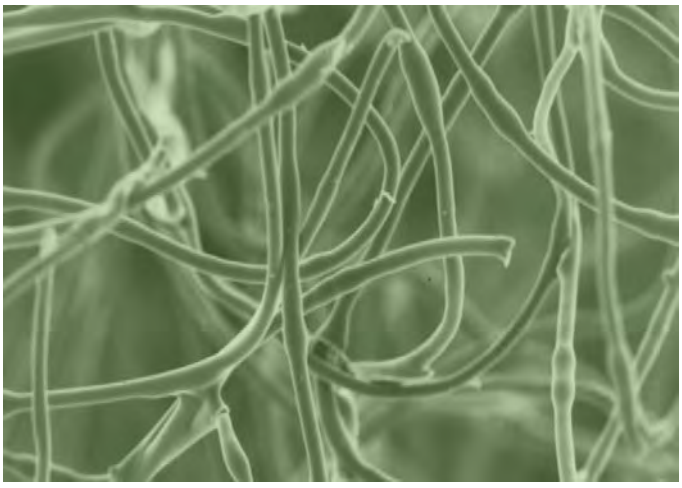
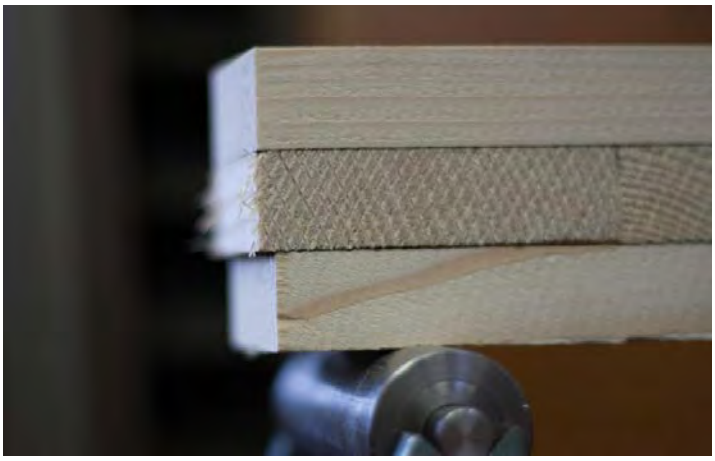


Illustration. PHOTO: Innovawood



Eco-beam testing. Eco-beam and column samples. PHOTOS: CBD, InnovaWood

Eco-beam and eco-columns

Ultimate outcomes of the CELLUWOOD project are the eco-beams and eco-columns, produced in the two partner companies TECNIFUSTA ENGINYERIA SL. and Inwood Developments Ltd. The developed natural binding systems have been applied to both eco-beams and eco-columns. The processing technologies have been tailored with the application of the natural bioresin systems.

This could be done with the conventional production facilities and gluing lines in the companies. No extra investment where required to apply the developed resins and gluing systems.

CELLUWOOD results

The project results can be classified in two groups:

- New adhesive, bonding and structural components:
  - lignin-based gluing system;
  - nanocellulose epoxy resin and casein resin for eco-beams;
  - inorganic core material for eco-columns.
- Structural construction products:
  - eco-beams and eco-columns.

New adhesive, bonding and structural components

Lignin-based gluing system

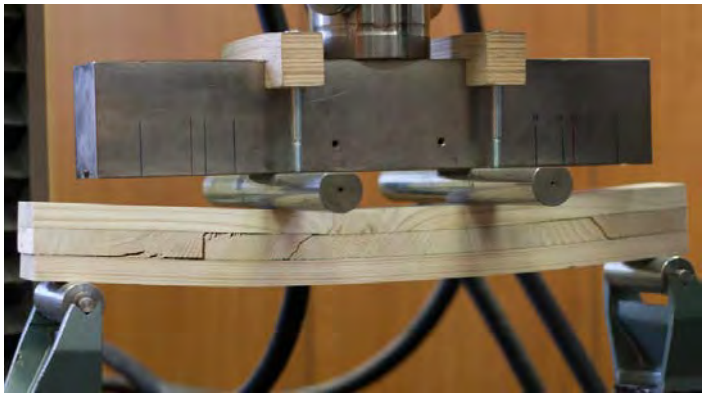
For this application the lignin modified phenol-formaldehyde (PF) resin developed by CHIMAR was used.

The obtained lignin containing resin is a "greener" adhesive with comparatively good strength and stiffness. The advantage of the use of lignin was in the following:

- lignin is a renewable bio material;
- lignin can successfully replace phenol when it is properly activated;
- lignin is available as a residue from other industrial processes and therefore could be cheaper (paper pulp).

The low emission lignin modified PF resin is easy to apply and cheap to buy, and its performance is equivalent to the existing commercial glues.

Eco-beams fabricated with the modified PF resin showed better mechanical properties than commercially available Melamine Urea Formaldehyde (MUF) resin beams. Compared to other commercial available resins, the only restriction for lignin-based resin would be its darker colour.



Lignin based glue testing. Eco-beam testing. PHOTOS: AIDIMA, CBD

This could still represent a limitation factor in wider use in wood construction and in particular in glulam products due to established architectural trends and aesthetic requirements set up by the sector professionals and customers. However, the application can be suitable for outdoor constructions and situations where colour effect does not jeopardize the design idea.

Innovative aspects

- cold press PF lignin modified bio-adhesive and corresponding hardener with superior mechanical performances (phenolic component replaced by 50%);
- the system can be effectively used in the production of glulam beams and columns with performance comparable to the products produced with conventional gluing systems. No extra investment are required to apply the developed resins and gluing systems in existing companies;
- the eco-beams prodced from lignin bioresins have been developed for the first time within the framework of CELLUWOOD project but are not available on the market yet.

Nanocellulose epoxy resin for eco-beams

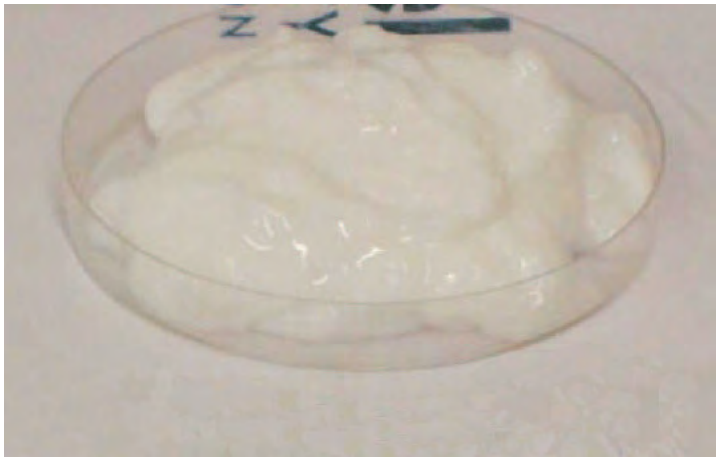
Nanocellulose-based materials are characterised by high strength and low weight. The high grade nanocellulose materials offer great reinforcing strength and/or optical clarity, while lower grade ones can offer an increased strength and improved properties at lower costs. Cellulose macro- and nanofibers could be used as a functional constituent to reinforce composite materials.

Two types of nanocellulose-based wood adhesives have been produced: the nanocellulose enhanced epoxy and nanocellulose reinforced casein. It has been found that both adhesives can be used and cured at the room temperature under a low pressure and display high performance. Laboratory tests have shown that the shear strength of epoxy resin increased by more than 80% when the addition of nanocellulose was at 3%. The commercial nanocellulose-epoxy bonded eco-beams have also shown superior mechanical performance over conventional products and showed potential for reduction of resin consumption for the production of laminated beams.

Nanocellulose has the potential to replace current used MUF and epoxy resins, and provide much efficient and high strength resin systems for laminated timber industries. However, it must be noted that at current early stage of nanocellulose development, the cost of the nanocellulose is still high, although a lower dosage of the nancellulose epoxy could be used for the same bonding outcomes, which could offset the costs.

Innovative aspect and comparative advantages

- the first successful research on nanocellulose dispersion in hydrophobic resin without using organic solvents;
- the first successful research on epoxy reinforcement with nanocellulose.



Nanocellulose epoxy glue. PHOTO: BRUNEL

Inorganic core material for eco-column

Another novelty concept developed in CELLUWOOD project has been the Inorganic Core Material (ICM) for eco-columns. The idea was to use wood residues from timber beam and column production as core material for the eco-columns. The key component for ICM is a modified sawdust and gypsum mixture formulation. The ICM composite columns have been produced and tested on laboratory scale. It is envisaged that once the interface between the ICM and enclose lumber is improved, the ICM composite columns can potentially be commercialised to use wood residues and reduce raw material costs for the column production.

Innovative aspects and comparative advantages

- new concept of ICM development for timber column;
- new technology of enhancing the strength of gypsum based composite;
- ICM is a versatile product. This light weight composite can be used as brick or core material of column;
- ICM is cheaper than solid timber.

Structural construction products: eco-beams and eco-columns

The developed eco-beams and eco-columns are strong re-engineered timber products bonded by a natural bioresin system. They are laminated with defect-free lumber that is produced with CELLUWOOD defect extraction and repairing technology and serve as structural materials.

The CELLUWOOD defect extraction and repairing technology consists of drilling out defective parts of the wood and replace it with a defect-free materials in such way that the strength of the wooden element for structural use is improved.

The eco-beams and eco-columns are framed in order to support buildings safely and carry loads imposed on wide spanning structures without excessive deflection or risk of shear failure.

Illustrations. PHOTOS: InnovaWood, AIDIMA

Innovative aspects and comparative advantages

The products are novel because:

- it has not yet been possible to make natural fibre composites reliably strong enough for incorporation in building structures;
- it has not yet been possible to laminate wood without recourse to use of strong, water-resistant glue made from almost the whole petrochemical feedstock.

Project impacts

Economic impact

The CELLUWOOD economic impact reflects in:

- strong contribution to a competitive market sector and fostering the further innovation including new functionalities and new wood and adhesive technologies;
- development of new infrastructure and new business in order to deliver new technology and products;
- providing an adaptable glulam production process for the small and medium sized companies with very low investment costs.

All products developed in the CELLUWOOD project (bioresins, the inorganic core material for columns, eco-beams and eco-columns) have high commercialisation potentials and could have impacts on the existing markets.

Social impact

An emerging new market could contribute to the employment in the sector both by securing existing jobs in mainly rural areas in Europe and possibly as well by creating new jobs. Applying the CELLUWOOD technology in more eco-friendly construction elements will improve health and safety of the consumer as more natural based resins are used.

Societal benefits on a large scale will also be won throughout Europe if, as expected, the results of this project will lead to an increased share of wood and wood-based materials used in the construction sector. This will directly affect the sustainability of society by shifting towards a CO_2 neutral renewable resource. It is also expected that some architectural trends in wood construction will evolve and the use of bioresin laminated wood products will increase thanks to its positive environmental and physical performances, in spite of some minor limitations (e.g. dark colour of the glue lines in glulam products caused by dark bioresin).

Illustration. PHOTO: RGBSTOCKS

Environmental impact

The environmental impact improvements achieved by CELLUWOOD have been analysed by using Life Cycle Assessment methodology. This methodology included all processes from raw material production to the glulam manufacturing. Particular emphasis was put on the comparison between the manufacturing of most widely spread commercial glulam gluing systems (PU and MUF) and the gluing systems developed in CELLUWOOD. As well the influence of the gluing system as a whole in the glulam manufacturing and the relative impact by volume of glulam and IMC core materials have been studied.

The bioresins have significant impact on reducing the amount of petrochemicals in wood products and therefore the use of bioresin is considered as an effective solution for reducing environmental impact of glued wood products. The developed lignin-based PF resin gluing system showed a clear environmental improvement compared to commercially available glues: 74% vs. MUF and 86% vs. PU resins. Besides the environmental advantages, the lower cost and better technical performance make the lignin-based gluing system as real eco-innovation and a great success for the CELLUWOOD project.

The nanocellulose-based gluing systems had a higher environmental impact compared to the commercial glues, despite that they were based on bio-based materials. This was mainly caused by the high environmental impact of the adhesion system used as base component for reinforced adhesives and not on the nanocellulose used.

Targeted market

The resin products developed within CELLUWOOD project can potentially replace existing MUF and epoxy resin application. Therefore, the promotion of the technology will target resin manufacturers, laminated timber industry and related sectors.

The promotion of the technology to resin and glulam manufacturers worldwide could be envisaged in collaboration with lignin and nanocellulose producers. The novel ICM concept using a gypsum and sawdust mixture as core material for columns can find its place in the wood construction market, in particular in the wall building and column manufacturing sector.

Further commercialisation of the eco-beams and eco-columns can be of interest to small businesses of craftsmen (woodworkers, refurnishing workers, restorers, repairers) and SMEs clusters, as these products provide an opportunity to expand and complete their product offer. Also for architects and design studios the eco products are of interest in the sense that they can directly be implemented and included in product portfolios for commercial activities (e.g. promotion of eco-friendly designed building).

Finally, the increasing DIY sector is a targeted customer of the new developed eco-products.

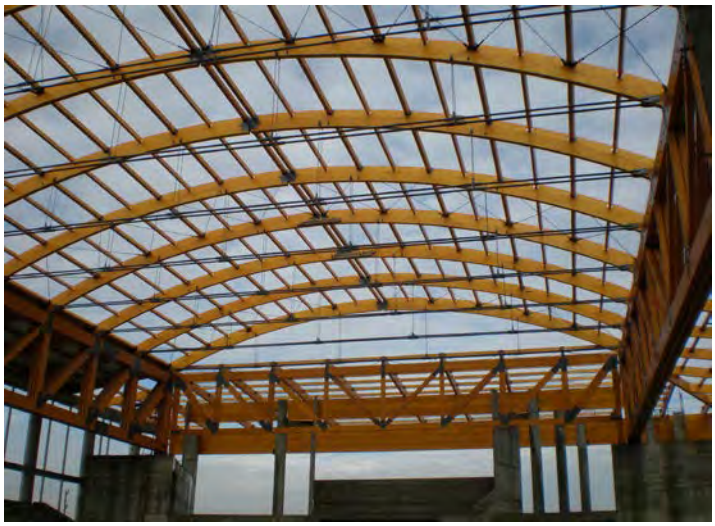


Illustration. PHOTOS: RGBSTOCK, InnovaWood

Consortium

InWood Developments Ltd (InWood)

The company was formed in 1999. In the last 20 years it advnced from just finger-jointing primarily cladding board fabricant to laminating beams manufacturer. During the existing period the company also has invested significant resources in innovation on defecting reparation and green gluing. **www.in-wood.co.uk**

CHIMAR HELLAS SA (CHIMAR)

Chimar is a Greek SME, provider of industrial technology, R&D and engineering services to the resin and timber and wood based panel industries. It offers its services all around the world for more than 37 years. CHIMAR develops in house and licenses know-how for the production of formaldehyde-based resins and chemicals used as resin additives. **www.chimarhellas.com**

Nano-Cellulose and Bio-Composites Research Centre, Brunel University (Brunel)

NRC3 at Brunel brings together some 50 specialist scientific and technical staff as the focus of Brunel's activities in promoting and developing the effective use of timber and other natural materials as an important and exceptionally versatile, renewable raw material. These expertise ranges from nano-microcellulose velvet and membrane and adhesion to macro bio composites materials for strong building materials and components.
www.brunel.ac.uk

CBD d.o.o. (CBD)

CBD d.o.o. - Contemporary Building Design consists of a group of researchers and construction engineers specialized for timber structures. Through demonstrating new timber construction techniques in every day construction practise CBD promotes sustainable and ecological construction for developing life-style and social values that shall prevail in the postmodern society of the future. CBD offers the paramont in construction of living through the use of contemporary building material, design and dedication to the life in connection to environment, health and simplicity. **www.cbd.si**

TECNIFUSTA ENGINYERIA SL (Tecnifusta)

Tecnifusta is an engineering company with 75 years of experience from traditional carpentry to high tech wood industrial transformation. The wide knowledge acquired during all this year has lead to the development of glulam production with a quality and guarantee as key basis of our work. Tecnifusta also works on projects for coverings, bridges, footbridges, arcades, pergola, modules, etc.
www.tecnifusta.com

Research and Development Association for the Wood, Furniture and Packaging industries (Aidima)

AIDIMA is a non-profit making organisation, which is active throughout Spain. The main aim of AIDIMA is to research and to transfer innovation to the Spanish forestry, wood and furniture sector due to increase production and product quality in global market. At present AIDIMA has 749 associated enterprises in Spain, from which over 90% are SMEs. **www.aidima.eu**

InnovaWood (InnovaWood)

InnovaWood is a European representative network in the Forest, Woodworking and Furniture sector. It represents organisations in the research, education & training and knowledge transfer areas. Its aim is to develop a more effective mechanism to support innovation, training and knowledge transfer in the European Forestry Wood Chain sector. The InnovaWood network comprises some 65 organisations in 24 countries, both research and education/training. **www.innovawood.com**

CELLUWOOD Team. PHOTO: InnovaWood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