SA Forestry Centre of Excellence (FCoE) - from Vision to Reality

by Rupert Wimmer, Austria (update 16 September 2023)

Content

1. Introduction

The South Australian Government has committed budget over 10 years to establish a Forestry Centre of Excellence (FCoE) in Mount Gambier, SA. The FCoE should deliver global leading research, development and education, to enhance the competitiveness, diversification and prosperity of the Green Triangle regional economy and communities, while building overall resilience in the Australian forest industry. In July 2023, Rupert Wimmer, full professor in wood science and technology, Vienna, Austria, has visited Uni SA campuses at Mawson Lake, as well as at Mount Gambier, under the UniSA Visiting Research Fellowship Program, with financial contribution of the Green Triangle Forestry Hub. As an outcome of that fellowship visit the following observations, ideas and recommendations are documented.

2. Essential research, criteria and setups

2.1 Vision and Objectives

A vision has been stated, which is "**be the national leader in research for the growing and processing of radiata pine, possibly also blue gums and other species.**" The envisioned leadership should be delivered **in partnership with other Australian and international institutions and researchers**. To achieve this vision, a focus on knowledge domains that are commercially critical to industry is essential. Priorities have been outlines for the following criteria, including **(1)** demonstrated industry support, **(2)** training of researchers, **(3)** research experience, skills and capability, **(4)** collaboration/connection with others, and **(5)** competent administrative support. The focus of the newly established FCoE will be (1) **Innovation**, by identifying new technical and organizational solutions to meet customer needs, (2) **collaboration**, which is partnering with industry and other service providers, (3) **people**, which is on developing team capacities, (4) **quality**, reflected by excellence, results and adoption, and (5) **environment**, i.e. being safe, healthy, environmentally, socially and ethically responsible.

The FSoE needs to be pivotal by the following entitlements:

- Understand industry research priorities and needs
- Having skills and experiences that are currently insufficiently present in the forest industry, o they don't exist at all.
- An established research team at a critical mass (about 20-30 people) having a clear excellence profile
- Running projects jointly developed with industry, and for industry, with demonstrated industry contributions

2.2 Secured funding

Apart from the 10-years **commitment** by the South Australian Government to establish the FCoE, the Australian Government also committed itself to invest in the forest and wood products industries' research and innovation capacities, to deliver Australian-made solutions to national challenges. Under the operational name of "Australian Forest and Wood Innovations" (AFWI), over $100 million in funding are devoted between 2023 to 2026-27. It is envisioned to have then three regional research centres, which will undertake forestry research and development, with one centre among the three being potentially the FCoE.

2.3 Long-term sustainability

Experience has shown that only long-term dedication delivers lasting results for industry and society. This long-term dedication is understood by the FCoE funding providers, which constitutes high chances to **deliver sustainable growth for industry and society**.

2.4 Research focus areas

Research areas are defined, as part of any further business planning. As an outcome of the many industry and institutional visits done in July 2023, the following five research areas are identified. Each research area should be led by a scientist at the senior level (Figure 1):

Figure 1: Research areas suggested for the FCoE. These five research areas reflect core needs of the existing industry setting of the greater Mt Gambier region.

2.4.1 Area 1: Forest Quality Systems

This research area is about **plantation tree growth**, primarily radiata pine, but also blue gum and other hardwood species. Area 1 covers topics as shown in Figure 2, and they are ranging from forest management, wood quality aspects, plantation water use, land-use conflicts, forest health topics and biosecurity (Figure 2).

Figure 2: Area 1 – Forest quality systems – proposed research themes

In this area, a core competence needs to be the assessment of **wood quality** at the standing tree level, **predicting potential suitability for future products**, using rapid evaluation instruments such as the "Resi" tool (Figure 3), Near Infrared spectroscopy, or devices that are able to sense growth stresses (as relevant in eucalypts). Area 1 should include a focus on "**lesser known wood species**", which refers to commercially lesser-used/unused species, by looking at various quality aspects and growth conditions, extractive contents, structural characteristics, kiln drying properties, or the suitability for various chemical and physical modification trials.

Figure 3: Fast evaluation of wood quality at the standing tree level, using the “Resi” tool (© Geoff Downes, Forest Quality Ltd)

Area 1 requires the buildup of competences in general **wood anatomy**, using light microscopes and microtomes. Work on different types of mechanistic **models**, i.e. tree growth or cambium models, as developed by Dr. Geoff Downes, are of interest as well. Area 1 could accommodate human interaction projects, including health & safety issues that potentially occur with the plantation-workforce (contact: Dr. Jill Dorrian). The understanding of **inner features in tree logs** through scanning and modelling is important to improve and optimize the quality outcome of trees grown in plantations (Figure 4).

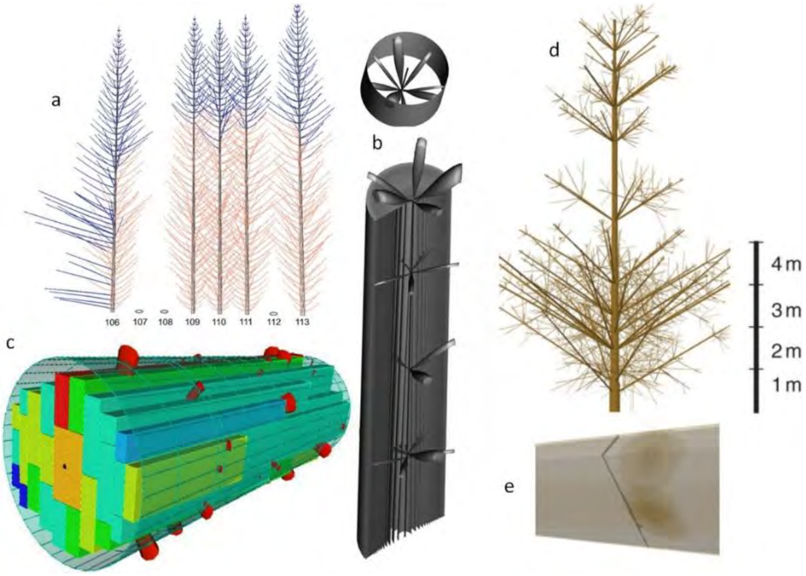


Figure 4: Example of the dynamic branch model for Norway spruce, showing inner features (branches) (a) three-dimensional representations of predicted branches in *Pinus radiata* (b) predicted branching in a sawmilling simulation (c) Simulated five-year-old P. radiata branches and form in a modelled tree (d) and converted to knots in a simulated board (from Drew et al. 2022).

2.4.2 Area 2: Industrial Engineering and Construction

This research area is concerned with aspects that take place with industry production processes, and with wood used in construction (Figure 5).

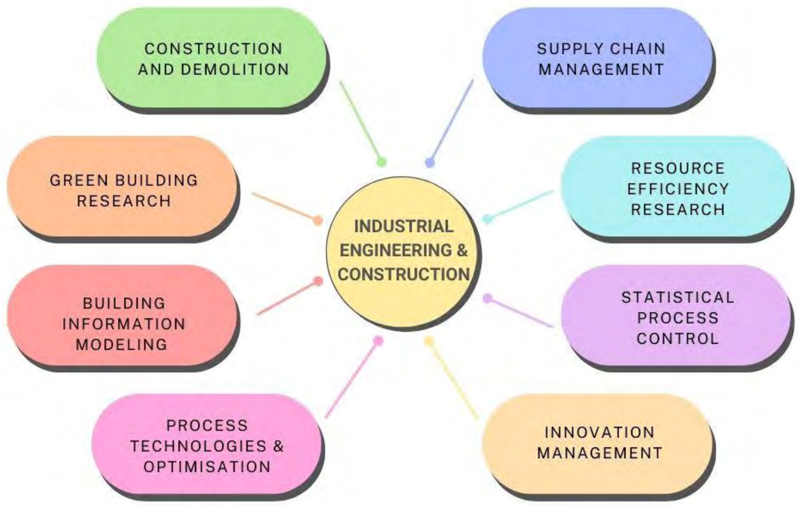


Figure 5: Area 2 – Industrial engineering and construction – proposed research themes

At the fundamental level, supply chain management should be related to this area, which is the management of the flow of goods, data, and finances, as linked to products or services. The forest-based industry has a proven track record in high resource efficiency. Along the entire value chain, data to identify losses and low-value sidestreams are crucial. For example, CLT is the most important product for mass timber buildings, however, resource efficiency can be rather low, with a wood material need of almost 3 m^3, to obtain 1m^3 of CLT, as a recent study shows (Figure 6).

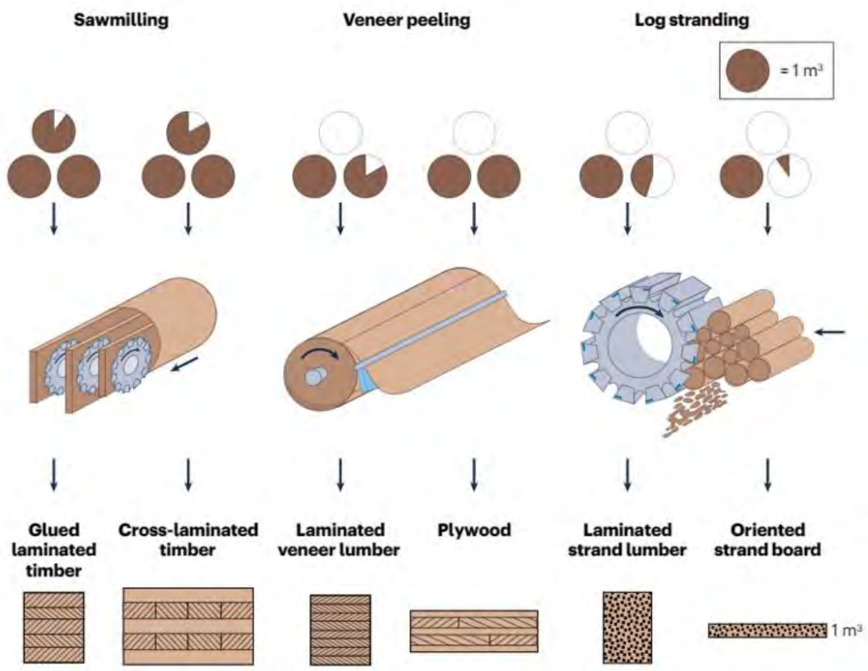


Figure 6: Resource demand of engineered wood products. Estimated amount of roundwood (without bark) required to produce 1m3 of product. Here CLT is the most resource demanding product, while OSB is the lowest. (from: Pramreiter et al. 2023)

The use of **residues** from raw material processing such as bark, chips, or sawdust, to manufacture e.g. panels or other products, with the reduction in specific water and energy consumption in various processes have constantly increased since the 1990ies. For example, bark can be a resource for various products, such as wine-cooler, or insulation panels (Figure 7). Actual **developments** of such materials should belong to Area 3.

Figure 7: Wine-cooler made from tree bark (from the start-up company https://www.getraenkekuehler.at/) (Left), Insulation panel made from tree-bark (from https://baubiologie-magazin.de/baumrinde-als-daemmstoff-der-zukunft/) (right)

Wood supply is limited, sparked with land or water-use conflicts, and the public acceptance of plantations, which increasingly requires **resource efficiency** in the area of raw materials. Efficiency in processing is improved through process technology optimization, also with applying statistical process control methods. Area 3 needs also a clear focus on **innovation management**, which is the combination of the management of innovation processes, and change management. In a broad sense, innovation management refers to product, business process, marketing and organizational innovation. As for the construction side, major topics are **green buildings**, with e.g. light-frame constructions, building information modeling (BIM), also construction and demolition (Figure 8). As the construction sector continues consuming globally around one third of already limited resources, the shift to more **sustainable building** and closed material loops becomes increasingly necessary, which goes hand in hand with **decarbonisation**.

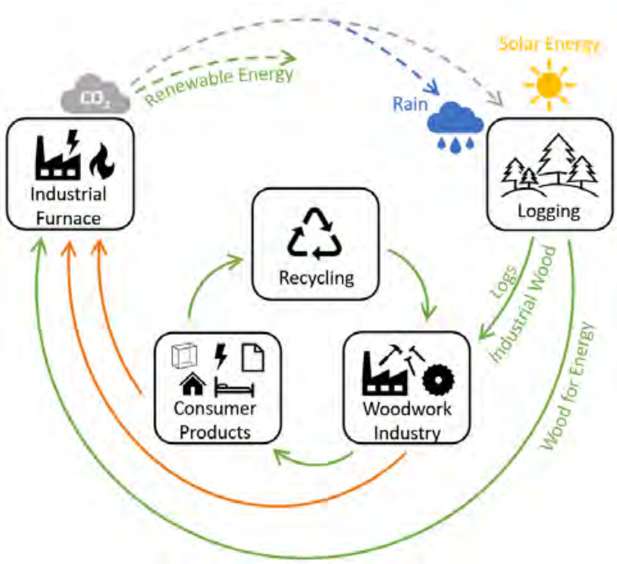


Figure 8: Circularity in the building sector using wood-based materials (from: Kromoser et al 2022)

2.4.3 Area 3: Wood-based Materials

This research area could be the most **comprehensive** one, in terms of infrastructure and budget needs (Figure 9). It **covers a broad range of wood-based material research**, from physical-mechanical properties of small and full-size samples, to research on engineered wood products, including particleboards, fibreboards (MDF), to (some extent) CLT, Glulam, and/or also plywood.

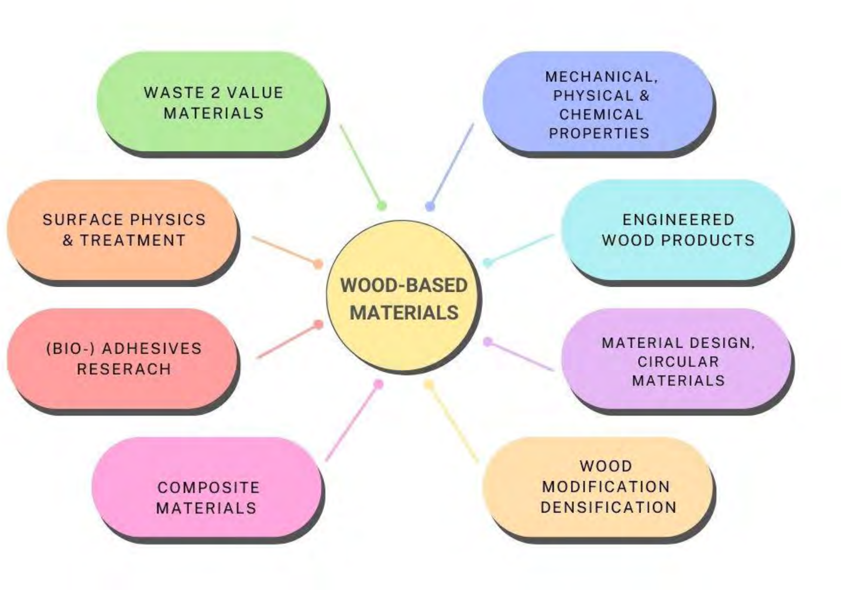


Figure 9: Area 3 – Wood-based materials– proposed research themes

With respect to **engineered wood products**, a research project could look at alternative CLT fasteners, to avoid the use of adhesives. For example, CLT fastened with dowels with hardwoods (eucalypts) could be of interest (Figure 10).

Figure 10: Spruce cross-laminated timber, fastened with dowels made from beech wood, © Thoma, Austria

Circular materials are becoming increasingly relevant. In general, circular materials could be any type of materials, including plastics, natural fibers (wood), or metals. Criteria are that the material has be recovered from their use-phase, it has to be successfully collected, sorted, reprocessed, and is ready for the next life-cycle to from a new product. Materials shall circle in one of the two cycles (**biological and technical cycle**; cradle to cradle concept, see Figure 11). Wood has actually the potential to circle in both circles, i.e. first in the technical cycle, and at the end in the biological cycle. In the **“cradle to cradle” design concept** the term “waste” actually becomes obsolete. There is a need for intensive research towards **full circularity**, and it requires **Design for Disassembly** (DfD). DfD is particularly applicable when considering wood-based structural framing systems, as found in many residential and commercial buildings (Figure 12).

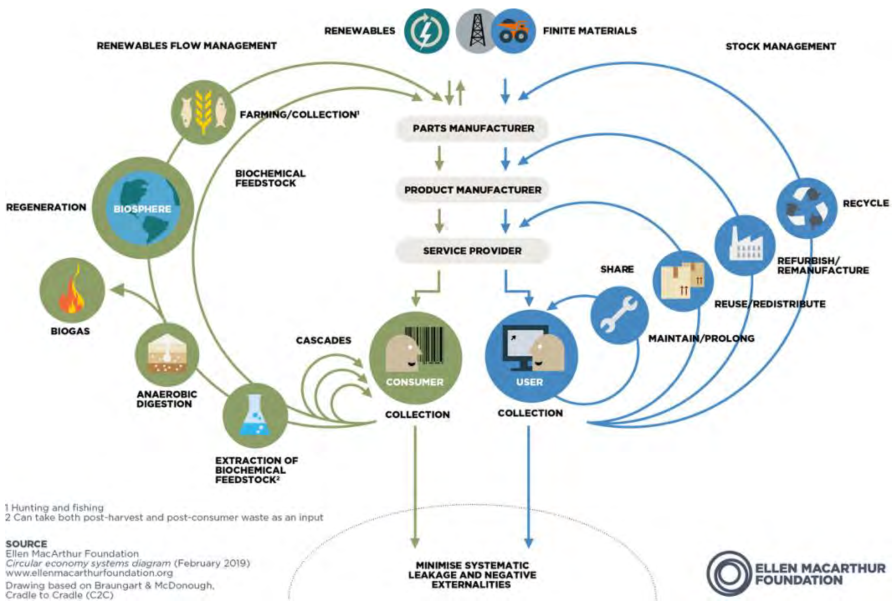


Figure 11: Materials circle in two cycles: (1) the biological cycle (left), and (2) the technical cycle (right). This is derived from the "Cradle-to-Cradle" design concept (Ellen MacArthur Foundation, Braungard & McDonough 2009).

Figure 12: Example for design for disassembly (here: window frames, from: https://www.archdaily.com/943366/a-guide-to-design-for-disassembly)

Wood modification has been practiced for decades, but needs to be tested, adapted and further developed for grown hardwood species (e.g. Scholz et al. 2010, Mohd Ghani & Lee 2021). Modification **technologies** include furfurylation, acetylation, DMDHEU treatment, thermal modification (torrification), and others (Figure 13). Through densification, also in combination with other modification types, **new property profiles** are achievable.

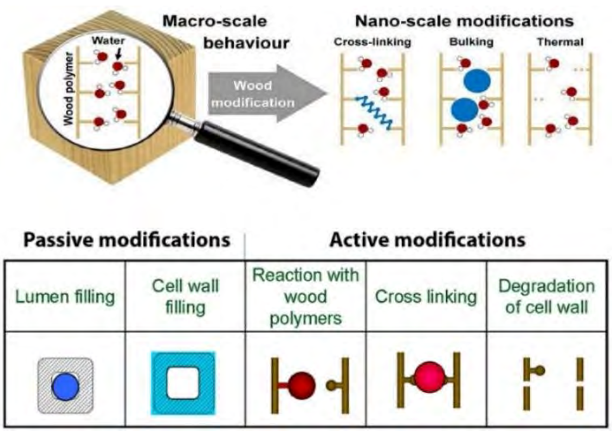


Figure 13: Different wood modification types, ranging from lumen and cell wall filling, polymer reaction, cross-linking, and cell wall degradation (from Sandberg et al. 2017),

Further research topics are different types of **composite materials**, including e.g. combinations of particleboards and fibreboards. Wood-plastic-composites should no longer be part of a smart future research portfolio. **Adhesives** are crucial and used with almost any type of wood-based materials, as most of the today's adhesives are still oil-based. Competence in bio-based adhesives is pivotal, by working on bonding solutions based on proteins, lignin, starch/sugar, hemicelluloses, tannins, or chitin, or combinations thereof. Goal is to improve the overall applicability, gluing performance and reactivity (Figure 14).

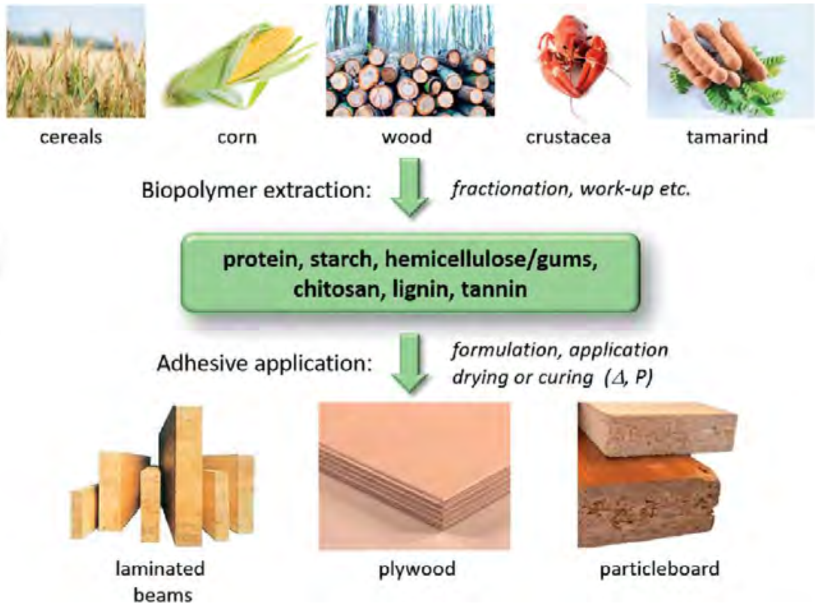


Figure 14: Natural ingredients for wood adhesives (from Norström et al. 2018)

Surface treatment of wood is important for improved service life, and visual appearance. This may include various types of coatings, varnishes, lacquer, wood stain, and also pre-treatments for improved coating properties. Pre-treatments may include plasma treatment, primer treatment, and others.

Another research interest of area 3 could be **materials made from waste streams**. This may include using wood particles from sawmilling, agricultural wastes, eventually in combination with cement, to produce composite materials to be used in **buildings** for noise insulation, thermal insulation, also having lower weights. Figure 15 shows cross-sectional SEM images of side-stream materials as used in particleboards.

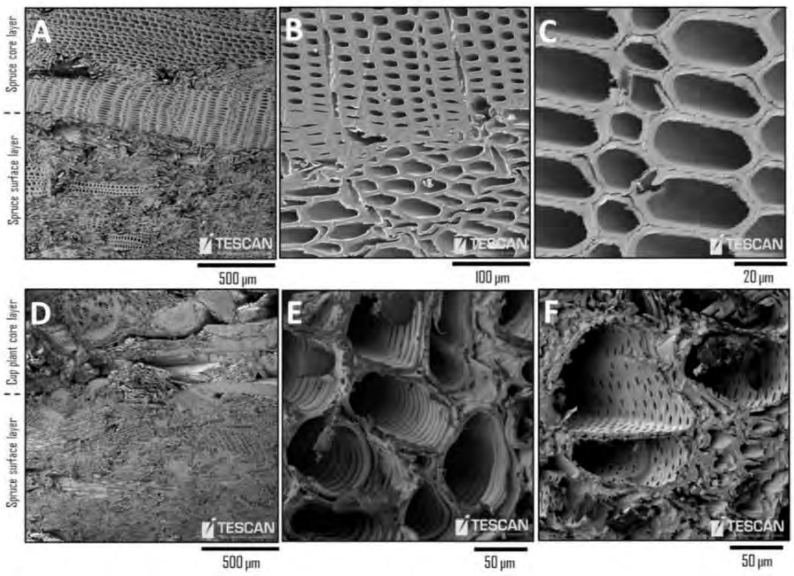


Figure 15: Cross-sectional SEM images of the spruce (A–C) and agricultural sources from waste streams, such as cup-plant (D–F). Cup-plant particles can be used as core layer, while spruce particles are used in surface layers, to produce particleboards (Klimek et al. 2021).

One more example for a material development is **3D printing of building components**, using wood-based and side stream materials in combination with **robot technology** (Figure 16).

Figure 16: Illustrations of possible robot-based 3D-printed house walls (from: Kromoser et al. 2022)

2.4.4 Area 4: Value chain development

Area 4 is concerned with the overall development of **wood-based value chains**, and it strongly includes **logistics**, **circularity**, **environmental analysis** and assessment, or **organizational decarbonization** (Figure 17).

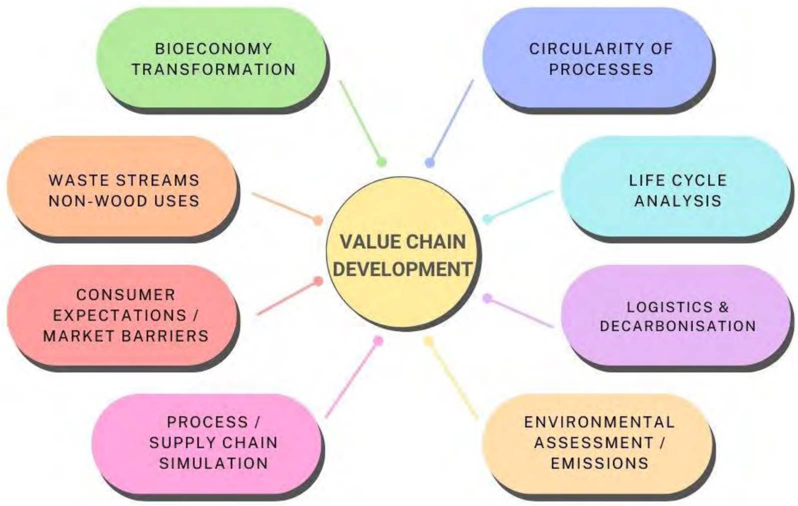


Figure 17: Area 4 – Value chain development – proposed research themes

Goal is to assist **transformations towards circular value chains**. Ideas of sustainable development and circular economy are developing, especially in the forest-based industry, and **Mt Gambier can be seen as a model region** where **circular value chains** are already established (Figure 18).

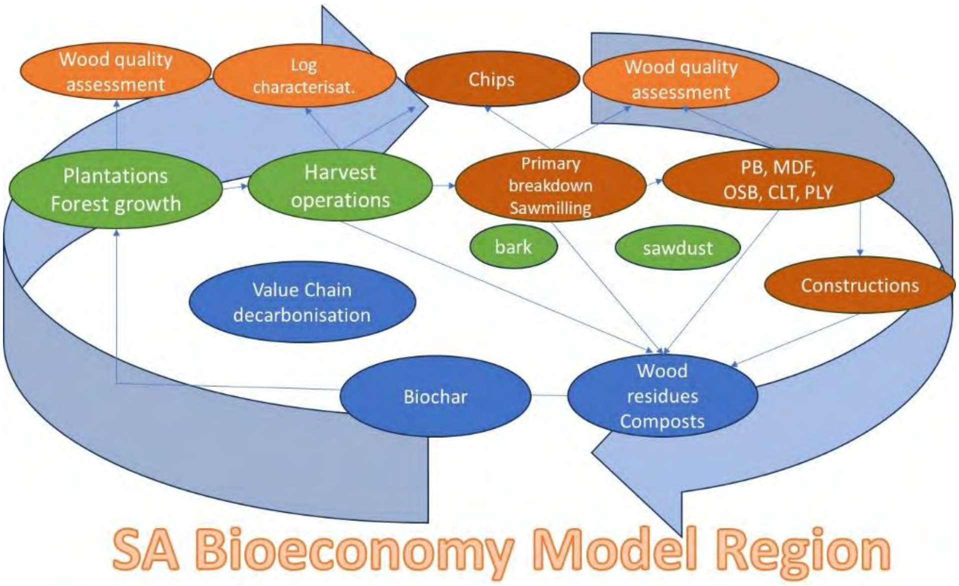


Figure 18: Mt Gambier as a Bioeconomy Model Region in Australia. Essential processes are connected with demonstrated circularity, which should be extended

This needs to be further developed, encouraging more companies to consider a **closed-loop economy**, with benefits to decarbonisation, reduced environmental impacts, reduced transportation costs and emissions, and job opportunities. Value chain processes should be **modelled**, as shown by Neague et al. (2021, Figure 19).

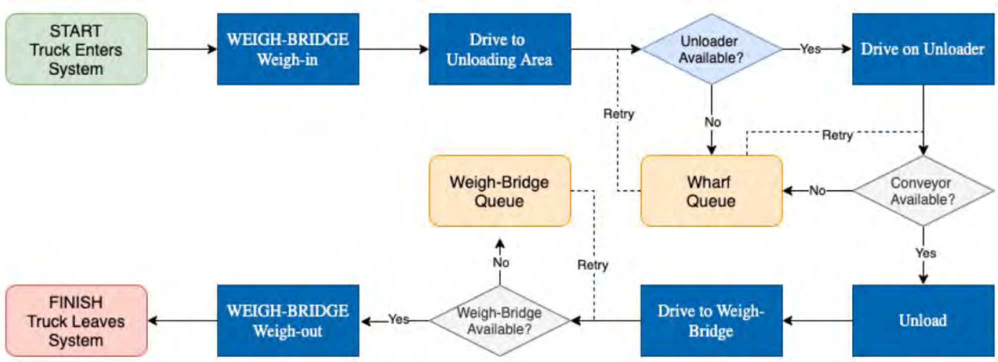


Figure 19: Discrete-event simulation of port terminals operations (from: Neague et al. 2021)

Area 4 may also conduct studies on **consumers expectations**, which could be done at warehouses such as Bannings. In addition, waste streams analysis and also non-wood biomass availability will provide valuable data to facilitate a **bioeconomy transformation**.

Life cycle assessment (LCA) is a tool to assess the environmental impact of materials, products and services, and should contribute to the decision-making process towards sustainability. LCA has been applied to a wide range of processes and sectors. Specific to the wood products sector, numerous studies have been carried out to investigate the environmental performance of wood-based products destined for different uses (Sathre et al. 2014).

Environmental assessment may also include emissions from bio-based materials, e.g. formaldehyde or volatile organic compounds (Figure 20).

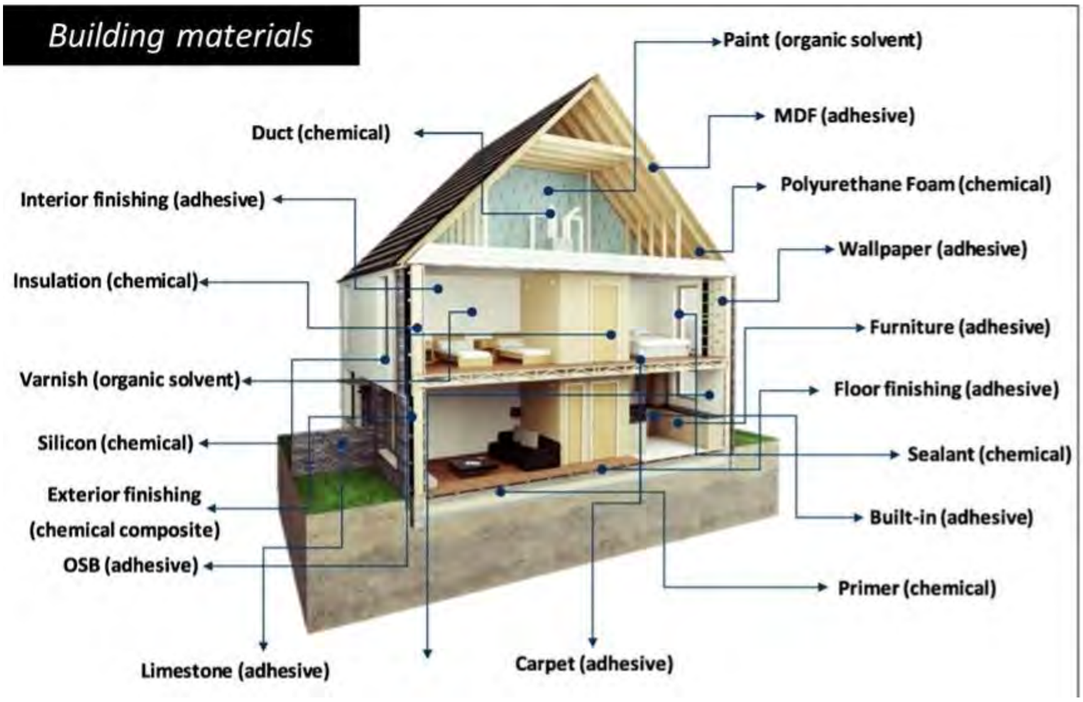


Figure 20: Possible emissions sources in building materials (from Wi et al. 2020)

2.4.5 Area 5: Services and Education

Area 4 is concerned with the overall development of wood-based value chains, and it strongly includes logistics, circularity, environmental analysis and assessment, or organizational decarbonization (Figure 21).

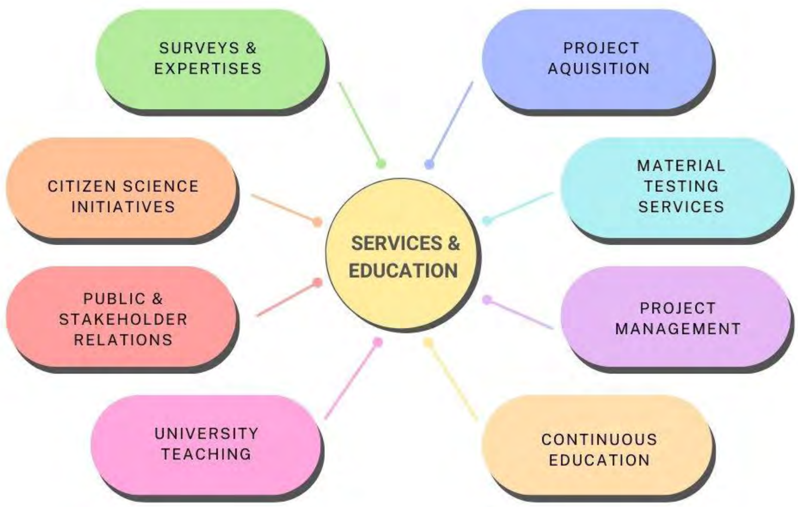


Figure 21: Area 5 – Service and education - – proposed research themes

In this area, industry partners are assisted with **project acquisition,** and **project management**. Industry partners also require **testing services**, and the future laboratories could be also audited for such tasks. **Education** includes continuous / adult education, university teaching, and various types of communication efforts to the public and to stakeholders.

University education should focus on establish first an undergraduate program in e.g. **Forestry & Wood Technology,** or Land Management and Timber Utilization. Later, a master program in **Timber Engineering & Management**, or Wood-based Materials and Technology could follow.

Citizen Science is research conducted with participation from the general public. Citizen science can be used in a wide range of areas of study, with most citizen science research publications being in the fields of biology, planation forestry, or wood science (Figure 22)

Figure 22: Citizen science projects on forest / wood topics

The FoCE may undertake various expert surveys for the public, for the industry, and other stakeholders.

3 Infrastructure and facilities

Required **infrastructure** and **facilities** for research and development needs to be defined. This could include not only lab infrastructure and pilot-plant facilities, but also experimental plantation sites, computer facilities for data analysis (also software), and meeting spaces for a wide range of collaborations. The following lists should be seen as examples of infrastructure needed to conduct the planned research of a FCoE (Figure 23).

The following infrastructure suggestions include:

- **Essential lab equipment** (esp. hydraulic press, conditioning room, climate chamber)
- Wood anatomy lab
- **Mechanical property lab**
- Wood modification lab
- Wood drying lab
- **Wood composites lab**
- Wood chemistry lab
- **Wood workshop**
- Special log scanning equipment

(**bold**: higher priority)

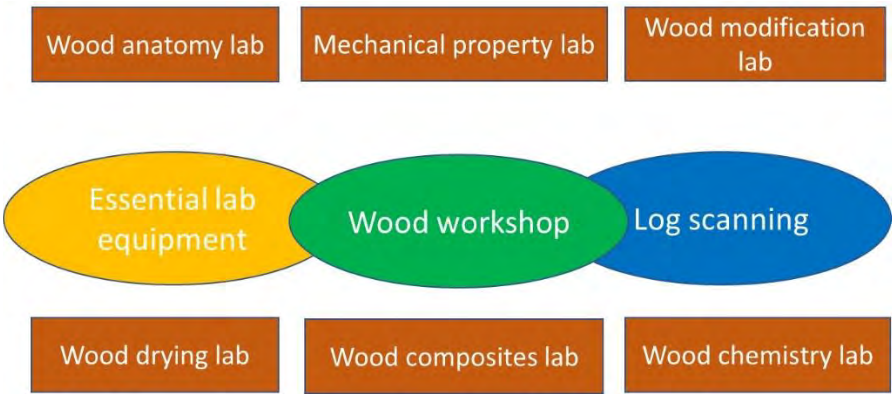
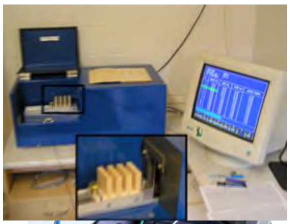
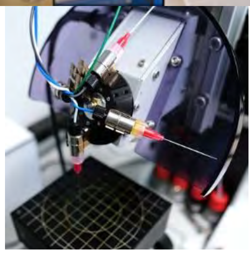


Figure 23: Infrastructure and labs of the FCoE

3.1 Essential lab equipment

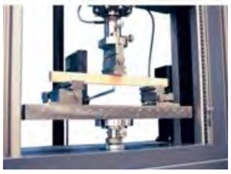
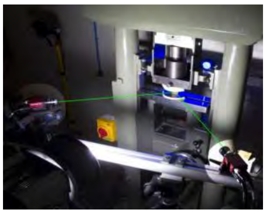
N	Device	Description	Photo
	Hydraulic press	pressing force: 4020 kN max. specific pressure 3,35 MPa (on area 50x50, up to 1200x1000mm) max. temperature: 220° C	
	Standard conditioning room	For the storage of wood (samples) at standard climate, i.e. 65 RH, 20°C, essential for any testing regimes	
	Climate chambers e.g. Memert	Temperature Ranges: -40°C to 190°C (without humidity) 10°C to 95°C (with humidity)	
	Spectrophotometer Conica Minolta CM-2600d	To measure surface color Integrating sphere size: Ø 52 mm Wavelength range: 360 nm - 740 nm Wavelength pitch: 10 nm Reflectance range: 0 - 175%, Display resolution: 0.01%	
	Gloss meter, e.g. GLOSSMETRO KSJ mod. MG268-F2	To measure glossiness of surfaces, by specular reflection (gloss)	
	Temperature sensor e.g data logger Dostmann electronic LOG 100	To control temperature Measuring range: -30...+70°C (internal) -50...+125°C (external) Accuracy: ±0,5°C(-20..+50°C) Memory: 60000 measurings Interval from 1 second to 24 hours	
	Portable Vibrometer Polytec PDV-100	Measures surface vibration velocitry, without contact. For predictive maintenance of machinery Operating vehicles, buildings, bridges or other large outdoor structures	
	Heat Flow Meter HFM 436/6/1E Lambda	To measure thermal conductivity of e.g. insulation materials Specimen Size: 600x600x200 mm Dimensions: 800x950x800 mm Plate Temp. Ranges :-20°C to 70°C	

	Densitometer (e.g.Grecon)	X – ray dense – lab measures the density profile vertically to the sample surface. To measure vertical density profiles of particleboards, fibreboards.	
	Contact angle measurement device e.g. Krüss DSA30	Static and dynamic measurement of surface contact angles	
	Surface roughness device e.g. Taylor Hobson Form Talysurf 2	To characterize surface topology	

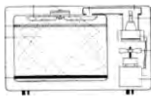
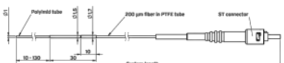
3.2 Wood anatomy lab

N	Device (with brand examples)	Description	Image
	Water bath, eg. Leica HI1210	The Leica HI1210 is a water bath with a surface that provides high thermal conductivity rates and outstanding scratch resistance due to its special plastic coating.Temperatures can be selected between ambient and 75°C. The broad, oversized rim of the water bath allows convenient storage for microscope slides, and the rounded inner corners of the instrument allow it to be cleaned easily and efficiently.	
	Sliding Microtome e.g. Leica SM 2010 R	Designed for LARGE specimens, ideal for brain sections. Specification: Maximum specimen size 80 x 60 mm. Section thickness adjustable from 1 to 60 um. Automatic advance between 0 and 30 um.	
	Rotary Microtome e.g. Leica RM 2235	Setting Values: 1–10 µm in 1 µm 10–20 µm in 2 µm 20–60 µm in 5 µm Trim Settings: 10, 30 µm Total Horizontal Specimen Feed: 30 mm Section Thickness Setting Range: 1 – 60 µm	
	Special purpose drying oven e.g. INCUCELL 55	acid and basic hydrolysis, extraction of non inflammable materials and decomposition of substances in solid phase. Is a drying ovens with highly resistant coating, protecting the internal chamber of aggressive substances like acids or alkaline liquids.	
	Light microscopes	Leica DMLS etc.	
	Laboratory scales		
	Fume Hood, fixed installation, or stand-alone, e.g. Cruma 1010	Remove gaseous polluting agents and/or solid particles/aerosols from the working space. Filters are suitable for all types of gases: organic, inorganic acids, formaldehyde, NH_3 and amines.	

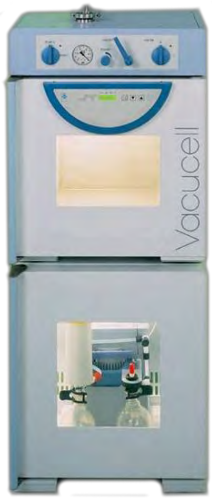
3.3 Mechanical properties lab

N	Device	Description	Photo
	Impact bending machine	To measure dynamic strength of solid wood samples	
	Universal testing machine: e.g. Zwick Z050	max. test load: 50 kN sample test area height: 1370 mm test area width: 440 mm crosshead speed: 0 - 500 mm/min crosshead travel res.: 0,007/0,016 µm loads: tension (also MOE) compression (MOE) bending (also MOE) shear	
	Digital image correlation (DIC) testing set	Two camera system, to measure material strain / internal stress when tested	
	Abrasion measurement: z.B. Taber abraser 5131	Rotary Abraser Taber 5131 is a test instrument designed to evaluate the resistance of surfaces to dubbing abrasion. Characteristic rub-wear action of Abraser is produced by the contact of a test sample turning on vertical axis, against sliding station of two abrading Wheel. The abrasion is evaluated accordingly to standards in force (ASTM F510-93).	
	Resi Tool	IML, to measure internal density trends in trees	

3.4 Wood modification lab

N	Device	Description	Photo
	Thermal Modification Chamber (Katres)	Internal dimensions: 800x800x500 mm Max. temperature: 250°C	
	Microwave Equipment (Romill)	Conveyer length: 3400 mm Conveyer width: 450 mm Max. thickness of material: 45 mm Mod. chamber: 600 x 600 x 600 mm Power: 0.6 – 6 kW Frequency of magnetron: 2.45 GHz	
	Microwave oven	Power: 0.9 kW	
	Vacuum – pressure impregnation equipment: JHP 1-0072	Maximum Overpressure: +9 bar Maximum Vacuum: -1 bar Capacity of Impregnation Tank: 50 l Capacity of the Storage Tank: 75 l Maximum Temperature:160°C	
	Laboratory fume hood		
	Autoclave	For steaming of material and ammonia treatment.	
	Steam generator - NEKL 25	Dimensions: 700 x 530 x 550 mm Volume of boiler generator: 25 l Max. operating pressure: 6 bar	
	Fiber optic temperature monitoring system OPTOCON - FOTEMP1-4	Measuring of temperature during microwave treatments of wood. 4 optical fibres	 
	Thermocouples	8/16-Channel Thermocouple/Voltage Input USB Data Acquisition Module Ready-Made Insulated Thermocouple 5TC-TT	

3.5 Wood drying lab

N	Device	Description	Photo
	Conventional kiln: BEFI (may also include steaming)	length: 1870 mm width: 1210 mm height: 1640 mm	
	Vacuum drying chamber - Vacucell standard 22	Working temperature of from +5°C over ambient temperature up to 200°C. Volume: 22l Power: 800W Dim. of shelf: 280×236 mm	
	Laboratory oven: Sanyo MOV 112	effective capacity: 97 l temperature range: 40° – 250° C	
	Convection oven: Siemens	combination of steam and hot air: 120° – 230° C hot air: 30° – 230° C steam: 40° – 100° C oven capacity: 32 l water tank: 1,3 l	
	Moisture meters	(dielectric, electrical resistance)	 
	Psychrometers		
	Infrarot-Thermometer Voltcraft IR 380	Measuring Range: -50 to +800 ° C	

3.6 Wood composites lab

N	Device	Description	Photo
	Cutting Mill, e.g. Retsch SM 300	Feed material: soft, medium-hard, tough, elastic, fibrous Material feed size: < 60 x 80 mm Final fineness: 0.25 - 20 mm Speed at 50 Hz: 700-3000 min^{-1} Power: 3 kW	
	Cutting mill		
	Vibratory Sieve Shaker Fritisch-Analysette 3 pro	Analysis of wood particles PC connection Timer	
	Glue / resination machine for wood particles	Spraying application to glue wood particles.	

3.7 Wood chemistry lab

N	Device	Description	Photo
	Gas chromatography (GC-FID Agilent 7890B)	Analysis of volatile and semivolatile compounds	
	Liquid chromatography (HPLC Agilent 1260 DA - detector)	Analysis of non-volatile and semivolatile compounds	
	Spektrophotometer UV-5100 UV-VIS Shangai Mathash Instruments (for Formaldehyde analysis, etc.)	190-1000nm	
	Universal automatic extraction system fexIKA vario control	Number of extraction points: 4 Basic container volume: 200 ml Working volume: 100 ml Heat output: 600 W Material coupling PTFE + stainless steel (1.4571) Material O-ring FEP coated Coupling temperature resistance max. 200°C Dimensions (W x H x D): 200 x 810 x 500mm	

3.8 Wood workshop

N	Device	Description	Photo
	Sliding table saw		
	Planner/Thicknesser		
	Vertical Band Saw - BERNARDO - HBS 500 N	Power: 3.5kW Cutting width: 500m Cutting height: 350mm Blade length: 4100mm Cutting speed: 1320m/min Table size: 500x640mm	
	Belt sander		
	Horizontal sawmill Pilous Forester CTR 520	To produce boards from logs; max. Ø of trunk: 520mm power: 4kW	

3.9 Special log scanning equipment

	Woodeye 5Scanner	For inner characteristics of logs, based on CT	

4 Forming a team of experts

The recruitment of a **diverse and inclusive team** of people working in forestry, wood science, ecology, economics, and related fields are of upmost importance. Individuals should have strong research backgrounds and a passion for advancing knowledge in the sector. Appropriate people need to actively **recruited**, but approaching other institutions and international collaboration partners. **Qualified people** are not easy to find, and attracting people that are interested to apply will take time and effort. Jobs should be distributed in relevant networks such as Innovawood, EUAXESS, Science Careers, ResearchGate, and others.

5 Monitoring and evaluation

Continuously monitoring the FCoE's progress towards its objectives and evaluate its impact is strongly recommended. Developing the FCoE is a challenging but rewarding endeavor. By focusing on collaboration, research quality, and societal impact, the FCoE can become a leading institution, contributing to a sustainable and prosperous future for forestry and wood-related industries. An **advisory team** should be established, which **periodically reviews the centres progress** and makes viable recommendations.

6 Literature

Braungart, M., & McDonough, W. (2009). Cradle to cradle. Random House.

Drew, D. M., Downes, G. M., Seifert, T., Eckes-Shepard, A., & Achim, A. (2022). A review of progress and applications in wood quality modelling. *Current Forestry Reports*, *8*(4), 317-332.

Klímek, P., Wimmer, R., & Meinlschmidt, P. (2021). TOF-SIMS molecular imaging and properties of pMDI-Bonded particleboards made from cup-plant and wood. *Applied Sciences*, *11*(4), 1604.

Kromoser, B., Reichenbach, S., Hellmayr, R., Myna, R., & Wimmer, R. (2022). Circular economy in wood construction–Additive manufacturing of fully recyclable walls made from renewables: Proof of concept and preliminary data. *Construction and Building Materials*, *344*, 128219.

Pramreiter, M., Nenning, T., Malzl, L., & Konnerth, J. (2023). A plea for the efficient use of wood in construction. *Nature Reviews Materials*, *8*(4), 217-218.

Mohd Ghani, R. S., & Lee, M. D. (2021). Challenges of wood modification process for plantation Eucalyptus: A review of Australian setting. *Journal of the Korean Wood Science and Technology*, *49*(2), 191-209.

Neagoe, M., Hvolby, H. H., Taskhiri, M. S., & Turner, P. (2021). Using discrete-event simulation to compare congestion management initiatives at a port terminal. *Simulation Modelling Practice and Theory*, *112*, 102362.

Sandberg, D., Kutnar, A., & Mantanis, G. (2017). Wood modification technologies-a review. *Iforest-Biogeosciences and forestry*, *10*(6), 895.

Sathre, R., & González-García, S. (2014). Life cycle assessment (LCA) of wood-based building materials. In *Eco-efficient construction and building materials* (pp. 311-337). Woodhead Publishing.

Scholz, G., Militz, H., Gascón-Garrido, P., Ibiza-Palacios, M. S., Oliver-Villanueva, J. V., Peters, B. C., & Fitzgerald, C. J. (2010). Improved termite resistance of wood by wax impregnation. *International Biodeterioration & Biodegradation*, *64*(8), 688-693.

Wi, S., Kim, M. G., Myung, S. W., Baik, Y. K., Lee, K. B., Song, H. S., ... & Kim, S. (2020). Evaluation and analysis of volatile organic compounds and formaldehyde emission of building products in accordance with legal standards: A statistical experimental study. *Journal of Hazardous Materials*, *393*, 122381.