WoodComp3D

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# Lignin-Bonded Composites from Sawmill Byproducts

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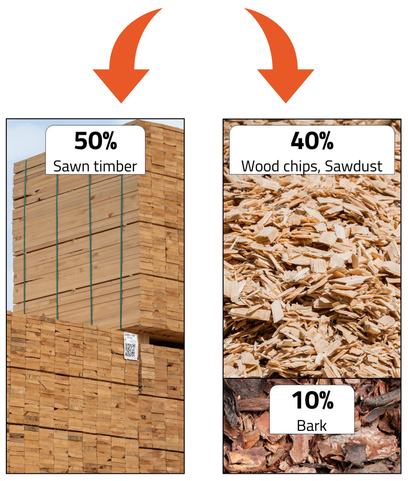
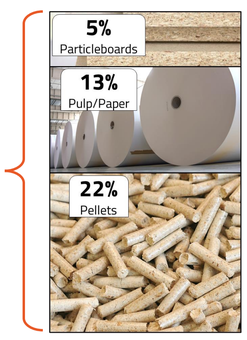
## Motivation and Background

- Up to 50% sawmill by-products (SBP) are generated during the production of sawn timber from round timber [1,2].
- Most of SBP are used energetically and the stored $CO_2$ is released.




- Material use.
- Limited to low-strength applications.
- Resistance depends on the adhesive.
- Emission of contaminants [3].

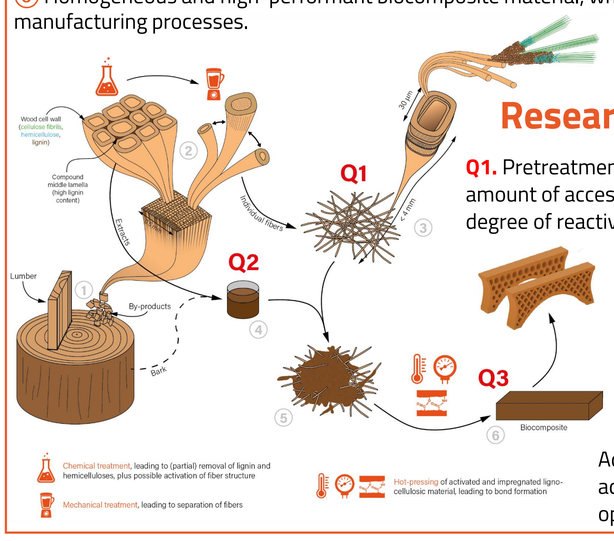
- Wood fiber structure (outstanding load-bearing properties!) is destroyed.
- Carbon is released into the atmosphere.

## Challenge!

- Bringing separate wood pieces into a composite
  - Fibers can bond and form new covalent bonds
  - Leading to high-strength properties [4].
- All lignocellulosic components – cellulose, hemicellulose, lignin, and extractives – are necessary
  - Reconstruct into a homogeneous high-performant material [5].

## Our Approach

(1) Sawmill by-products with different particle sizes.
(2) A combination of thermo-chemical-mechanical pretreatment to obtain single fibers with tunable lignocellulosic composition.
(3) Accessible and highly reactive fibers without destroying the inherent microstructure.
(4) Solubilized components (lignin, hemicellulose, and extractives) with high reactivity and cross-linking capability are used as a binder.
(5) Re-assembly stage using temperature and pressure, for the formation of strong bonds.
(6) Homogeneous and high-performant biocomposite material, which can be used in additive manufacturing processes.




## Research Questions

**Q1.** Pretreatment and activation? Highest amount of accessible fibers with the highest degree of reactivity?



**Q2.** Additives for binding? Extracts from the SBP to be used as binders and additives

**Q3.** Bonding, combination, and reassembly? Adding and bonding of additives/fibers under optimal process parameters

## Results so far

### Disassembly of feedstock into fibers with non-cellulose components

- **Tested pretreatments:**
  - *[Liquid Hot Water]* (LHW, 160°C, 30 min) + *[Refining]* (Jokro mill) [6]
  - *[Organosolv]* (OS, 60%wt EtOH, 160°C, 30 min) + *[Refining]* (Jokro mill) [6]
  - *[Soda]* (NaOH, 1.5 %wt, 100°C, 30 min) + *[Refining]* (Jokro mill) [6]
  - *[Peracetic acid]* (90°C, 60 min) + *[Mixing]* (Kitchen mixer, plastic blades) [7]
- **Feedstock:**
  - Austrian Spruce
  - Woodchips

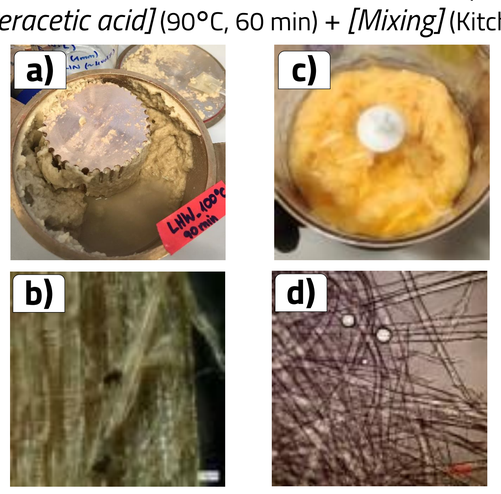



**Figure 1**. Sawmill byproducts pretreated with LHW + mechanical refining (a) and PAA + Mixing (b), and respective light microscope images: (c) LHW and PAA (d). LHW is taken as a representative sample for OS and NaOH. All three pretreatments (LHW, OS, NaOH) showed no defibrillation.

### Main Findings

- LHW, OS, and NaOH did not fully defibrate into single fibers
  - Trade-off of fiber shortening.
- PAA only required mild mechanical pretreatment to reach complete defibrillation.
- PAA selected for further testing of the production of composites.

### Reassembly of fiber material with lignin as an additive

- **Methods:**
  - Materials:
    - PAA fibers combined with UPM BioPiva 395 (softwood kraft lignin)
  - Biocomposite production: Hot compression molding
    - Beams dimensions: 10 mm x 10 mm x 120 mm
    - Fiber-lignin material: 10 g to 25 g
    - Temperature: (110 °C, 130 °C, 170 °C, and 200 °C) for 20 min
    - Pressure: 25.45 MPa

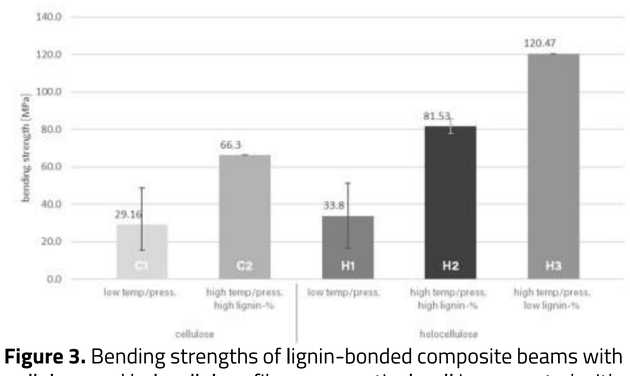



**Figure 3.** Bending strengths of lignin-bonded composite beams with cellulose and holocellulose fibers, respectively, all impregnated with lignin, and for various pressing conditions (low temp/press: < 170 °C and 25 MPa; high temp/press: 200 °C and 45 MPa; low lignin-%: 13 % added kraft lignin; high lignin-%: 26 % added kraft lignin).

- **Combination:**
  - Dry mixing vs. Impregnation:
    - Dry-mixing resulted in subpar strength values of up to 12 MPa.
    - Impregnation with lignin solubilized in ethanol [8]: Key for proper binder-fiber mixing.

**Figure 2.** Impregnation of the produced fibers and solvent removal to prepare the sample to be pressed.

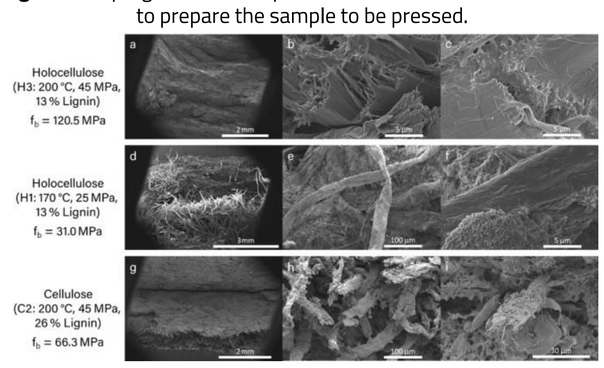
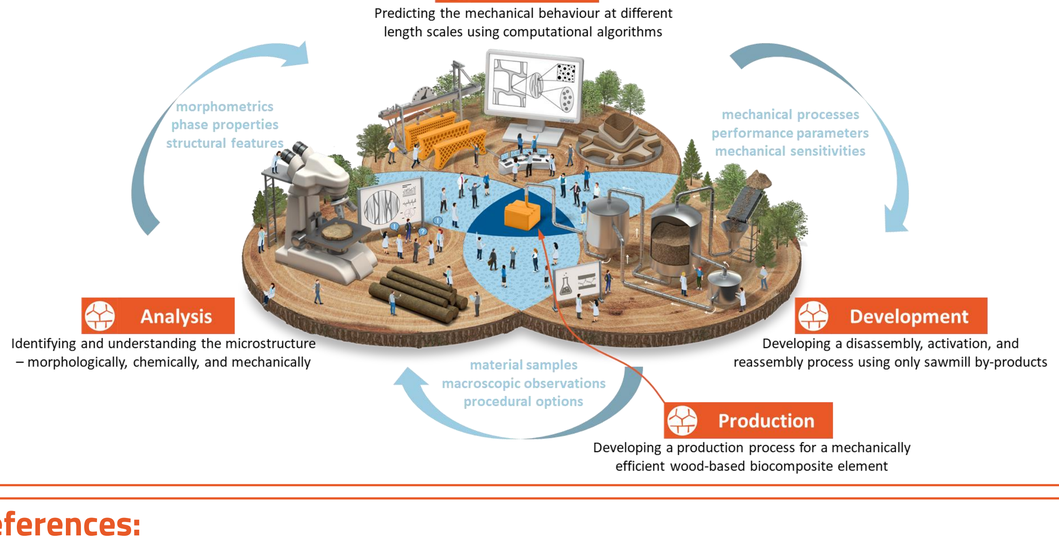



**Figure 4.** SEM images of fracture surfaces of three representative beams for both holocellulose and cellulose beams, varying pressing conditions, and after bending tests up to failure.

## Consortium - Interdisciplinarity




## Conclusions

- Fibers containing non-cellulosic components have the potential to yield biocomposites with enhanced mechanical properties compared to cellulose pulp.
- Fiber swelling allowed lignin to impregnate the fibers.
- The best-performing biocomposite (H3) exhibited properties more akin to those of a composite with uniform characteristics rather than conventional fiberboards.

### Limitations and Opportunities:

- Used lignin (Kraft): Limited reactivity → Other lignins (OS, IL, DES) might have higher reactivities
- Pretreatment and pressing parameters to be optimized
- Influence of ethanol as impregnating agent on the glass transition temperature
- Potential benefits of incorporating small amounts of water in conjunction with another solvent should be explored
- Further testing is necessary to comprehensively understand the behavior of the biocomposite material across all length scales
- Interdisciplinary research program with chemistry-based and simulation-guided approach

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