WoodCircus

Underpinning the vital role of the forest-based sector in the Circular Bioeconomy

D6.1	**RTDI plan for wood industries towards the circular economy**
WP no and title:	WP6 – Transferable Practices, Strategic RTDI & Policy Support Actions
Responsible Author(s):	Michael Burnard, InnoRenew CoE
Contributor(s):	Erkki Verkasalo, LUKE Anne-Christine Ritschkoff, VTT
Date:	Draft: 22 October 2021 Interim revision: 17 November 2021 Final Version: 10 December 2021
Version:	Public

General Information about the project

Duration:	November 1st 2018 – December 31st 2021
Type of Project:	EU Horizon 2020 Coordination and Support Action Project (CSA)
Consortium:	17 Partners from 7 European countries

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 820892.

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1 Introduction

1.1 WoodCircus

The WoodCircus project is a Horizon 2020 coordination and support action operating under grant agreement No. 820892. WoodCircus increases knowledge, raises awareness, and improves conditions for an efficient transition towards increased circularity in wood-based value chains and fostering the increased competitiveness of the European woodworking sector.

The WoodCircus consortium is composed of 17 partners that represent the many interests of Europe's woodworking industries: five companies, three federations or associations, and seven research organizations. The management structure is designed to fit the project's objectives and the nature of a CSA project ensuring precise and timely information exchange among a high number of partners and stakeholders. The project management, quality assurance, and risk management procedures of WoodCircus are designed to support the proper implementation of the project in a lean, open, and supportive manner. Efficient and supportive management is practices in all tasks and activities of the project implementation, dissemination, and communication activities by the coordinator and project partners.

The WoodCircus project is positioned to provide timely recommendations to policy makers, industry members, and other stakeholders regarding the efficient and wise implementation of circular economy practices in the woodworking industries and wood construction value chain in Europe. To successfully implement a circular economy, crucial advances are needed to address changing production and construction operations, assessment methods, policy and citizen priorities, and economic and sustainability concepts. These advances can only be achieved through coordinated efforts in research, technology, development, and innovation (RTDI) actions that target key aspects of circular economy implementation. It is critical that the research is conducted collaboratively between industry members, the public, and scientists and that the outcomes are well communicated to stakeholders across Europe and the globe.

1.2 *State of the art*

RTDI efforts towards the circular economy are not new to industrial sectors broadly or specifically to the woodworking industries. Indeed, many of the core concepts, like waste reduction, side stream utilisation, and material recovery have been implemented in the woodworking sector for many years[1]. Recent developments in circular practices have been related to material cascading, environmental impact assessment, resource scarcity, economics, business models, replacing fossil-based resins, coating materials, and other wood treatments, that limit circular potential, design and product-based solutions to improve recovery, and systematic approaches to support material recovery amongst other topics.[1,2,3,4]

While solutions are available on the market that support circularity in the sector, the gaps and occasionally limited success of those solutions points to the need for concerted RTDI efforts that cross disciplinary boundaries and provide practical advances that can be readily deployed by companies, institutions, the public, and policy makers in a socially and economically feasible way.

For a detailed overview of existing good practices and sector analysis, see WoodCircus deliverables 2.2, 3.1, 3.2, and 4.2 or review the published good practice catalogue online at https://doi.org/10.32040/woodcircus-gpc.

1.3 *Advances beyond the state of the art*

This report provides a broad perspective on the RTDI needs to support circularity in business and operational aspects of the woodworking industries and wood construction value chain. Rather than focusing on specific details of RTDI activities, it suggestions priority topics where the opportunities for

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[1] c.f. Araújo, C. K. de C. *et al.* (2019) 'Circular economy practices on wood panels: A bibliographic analysis', *Sustainability (Switzerland)*, 11(4), pp. 1–21. doi: 10.3390/su11041057.
[2] Höglmeier, K., Weber-Blaschke, G. and Richter, K. (2013) 'Potentials for cascading of recovered wood from building deconstruction - A case study for south-east Germany', *Resources, Conservation and Recycling*, 78, pp. 81–91. doi: 10.1016/j.resconrec.2013.07.004.
[3] Cristescu, C. *et al.* (2020) *Design for deconstruction and reuse of timber structures – state of the art review Design for deconstruction and reuse of timber structures – state of the art review*. doi: 10.23699/bh1w-zn97.
[4] Burnard, M. *et al.* (2015) 'The Role of Reverse Logistics in Recycling of Wood Products', in Muthu, S. S. (ed.) *Environmental Implications of Recycling and Recycled Products*. Singapore: Springer Singapore, pp. 1–30. doi: 10.1007/978-981-287-643-0_1.

advancement are most clear, offer the greatest strides forward, and where obstacles can be removed.

2 Research, Technology, Development, & Innovation Priorities

The RTDI needs of the woodworking industries and wood construction value chain are many – continued advancement in the sector is a key driver of growth, competitiveness, and reduced environmental impact. However, those priorities that stand out as the most impactful towards circular practices are detailed within this section.

The WoodCircus project limits its recommendations to the woodworking industries and has a special focus on the value chain of wood-based construction and the solutions needed to create sustainable, safe, and inclusive buildings and infrastructure of all types. This report does not address the role of forestry or the markets for roundwood.

2.1 Waste reduction & side stream utilisation

Side stream utilisation. In general, wood production processes are efficient, with nearly-closed loops of materials, energy, and water There is little to no wood waste produced in manufacturing, even in differing states (i.e., solids, liquids, gasses). Instead, residues and side streams are collected and used for value-added processes and products, or converted to energy or energy products (e.g., pellets, briquettes, biogas). While onsite conversion to energy reduces the demand for energy from the grid for material conversion and processing, optimisations in sorting and conversion of input materials (e.g., logs) for high value yield of primary products can reduce low-value side stream production. Scanning technologies that allow for data-driven decision (i.e., through data modelling, machine learning, etc.) can improve value creation and reduce waste or side stream generation in the first place.

Increasing high value side stream utilisation through various collaboration models (i.e., co-location of a side stream processer at or near a side stream producer, horizontal integration, start-ups) can reduce transport costs and environmental impacts. Well-functioning industrial ecosystems increase productivity, efficiency, and added value in the entire value network.

Material cascading. In principle, material cascading limits the quantity of materials that end up as waste, by recovering, and reprocessing materials after their first service life. The material cascade recognises that complete circular reuse is limited and that a certain amount of waste is likely to be generated when processing recovered materials. In the case of wood, this may be removing the surface of sawn timber that has been coated (e.g., with paint) or removing the laminate surface on particleboard or medium density fibreboard. Typically, the waste generated can be converted to energy, but the main emphasis of the cascading principle is to extend the duration materials are utilised to reduce their overall environmental impact[5]. Although there are several limiting factors to increasing material cascading, the technical challenges that need to be resolved generally include identifying contaminants in the materials, clearly understood trade-offs between energy use and material use of wood products (with regional context), maintaining material quality through service life to maximise recoverable quantities and convince customers in the market of the functionality of cascaded materials, data on the availability of recoverable wood to create prediction models for future material flows, and data for environmental impact assessment of recovered material to assist in decision making[6].

2.2 Waste management & logistics

Value chain approach. Resources, technology and processes, products and a multitude of practitioners / stakeholders build the complex dynamics of wood-based value chains. Value chains for wood-based side streams and waste wood include different steps from production to valorisation, covering sourcing, processing, transport, storage, and distribution to the market. Figure 1 illustrates the complexities and interactions in wood side stream and waste value chains. Materials of interest can be resources or products, various processes and levels of technology may be applied to achieve the desired

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[5] Höglmeier, K. *et al.* (2015) 'LCA-based optimization of wood utilization under special consideration of a cascading use of wood', *Journal of Environmental Management*, 152, pp. 158–170. doi: 10.1016/j.jenvman.2015.01.018.

[6] *c.f.* Mehr, J. *et al.* (2018) 'Environmentally optimal wood use in Switzerland—Investigating the relevance of material cascades', *Resources, Conservation and Recycling*, 131(June 2017), pp. 181–191. doi: 10.1016/j.resconrec.2017.12.026.

products, and participation and integration of practitioners and stakeholders can be organised in different ways.

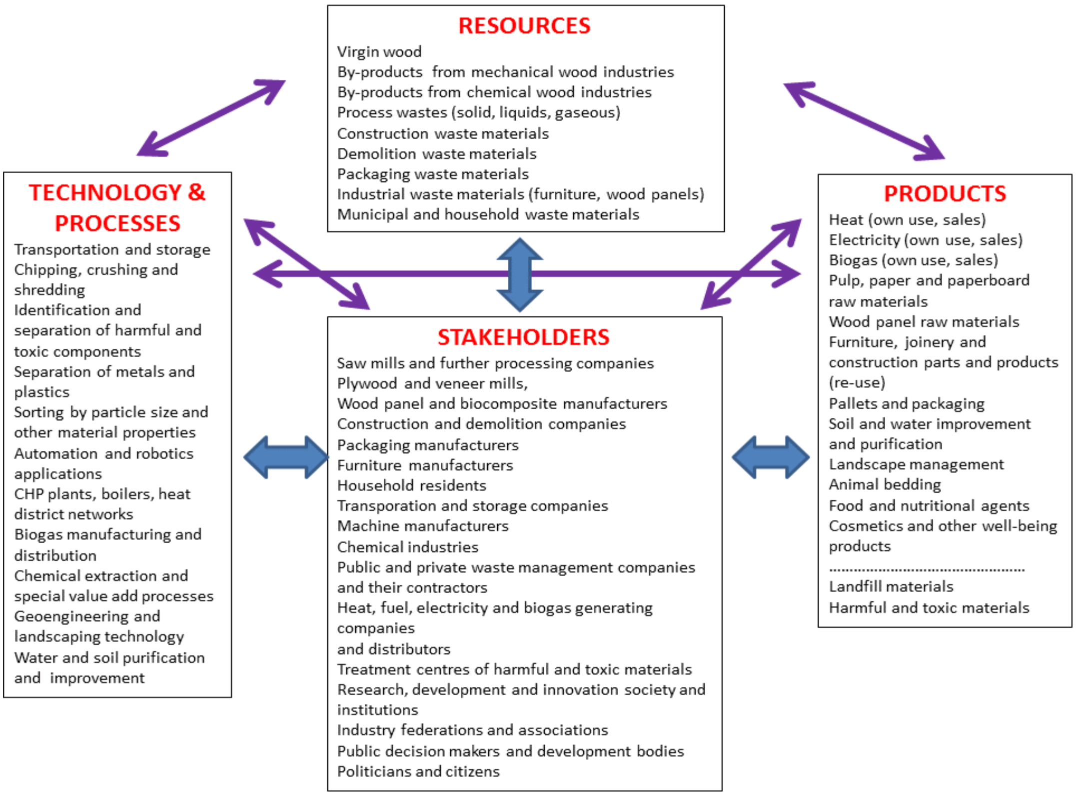

Figure 1 Components of value chain dynamics of wood-based side streams and waste wood.

Joinery, furniture, composite product as well as prefabrication for construction industries need more options to profit from their side streams. Europe's existing markets for side streams and wood waste tend to be reliable for the by-products of primary woodworking industries (sawmills, plywood, and LVL mills), but prices can be vary considerably.

Demand in for by-products from wood panel and packaging industries is increasing, as is it is in chemical industries and for advanced biorefineries for techno-chemical bulk products (e.g., adhesives, surfactants, dispersion agents, liquid fuels) and consumer products with specific functionalities (e.g., foods and nutritive agents, health promoting products, detergents, and cosmetics). The major drivers for these markets are the substitution of fossil-based materials and energy, trends towards bioplastics, prospective lack of virgin wood, and consumer preferences for healthy and sustainable products.

Construction and demolition waste meets more challenges in the market as the target should be more reuse and recycling rather than incineration for energy. Offsite manufacturing (i.e., pre-fabrication) of wooden elements is increasing in construction and minimizes the volume of construction and later demolition waste. Developing recycling options for problematic materials in buildings should be supported, MDF and glass materials as the most crucial now.

Novel products, markets and stakeholders inevitably lead to new supply and value chains, enterprise networks and collaboration, raw material and process integration, storage and transportation logistics and scaling the production at different steps for optimal build-up of industrial ecosystems and value-add. Depending on the region and case, production plants and processing enterprises may form different value chains where the degree of integration, concentration and decentralization varies.

Combining value-add, resource efficiency, renewability and recyclability, sustainability and financing of investments are key issues for the success of woodworking industries and building and living with wood sector in circular economy. Research has generated a lot of innovative showcases for the utilization of industrial side streams from wood product industries, but the problems often lie in their commercialisation, proofs-of-concept, funding availability, investment risks and company commitment.

Cleaning and sorting waste wood. Waste wood from construction, municipal waste collection, and industry is highly heterogeneous in type, shape, quality, and, consequently, recoverability. Several developments are needed to increase the utilisation and added value of recovered wood. For example, the ability to quickly identify contaminants, recognise quality of material (shape, wear, etc.), and determine the optimate recovery path will provide a basis for companies to be able to collect, market, or purchase recovered resources more securely and efficiently. Technological developments are needed in scanning technologies (e.g., spectroscopy to identify contaminants[7], or image processing to determine quality[8]), and the modelling (i.e., machine learning or artificial intelligence) to inform decision making, as well as the operationalisation of these technologies in production lines.

Systemic collection, sorting, and delivery of recovered wood. While emerging and future business models may include collecting used wood-based products for a company's own use and/or upgrading and allocating them to the next user and cycle of use, a systemic approach to ensuring wood products see future service lives as new products and are economically attractive to the members of value network is necessary. This is due to the heterogeneous nature of the material, the spread of collection sites (e.g., building demolition, municipal and private collection facilities, production facilities), lack of centralised sorting and cleaning facilities, and, sometimes, the multitude of competing end-uses and potential practitioners in the value network. Applying logistics optimisation is needed to improve the availability, processing, and utilisation of waste wood at national and regional scales[4]. These reverse logistics models require research at the mathematical and computational levels and in hardware and software technology, but critically need domain knowledge to ensure material characteristics, technical opportunities, legislation, and business needs are included in the models.

Regulation and standardization. Consistent and motivating regulation and support policies are needed for all wood side stream business models. Harmonisation of policies and guidelines across member states – and eventually beyond the European Union - is necessary to ensure transferability of practices, international collaboration and reach, and for material collection schemes to gather sufficient quantities of materials. Companies need stable, predictable and up-to-date regulatory framework conditions to develop their operations and markets for novel products. Clarifying classification of recycled materials is needed to increase the quantities of wood-based and other construction wastes after collection and sorting. *This means adding*

[7] Pigorsch, Enrico, et al. (2014) 'Sorting of waste wood by NIR imaging techniques.' *Proc. Sensor-Based Sorting* : 127-136.
[8] Verheyen, M. *et al.* (2016) 'Vision-based sorting of medium density fibreboard and grade A wood waste', in *2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE, pp. 1–6. doi: 10.1109/ETFA.2016.7733546.

regulatory requirements and investigating the best protocols to upgrade sorting wood wastes for more desirable products and environmentally friendly fractions. Regulations should be developed to support reuse before recycling of materials, for example from wooden buildings, and to be up-to-date with the technical developments of the materials and products. Cost incentive systems should be studied for the development of reuse and recycling, for example, criteria for eco-design, subsidies for waste recovery equipment, etc. Policy and market studies are needed to clarify the regulatory and market situations internationally to provide both policy makers and companies with clear boundaries and guidelines for future developments.

Environmental impact assessments (and their implementation methods like LCA, LCC, EPD, PEFs, etc.) and CE marking are needed for market penetration. They should support alignment with regulations and protect companies and consumers from unexpected disturbance in the market. Quantification of environmental benefits of the actions to improve the circularity properties of any product will help decision makers, companies, and consumers make informed choices. For example, there are incentives that encourage (or require) waste management and recyclability to be accounted for during the pre-planning of construction and demolition projects.

Development work and consultation is needed to find ways proactively form new strategies or procedures when landfill bans or other environmental risk mitigation actions are created. In other words, research and collaboration is necessary for companies to get ahead of environmental strategy actions, rather than reacting to them after implementation. Competing uses of raw material side streams is a matter of discussion between stakeholders and decision makers. The EU's waste management directives set pressure for policies in side stream and demolition waste control, urging the development of new options for recycling in companies.

2.3 Product design & manufacturing

Design for disassembly (DfD). DfD, or when applied to buildings, design for deconstruction and reuse (DfDR) – is a design strategy to simplify the deconstruction of buildings and maximise the reuse of their components by planning for it during the design phase. To simplify the later building deconstruction phase, products and systems must be reversable and should maximise the amount of recoverable material by minimising any damage caused through the disassembly process. Solutions for both individual components (e.g., particleboard) and for systems (e.g., a wall or floor) should be developed or improved to increase direct reuse, recovery, and recycling. Technical developments are needed to overcome challenges related to reversable joints, adhesion, applied coatings, contaminants (i.e., metal components that may not be easily removed resulting in damaged materials), etc. Behaviour change and consumer expectations may be required as well. For example, a disassembly option may result in less building permanence and greater options for adaptation through component change rather than demolition. Supporting product development through research is necessary to achieve this goal, and to measure its effectiveness in climate change mitigation.

Waste reduction. Although wood product manufacturing generally produces little waste, products are often designed without an end-of-life scenario other than waste generation. Both product design and business model change can help to limit the amount of waste generated when products are landfilled. While consumer behaviour may be a limitation in some cases, designing and producing long-life products, or having a system for collecting products at end-of-life will reduce the amount of waste generated. Products may also be designed to simplify repair or services offered to increase repair that extends life.

2.4 Construction systems

Construction and demolition waste. Waste generation on construction sites – during construction, renovation, and deconstruction - is significant in terms of quantity and potentially avoidable climate impact. Reducing waste generation may be minimised through product design, offsite manufacturing of building components, and alternative construction systems. Providing solutions for on-site sorting and collection of wastes can increase the recoverable fraction and provide valuable input materials for manufacturers. New business models (i.e., a service to provide on-site sorting and collection of materials), regulation to valorise second-life materials, and updates general construction practices can help to minimise the quantity of waste destined for landfills. However, research must be conducted to assist in product and service development, and to identify the impact areas than should be addressed as a priority.

Substitution effects. Substituting wood-based products for functionally equivalent products may lead to significant carbon avoidance (displacement factor between 0.27 tonnes of carbon per tonne stored in wood to 1.16 tonnes)[9]. Systematically and accurately assessing substitution effects is limited by methodological incongruencies primarily occurring in boundary conditions and model assumptions. Establishing an agreed model for assessment will assist in fine tuning the amount of carbon avoided and help decision makers in policy making and across the value-chain in selecting processes and products that reduce the environmental impact of construction and products within buildings.

Design for Deconstruction and Reuse. Improving the deconstruction phase of buildings relies on improved product and construction systems during the design and build phases. Achieving a high rate of material reuse following deconstruction would help embed the wood construction sector into the circular economy and alleviate a major source of waste destined for landfills. Many strategies to recovery products in place. However, reuse of construction materials is limited due to lack of demand, building regulations, and limited design standards[10]. Overcoming these barriers requires regulatory change, product development, and behavioural change in both the construction and woodworking sectors.

2.5 Business models, strategy, marketing & management

Circular business models. New business models that supplant those based on a linear economy are needed to transform the woodworking industries. Transitioning between linear and circular models and operations requires greater collaboration between companies, consumers, and regulators to

[9] Hurmekoski, E. *et al.* (2021) 'Substitution impacts of wood use at the market level: A systematic review', *Submitted to Environmental Research Letters*.

[10] Cristescu, C. et al. (2020). Innovative Design for the Future – Use and Reuse of Wood Building Components – Report: 1. *InFutUReWood*. doi: 10.23699/bh1w-zn97

ensure businesses, people, and society all benefit from circular products and materials[11].

The Organisation for Economic Co-operation and Development (OECD) notes five categories of circular business models[12]:

- **Circular supply models.** Focus on closed material loops through cradle-to-cradle design, with an emphasis on a renewable, bio-based, and recovered materials to replace traditional inputs.
- **Sharing models.** Places businesses in the sharing economy – that is shared use of underutilised assets. Sharing is typically supported by dedicated platforms that support joint ownership or joint access. Housing has fit in this category for some time, with time-shared ownership and personal accommodation renting as examples.
- **Product life extension models.** A simple solution, when supported by research and technological development, is to increase the durability of products to extend their service life. Adding reuse and repair operations to further extend service life. The OECD notes that remanufacturing can be included in this category as it adds an "entirely new life to the products".
- **Product service systems models.** Links a physical product with an associated service. The most basic models include additional value propositions to a basic production and sales model, such as included repair or maintenance contracts. Another form of this model is short- and long-term leasing, as is common with office equipment. Perhaps the most innovative form of this type of model is based on results rather than the product or service that delivers them. In this form, the contractual agreement is for the outcome, not the mode of achieving it. The OECD provides the example of ensuring a temperature level in a building, rather than the heating or cooling installation itself.
- **Resource recovery models.** Finally, these models are based on creating secondary raw materials from waste streams. Collection,

[11] United Nations Economic Comission for Europe, (UNECE) and Food and Agriculture Organisation of the United Nations, (FAO) (2021) *Circularity concepts in forest-based industries.* Geneva.
[12] OECD (2019). Business Models for the Circular Economy: Opportunities and Challenges for Policy. Organisation for Economic Co-operation and Development, Paris, France.

sorting, and production are the key elements of these models that otherwise fit into traditional business models.

These business models, and any innovative models that are developed, should be tested at the company, product, consumer, and regulatory level to minimise the risk business take on as they transition from linear to circular models. In addition to the business-oriented research needed to support these models, they point to other research needs: e.g., resource recovery models can benefit from (reverse) logistics research, product life extension models benefit from wood durability research, etc.

2.6 Work & skills

New skills and employee profiles. The circular transition requires a heterogeneous set of skills across all levels of an organisation[13]. Education at all levels must adapt to accommodate these needs from primary through secondary and life-long learning schemes. Most current skills remain relevant, but may need a shift in priority (i.e., from production to maintenance and repair) to fit in new circular business models. Some jobs may simply just receive updated "branding" to align them with circular priorities (i.e., the work of a solar panel installer remains the same, but it becomes circular in the view of prioritising regenerative resources[13]). Circular business models will likely call for new employee profiles, providing opportunities for new careers in the woodworking industries. Employers must be ready for this transition and understand that new skills are required. A comprehensive review of skills needed for new circular business models in the woodworking industries is needed and should be supported by the development of higher education and vocational training programmes.

Innovation readiness. Although some circular solutions are ready for implementation, or are implemented in some firms, many solutions are adopted because companies lack the absorptive capacity to implement them. Absorptive capacity is the capability of a company to implement external knowledge – like innovations – and may be limited by capital availability, cultural aspects, technological capacity, or other factors. Identifying and

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[13] Burger, M. *et al.* (2019) 'The heterogeneous skill-base of circular economy employment', *Research Policy*, 48(1), pp. 248–261. doi: 10.1016/j.respol.2018.08.015.

implementing a means to support companies, especially smaller companies like those that make up a large share of the woodworking industries, to implement innovation and circular practices is necessary to support broad transitions. Support can come from training programmes, collaborative business models that link smaller scale companies together to share the burden of innovation implementation (and to reap its benefits), and technological developments designed to fit within smaller organisations, amongst other solutions.

2.7 Impact assessment systems

Carbon storage and substitution. Environmental impact assessments provide decision makers in business, governmental, and the consumer market with information about the products or solutions they choose. However, current methods do not account for biogenic carbon sufficiently or consistently, creating a deficit of comparable knowledge between products and solutions[14]. Biogenic carbon – the carbon emitted during the transformation or degradation of biomass – when captured from the atmosphere through the growth of natural building materials, like wood, can sequester more carbon in the built environment that was used to produce and transport them. However, the appropriate method for accounting for this value consistently and accurately remains under debate as alternative methods produce significantly different results[15]. Resolving this debate requires both research and development activities as well as evidence-based policy making to implement the most accurate approach.

When methodologies for accounting for carbon sequestration are determined, the substitution effect of replacing non-wood elements in buildings with wood can be accurately determined, and projected. This will allow long-term modelling to support the decarbonisation of the built environment.

[14] Hoxha, E. *et al.* (2020) 'Biogenic carbon in buildings: a critical overview of LCA methods', *Buildings and Cities*, 1(1), pp. 504–524. doi: 10.5334/bc.46.
[15] Garcia, R. *et al.* (2020) 'Accounting for biogenic carbon and end-of-life allocation in life cycle assessment of multi-output wood cascade systems', *Journal of Cleaner Production*, 275, p. 122795. doi: 10.1016/j.jclepro.2020.122795.

End-of-life scenarios for wood-based products. Like the carbon storage and substitution challenge, accounting for material life-cycles beyond their first, is not clearly defined. Different end-of-life approaches, such as cascading, re-use, combustion, etc., produce different environmental impacts that are not well understood. Cascading, for example, shows potential to limit green house gas emissions and increase the available new wood supply significantly, especially for panel products,[16] but it remains unclear how to optimise the end-of-life from an environmental impact perspective.

Data availability. To conduct an impact assessment, reliable and timely data is needed. At the product or company level, this information is generally available, though not always collated in advance. At regional or national levels, material flow and impact data are generally not readily available limiting the accuracy of regional or value-chain level analysis[17]. Impact assessments should be part of both company-level planning and policy-level decision making related to circular practices. To ensure data driven decision making related to circularity, better data should be collected and available.

2.8 Networks, support systems, & RDTI ecosystems

Strategic partnerships. Organising research within relevant sectors to strive for common goals requires the formation of steering groups, national and international agreements, and should result in well-formulated funding opportunities for research topics that are considered to advance the state-of-the-art and implementation in circular solutions for woodworking industries and their value-chain partners. A Joint Undertaking such the upcoming *Circular Bio-Based Europe Joint Undertaking* (CBE JU) is a potential avenue to accelerate research and development activities in the field. However, a similar effort specifically oriented towards woodworking industries should be adopted to ensure the role of wood-based products are maximised in the Europe's circular bio-economy.

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[16] Höglmeier, K. *et al.* (2015) 'LCA-based optimization of wood utilization under special consideration of a cascading use of wood', *Journal of Environmental Management*, 152, pp. 158–170. doi: 10.1016/j.jenvman.2015.01.018.
[17] Virtanen, M. *et al.* (2019) 'Regional material flow tools to promote circular economy', *Journal of Cleaner Production*, 235, pp. 1020–1025. doi: 10.1016/j.jclepro.2019.06.326.

At the organisational level, identifying strategic and development partners for common work on projects, consortium building, and proposal preparation can boost the chances for success in terms of funding received, but also in the eventual upscaling and commercialisation of the results.

Organising research work at the international level can be difficult as countries provide different levels of incentives and differing priorities. However, researchers can self-organise to harmonise work, transfer knowledge, and share resources. The European Cooperation in Science and Technology association (COST)[18] funds network building, training schools, and research visits within Europe and amongst partner countries. Organising a COST Action focused on circularity in woodworking industries is recommended to accelerate international cooperation, strategic development towards common goals, and transfer knowledge between actors internationally.

To develop and support the utilization of wood-based side streams as a part of a local economy, especially in rural areas, steady collaboration between Triple Helix actors should be supported. Local wood supply, use of local species and competitive offers to substitute long distance imports may be useful options to investigate with the goal of increasing local use of side streams and waste.

2.9 Social acceptance, perceptions, & preferences

Consumer preferences and acceptance. In both product design and business model creation, consumers must be involved as critical stakeholders. Doing so by engaging behavioural research related to intention to participate in business models can provide unexpected insights, like the limited value of ownership, emphasised preferences for take-back schemes, and the need gradual transitions to change consumer habits effectively[19]. Similarly, engaging in best practices for stakeholder involvement from other fields, such

[18] https://www.cost.eu

[19] Elzinga, R. *et al.* (2020) 'Consumer acceptance of circular business models', *Journal of Cleaner Production*, 254, p. 119988. doi: 10.1016/j.jclepro.2020.119988.

as goal modelling in requirements engineering for software development[20], or by implementing co-design practices[21].

Changing role of the consumer. Waste mitigation may be as important as any steps to better utilise waste[22]. This duty falls on both the manufacturer and consumer. Changing consumption patterns that limit the production of waste by consumers by providing simple alternatives to discarding used items requires consumer buy-in, new business models, and likely supporting legislative frameworks.

2.10 Summary of priorities

The priority areas of research are summarised in Table 1 and are annotated with the current status of RTDI activity, and the priority level.

Category	Recommendation	Status	Priority
Waste reduction & side stream utilisation	Collaboration models to increase the use of side stream should be investigated, described, and best practices transferred to other regions or sectors.	Some co-location cases appear promising. Horizontal integration known to be effective.	Medium
	Material cascading systems can be improved to increase the reuse of solid materials before downsizing materials. Investigations into collection and sorting methods to	Effective in panel products market, especially particleboard.	High

[20] Taveter, K. *et al.* (2019) 'A Method for Eliciting and Representing Emotional Requirements: Two Case Studies in e-Healthcare', in *2019 IEEE 27th International Requirements Engineering Conference Workshops (REW)*. IEEE, pp. 100–105. doi: 10.1109/REW.2019.00021.
[21] Blomsma, F., Pigosso, D. C. and McAloone, T. C. (2019) 'A theoretical foundation for developing a prescriptive method for the co-design of circular economy value chains', *Proceedings of the International Conference on Engineering Design, ICED*, 2019-August(August), pp. 3141–3150. doi: 10.1017/dsi.2019.321.
[22] Jarre, M. *et al.* (2020) 'Transforming the bio-based sector towards a circular economy - What can we learn from wood cascading?', *Forest Policy and Economics*, 110(August 2018), p. 101872. doi: 10.1016/j.forpol.2019.01.017.

	maximise reuse of larger components is needed.		
Waste management & logistics	Optimise municipal and production site waste sorting using sensing technologies (e.g., near-infrared scanning) to support separating high value woody materials	Some practical testing and limited deployment in other applications	High
	Build collaborations between wood users to provide a user base of recovered wood to support collection and delivery systems	Implemented nationally, needs upscaling	High
	Optimise cross-border waste transfer systems using reverse logistics	Conceptual, limited application in other fields	Medium
Product design & manufacturing	Ecodesign solutions that include built-in recovery schemes	Implemented, needs upscaling, transfer	High
	Design for disassembly / deconstruction can be better applied to building products and systems to result in improved reusability of building components.	Some useful methods employed. New product and system developments needed.	High
	Minimise waste generation – the Reduce component of the 3/9 R scheme – through improved manufacturing and building strategies. Offsite manufacturing is promising. Detailed assessments of	Offsite manufacturing is an established practice and can minimise waste	High

	impacts are needed as well as transfer of best practices.	generation. Transfer of best practices needed	
Construction systems	Construction and demolition waste can be minimized through novel construction systems and mitigated through new business models that collect, sort, and valorise waste as it develops on site.	New systems and business models bust be developed and tested. Offsite manufacturing has high potential.	High
	The substitution effects of using wood in products to replace fossil-intensive products is a promising, if under evaluated, solution. Research is needed to support product development and to advance assessment methodologies.	Studies exist with limited case studies or larger market evaluation.	High
	Design for Deconstruction is a promising approach to reduce end-of-life waste, yet many regulatory, product, and market challenges remain.	Several promise cases, but long-term evaluation remains theoretical or limited.	Medium
Business models, strategy, marketing, & management	Circular business models are emerging and being tested. Applying these within the woodworking industries can advance the sector. Novel models specific to wood should be investigated.	Cascading is well established within the subsets of the sector. Valorising this process	High

		through new business models and finding other circular approaches to wood use remain elusive.	
Work & skills	New training and reskilling systems must be developed to help companies transition.	Higher education programmes are beginning to teach about the circular economy, but vocational training must be available as well.	Medium
	Innovation is necessary to adapt to circularity, yet few companies have the capacity to fully integrate new solutions and approaches. Models for collaboration may help smaller firms adapt to the circular economy.	Collaborative business models remain scare in practice, and especially within the wood sector.	Medium
Impact assessment systems	Methodological advance and agreement are necessary to accurately reflect the carbon storage and substitution effects of replacing fossil-intensive products with wood-based solutions.	Several accounting methods exist and must be reconciled or innovated upon to help decision makers.	High

	Accounting for different end-of-life scenarios for wood products should be accurately reflected in impact assessment methodologies. Research and adoption of evidence-based solutions is needed.	Consistent accounting methods are not yet determined.	High
	To accurately assess environmental impacts, reliable data is required. Companies should be incentivised to collect this data and to share the data (within reason) for more accurate assessment.	Both company-level and policy-level action is required improve data collection and availability.	High
Networks, support systems, & RTDI ecosystems	A strategic approach is required to enhance collaboration. Several options are available and should be more widely adopted.	Joint Undertakings, COST Actions, and organisational-level involvement in networks exist, but focus on circular use of wood is necessary to advance the field.	High
Social acceptance, perceptions, & preferences	Consumer demand for low-impact products seems to be growing. However, there is limited knowledge about consumer acceptance	More use case assessment is needed.	Medium

	related to recovered wood products or participating in new business models based on circular wood use.		
	Consumers have a role in circular use of materials, and that role is likely to disrupt the conventional use pattern for products. Therefore, it is critical to involve consumers in the co-design process of new products, services, and business models.	Co-design approaches exist and may be adapted to suit this purpose well. Limited studies are available on outcomes.	High

3 Related Outputs

The New European Bauhaus (NEB), a mechanism for reshaping Europe's approach to construction and building use within the EU Green Deal, has been taking shaping during 2021. The WoodCircus project and some of its consortium members have joined the NEB. Amongst these partners and others, the Wood4Bauhaus initiative was launched, which was initiated with a well-received conference on the role of timber in the NEB. This event resulted in requested contributions by EC from the Wood4Bauhaus alliance. One of the requested contributions were recommendations for research topics to advance the role of nature-based materials, like wood, in the NEB. Those recommendations were jointly created by WoodCircus consortium members and other contributions. Some recommendations included a focus on circular practice. The recommendations are attached in Appendix 1.

WoodCircus deliverable D2.2, *Resource efficiency, side streams, and value chain analysis*, identified several research and development needs as well. Those are reflected in this document, but provide additional insight into subject, particularly making suggestions related to specific strengths and weaknesses identified in that deliverable. Those items of note that supplement, rather than repeat, the recommendations in this document are:

- Promotion of holistic sustainability and further development of green building chains is need. Holistic sustainability approaches must address economic, ecological, social, and cultural aspects.
- Supporting system-wide performance increases in addition to targeted support for within-system aspects. This must include cross-border and triple helix collaboration.
- Consistent and predictable regulations and policy frameworks should focus on harmonization across member states, consistency between impact assessment tools and regulations, limit disruption in consumer markets, and support (continuing) education changes to help companies adapt to circular approaches.
- Policy framework must consider economic incentives for companies that don't increase the economic burden on consumers. Societal thinking is needed to optimise incentives in this way.

4 Conclusion and General recommendations

Research, technology, development, and innovation are the drivers of change needed to fully support the woodworking industries transition to the circular practice, and for them to become leaders in Europe's circular bio-economy. The WoodCircus project has analysed the woodworking industries across Europe as a whole and within four macro-regions to identify the existing best practices, assess performance, find transferrable solutions, and to shape policy recommendations. In doing so, the project identified several gaps that can be addressed through target and collaborative RTDI actions. The recommendations provided in Table 1 summarise the most urgent needs for the sector and the support required from policy makers. Resolving the knowledge and performance gaps can propel the woodworking industries into exemplary actors in the circular bio-economy, but technology and innovation adoption may be a limiting factor, even as solutions emerge from the RTDI process. Collaboration between actors is crucial to ensure both that solutions are developed for critical issues and that they can be adopted by industry.

Looking towards 2030, 2040, and beyond ongoing assessments will needed to identify emerging and insufficiently resolved gaps. Researchers, policy makers, industry members, and the public should engage in on-going communication and discussions to discover, highlight, and resolve challenges faced by all stakeholders to solidify circular bio-economy in Europe.

In the end, policy makers must provide a framework to support the transition justly and efficiently. Researchers and industry members must engage in policy making work to assure the implementation of the of the circular economy follows scientific evidence and addresses the practicalities faced by industry. The WoodCircus White Paper 2040 makes several recommendations for all stakeholders to ensure the woodworking industries become leaders of the circular bioeconomy in Europe. That document is available in 11 languages and is reported in WoodCircus deliverable D6.2. The White Paper can be found on the WoodCircus website.

5 Appendecies

Appendix 1: RTDI recommendations delivered to New European Bauhaus decision makers June 2021.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 820892.

wood4bauhaus

Wood Sector Alliance for the New European Bauhaus

Brussels, 26 May 2021

Research Needs and Priorities supporting *Sustainable Construction with Organic Materials* under the European Green Deal

There is a clear need to close scientific gaps in organic materials and building research to accelerate the transformation of the construction sector. Organic materials, like wood, have a high potential for climate change mitigation, societal impact, and are prime candidates for greater research and innovation support related to the construction sector. Areas of key importance are:

1. **NOVEL AND ENHANCED CONSTRUCTION SYSTEMS for carbon-positive, long-life organic materials and building products** to boost and move the market towards more diversity, higher circularity and affordable solutions. Key topics include: hybrid, modular and novel construction products and systems, maximizing lightweight and insulation properties, design for disassembly and conversion of the building stock to material storage banks, (engineer from buildings back to resources and novel uses: reversible joints and structures, fire safety, alternative and undervalued tree species, wood modification, industrial upscaling, interior uses, standardization (Eurocodes) and building regulations.

2. **CIRCULAR ECONOMY solutions fostering repair, reuse and recycling and tackling waste and environmental issues in the sector**. Key topics include: Circular Design, assessing the life span of construction materials, long-life products and enhanced durability, resource and material efficiency, fossil-free, reversible adhesives for load-bearing structures, reverse logistics, waste wood and urban mines, cascade use of materials, valorisation of by-products and side streams, life cycle of buildings, incorporating the Circular Economy of functionalities and new business models into the construction sector.

3. **DIGITALIZATION and Industry 4.0 as key lever** to overcome barriers faced by the SME-dominated sector and to support circularity. The goal is to connect entire value chains from resources to manufacturing, customers and users through end-of-life phases. Key topics include: material traceability, resource use optimization (from product to landscape and market level), digital twins/digital design (materials, systems), automation in prefabrication, organic sensing, logistics and value chain networks, novel platforms and business models, building information models (BIM), intelligent buildings, digital hubs.

BASAJAUN and WoodCircus received funding from the EU Horizon 2020 research and innovation programme under grant agreements no. 820892 and 862942.

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4. **INTERDISCIPLINARY research and co-creation to break down silos, achieve a holistic perspective and widen societal impacts.** Putting users in focus in all key topics: human health benefits through comfort, wellbeing and productivity enhancements, architecture and urban space, aesthetics, biomimetic/ biophilic design, recovery of traditional knowledge/skills and cultural heritage, the creative sector, open innovation testbeds, citizen science.

5. **FAIR AND INCLUSIVE European Research Area for the sustainable built environment** to overcome regional and rural-urban divides and unbalanced representation in research excellence and innovation capacity of organic materials. Key topics include: affordable solutions, proactivity for gender diversity in STEM, inclusive and participatory design, Teaming with Widening countries especially Central-Eastern Europe, mobility actions for capacity building, transdisciplinary higher education programmes, upskilling and Dual Learning of the sector workforce, internationalization of the R&I ecosystem.

We advocate for a **EUROPEAN JOINT COORDINATION GROUP** for our R&I ecosystem to gain critical mass and scale for joint action and overcome fragmentation of the stakeholder landscape. The main purpose is i) to engage the ***industrial construction sector***, ii) to co-create with ***Partners of the New European Bauhaus*** especially in the areas of architecture, design and urban transformation, and iii) to link to ***European Partnerships under Horizon Europe.*** Although none cover the entire value chain in a comprehensive manner, these partnerships can strengthen the role of organic materials in the New European Bauhaus: Build4People (conventional construction sector), Made In Europe (manufacturing industries), DUT Driving Urban Transitions, CBE Circular Bio-based Europe (biobased products/ biorefinery), Rescuing Biodiversity. A first step has been made with the foundation of our Wood4Bauhaus Alliance. This group intends to partner up other European key actors and initiatives, such as the Forest-based Sector Technology Platform (FTP) and more industrial representatives.

It must be noted that we have excluded research needs regarding the supply side of organic materials, e.g., ecosystems, forestry, wood markets. They represent another important domain with its own major challenges but has strong links to the construction ecosystem.

We wish to highlight that the scientific community and the innovation system in the field of organic materials are very heterogeneous and include numerous groups and diverse domains. The disciplines involved range from genetics to ecology to material science and engineering, and related fields such as health, social sciences and ICT. The solutions studied address hundreds of species, materials, products, applications and end-uses. This creates a structural disadvantage to compete successfully in European calls for proposals against large established sectors with greater political visibility.

INNOVAWOOD EUROPEAN PANEL FEDERATION EIB EOS European Federation of Building and Woodworkers BASAJAUN wood CIRCUS

BASAJAUN and WoodCircus received funding from the EU Horizon 2020 research and innovation programme under grant agreements no. 820892 and 862942.

We also note that many of the topics are underrepresented or are missing a clear focus on organic materials in construction in the Horizon Europe work programmes. While forests and forestry are well represented, construction with organic materials requires extra attention. Several relevant calls are included, yet the opportunities for organic materials in buildings appear to be too few to drive the research advances needed. Even if various call topics target the built environment, only a few projects on organic materials can be successful under these calls. It is questionable if these will be sufficient to deliver the desired impact necessary to trigger a decisive transformation within the construction sector.

This underrepresentation is also true for other funding lines: ERC grants have no domain appropriate for wood science/building science, thus limiting the incentive to pursue breakthrough basic science in the field; the EIC lacks a challenge focus to support sustainable construction, despite its relevance to climate mitigation.

In the following, we highlight a selection of relevant Horizon Europe calls that may be suitable for this R&I community and the NEB challenges. A more extensive and comprehensive review of the upcoming calls is under preparation. We have identified over 75 potential calls for our R&I community, where the role of organic materials for carbon storage and substitution of fossil materials is not emphasized sufficiently or barely referred to at all.

In conclusion, the Wood4Bauhaus Alliance advocates for a level playing field for organic materials in European research programs and policy. Organic materials can meet the urgent challenge posed by climate change, enhance the implementation of the EU Green Deal, and lead the way towards a more beautiful and sustainable built environment through the New European Bauhaus.

BASAJAUN and WoodCircus received funding from the EU Horizon 2020 research and innovation programme under grant agreements no. 820892 and 862942.

Relevant upcoming Horizon Europe Calls: a few examples with comments

HORIZON-CL6-2022-CircBio-01-06. Strengthening the European forest-based research and innovation ecosystem (4M€/project). *Keywords in call text*: forestry and forest-based sector, overcome fragmentation, biodiversity and bioeconomy issues, renewable building materials for healthier living, EU network of research funding and research policy organisations, assess potential flagship projects.

Comment: Important call for forest research to form a Horizon Europe Partnership. It could support partially the setup of the European Joint Coordination Group (see point 6). Renewable building materials and wood products are considered under "assessment of flagships", however, the built environment is not specifically mentioned. Connecting with market actors is not explicit. This raises the question if the budget allows for significant tasks targeting the construction sector. Topic scope and budget could be enlarged to make sure of this.

HORIZON-CL4-2021-TWIN-TRANSITION-01-05. Manufacturing technologies for biobased materials (4-6M€/project). *Keywords in call text*: innovative biobased products to substitute traditional materials with high environmental footprint; multidisciplinary research field combining engineering, physics, chemistry, biology, material science; easy to reuse and recycle; construction, food, medical, packaging and textile industries, composite, circularity by design, EP Made in Europe.

Comment: Interesting call considering construction offering fair chances (4-5 projects to be funded). However, three different manufacturing chains need to be covered by one project. Organic materials are not referred to explicitly; biobased is not specific enough.

HORIZON-CL4-2022-RESILIENCE-01-16. Building and renovating by exploiting advanced materials for energy and resources efficient (5-7M€/project). *Keywords in call text*: Building envelopes and renovation materials, new materials, innovative retrofitting, new insulation materials, "green" construction, sustainable building materials, circular design, self-sustaining buildings, Open Innovation Testbeds, EP Built4People.

Comment: Clearly interesting call for high-end facades and advanced renovation solutions. Relevant for wood panels and hybrid solutions. Limited opportunity for solid wood products/ mass timber or affordable solutions.

HORIZON-CL4-2021-RESILIENCE-01-04. Developing climate-neutral and circular raw materials (12M€/project). *Keywords in call text:* raw materials recycling, urban mines, wood- and rubber-based, construction and forest-based raw materials, wood-based panels, Critical Raw Materials (CRM), waste electrical and electronic equipment (WEEE), multi-material paper packaging, industrially- and user-driven multidisciplinary consortia, exploitation and business plans.

Comment: Very interesting call for sizeable projects with industry. Explicit focus on waste wood recycling included, among others. High competition expected as only three projects can be funded.

BASAJAUN and WoodCircus received funding from the EU Horizon 2020 research and innovation programme under grant agreements no. 820892 and 862942.

HORIZON-CL5-2022-D4-01-02 Renewable-intensive, energy positive homes (4-6M€/project). *Keywords in call text*: new constructions and renovation of cost-effective energy positive, climate neutral residential buildings, affordable and efficient construction materials, BMS/BAS, Built4People

> *Comment*: Strong focus on energy efficiency and cost-effectiveness mainly through smart technologies. Materials are mentioned as one bullet point out of nine. Doubtful that organic materials can play a larger role.

HORIZON-CL6-2022-CIRCBIO-02-01-two-stage: Integrated solutions for circularity in buildings and the construction sector (6-8M€/project). *Keywords in call*: waste prevention/ recovery, lifetime extension, lifecycle performance of buildings/ components, disassembly, digital logbooks, upgradability, durability, material efficiency, dismantling, recyclability, BIM, PEF, New European Bauhaus

> *Comment*: Very relevant call that can demonstrate the performance of organic materials.

HORIZON-CL4-2022-RESILIENCE-01-20: Climate Neutral and Circular Innovative Materials Technologies Open Innovation Test Beds (10-12M€/project). *Keywords in the call text*: Green Deal Strategy, clean products and materials, large-scale deployment and demonstration across sectors and across the single market, SMEs, open innovation

> *Comment*: Potentially suitable call to foster exploitation and uptake of R&D results and innovations from climate-friendly materials into the broader industrial sector. However, organic or biobased materials are not referred in any way.

HORIZON-CL2-HERITAGE-2022-01-04. Traditional crafts for the future: a new approach (3.5-4M€/project). *Keywords*: traditional craftsmen techniques, traditional artefacts encompassing the full range of materials (stone, ceramic, metal, wood, fabric, paper/papyrus, etc.), vocational training, curricula, entrepreneurship skills.

> *Comment*: Interesting call to revalorize traditional craftsmanship knowledge. Only two projects can be funded and are asked to cover the whole range of materials. Limited possibility to create significant impacts with organic materials.

BASAJAUN and WoodCircus received funding from the EU Horizon 2020 research and innovation programme under grant agreements no. 820892 and 862942.

Background information

The European Commission's New European Bauhaus calls for a creative, interdisciplinary, novel movement embedded in society to imagine a **sustainable** future together and to engage on a transformative path towards **affordable** and **beautiful** living spaces in urban and rural environments. A key step is the transformation of the building sector into a circular model that can also counteract the escalating climate crisis. This transformation requires prioritised research in the use of organic materials in buildings.

The Wood4Bauhaus Alliance's main objective is to shape a better and sustainable future with beautiful, healthy and inclusive living, working, and learning spaces as part of a sustainable, low carbon-built environment. Our platform shall foster an open, long-term dialogue with all interested stakeholders and help share good practices related to the Circular Economy and Green Buildings. Our goal is to inspire as many actors as possible to co-create and develop contributions to the New European Bauhaus from European to regional and local level, all in the common interest to advance and exploit as much as possible nature-based materials, innovative building systems and smart solutions to mitigate climate harm and benefit European citizens. The Alliance will therefore:

- Encourage research and innovation for novel and innovative uses of wood in the built environment,
- Foster new collaborations and co-creation between different stakeholders across disciplines, sectors, and society, and
- Facilitate knowledge sharing and skills development especially towards future generations.

The Alliance comprises the following partners:

InnovaWood is EU network for wood science, research, innovation and education of 60 organisations in 28 countries, including RTOs, universities, VET centres and cluster organisations.

The European Confederation of Woodworking Industries (CEI-Bois) is an umbrella organisation of 21 European and national organisations from 15 countries backing the interests of the entire wood sector.

The European Panel Federation (EPF) represents 100,000 direct jobs and counts more than 5,000 wood-based panel manufacturing and furniture companies in 25 countries.

The European Federation of Building and Woodworkers (EFBWW) is the European Trade Union Federation grouping 76 national free trade unions from 34 countries with members in the building, building materials, woodworking, forestry and allied industries and trades.

The European Organisation of the Sawmill Industry (EOS) represents 35,000 sawmills in 12 countries.

The InnoRenew CoE is a new research centre in Slovenia focused on sustainable construction with renewable materials. It was founded with support from Horizon 2020 Widespread-2-Teaming grant no. 739574.

BASAJAUN and WoodCircus are R&D project consortia fostering sustainable wood supply chains from forest harvesting to final buildings and Circular Economy solutions in the sector. They have received funding from the EU Horizon 2020 research and innovation programme under grant agreements no. 820892 and 862942.

Contact: info@wood4bauhaus.eu | Web: wood4bauhaus.eu