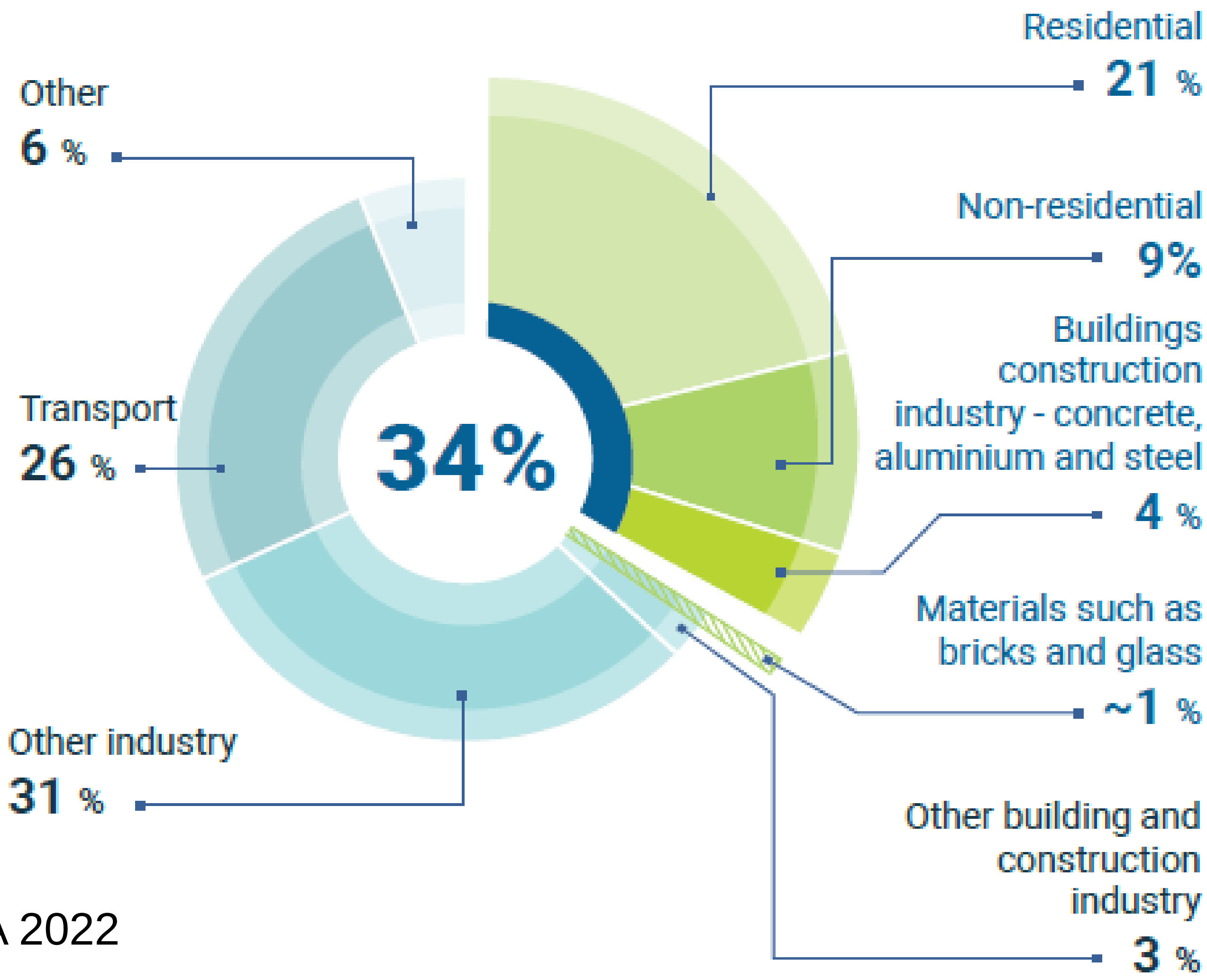
ETH, Institute for Building Materials, Chair of Wood Materials Science
Empa, Cellulose and Wood Materials Laboratory, WoodTec group

Wood materials – potentials and limitations

Ingo Burgert et al.

IAWS Academy Lecture
SWST convention, Portoroz, 30.6.-5.7.2024

Share of buildings in total final energy consumptions in 2021

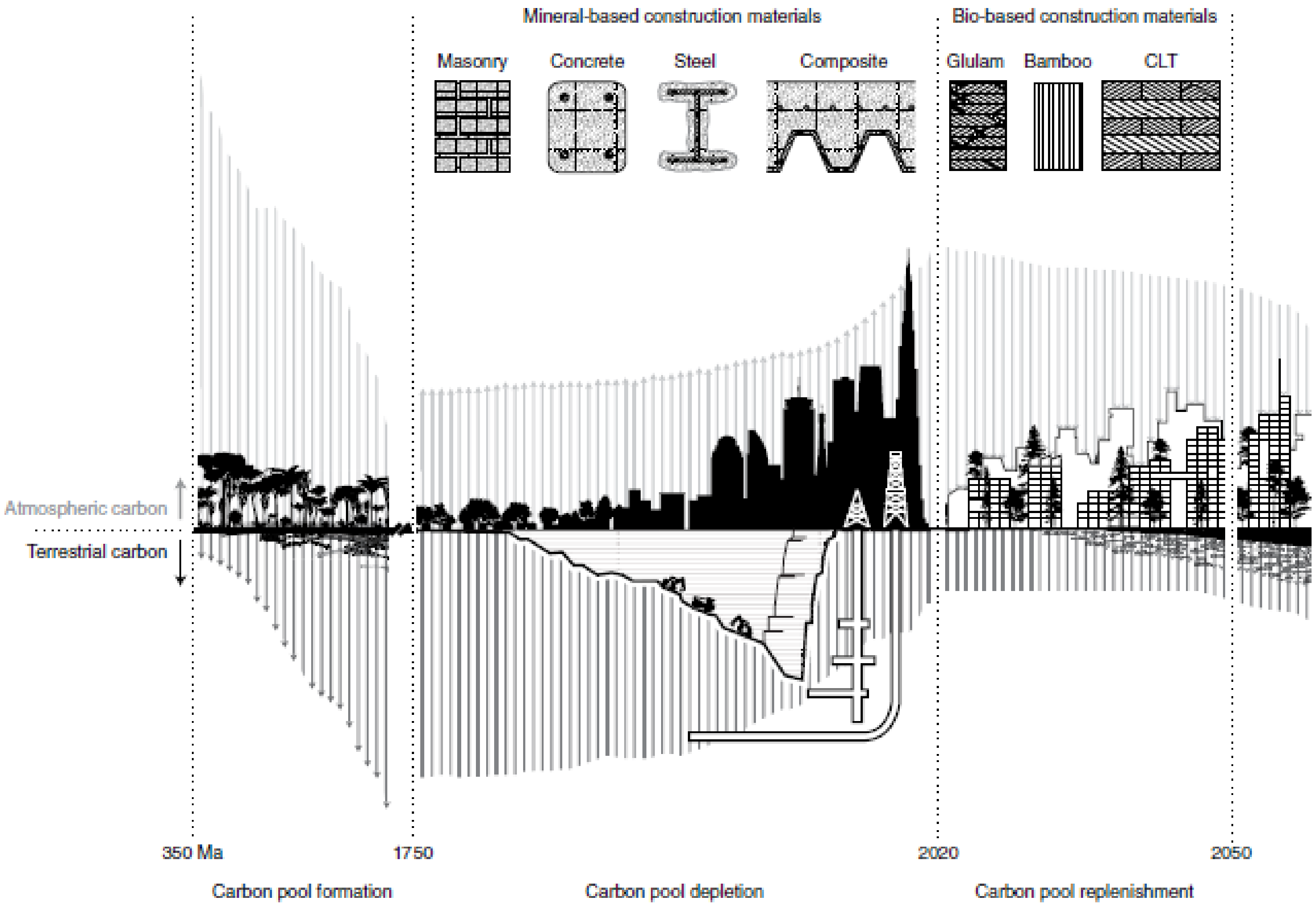


Source IEA 2022

United Nations Environment Programme (2022). 2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Nairobi.

Buildings construction – potential of wood

Main focus on climate change mitigation and sustainability



Churkina…Schellnhuber (2020) Nature Sustainability

- Contributing to lower or zero emission in the building sector requires easy and rapid scalability
- Retaining sustainable forestry and biodiversity
- Circular wood products
- New and improved wood processing techniques and wood-based products
- Hybrid materials

Buildings construction – required measures and potential contribution of wood

DESIGN BETTER BUILD WITH LESS

- Life-cycle analysis
- Resource-efficiency
- Circular approaches
- Durability and recycling
- Local value chains

USE ALTERNATIVE BUILDING MATERIALS

- Develop supply chains
- Standardize and certify products
- Mainstream alternative materials in conventional construction

DECARBONISE CONVENTIONAL MATERIALS

- Energy - efficiency
- Reduce Carbonised energy
- Process innovation
- Substitute with materials and natural fibers

REDUCE OPERATIONAL CARBON

- Minimize heating and cooling loads by using naturally insulating passive materials from bio- based fibers and/or clay
- Incorporate on-site energy collecting and storing materials into building envelopes
- Design material components for disassembly and reuse

Source: Adapted from Programme for Energy Efficiency in Buildings 2022.

United Nations Environment Programme (2022). 2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Nairobi.

Wood Materials Science at ETH and Empa

Wood Materials Science at ETH ⟷ WoodTec at Empa

Key objective

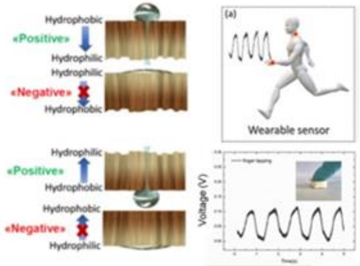
Help making wood a decisive resource for future bio-economy

- Renewable resource
- CO_2-storage capacity

→ **Performance by retaining the hierarchical structure of wood**

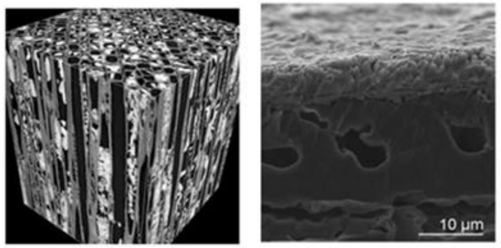
Functional Wood
Embedded functionality

- Sensing
- Optics
- Electronics
- Transport
- Separation
- Catalysis



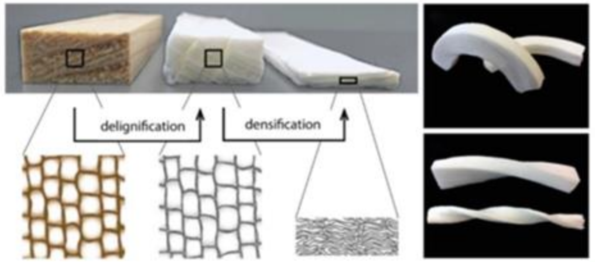
Enhanced Wood
Property improvements

- Surfaces
- Gluing
- Flame retardancy
- Wood-hybrids
- Durability



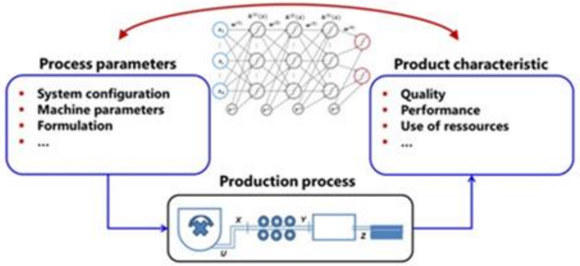
Cellulose Composites
High-strength biomaterials

- Mechanical performance
- Shaping of elements
- Densification
- Biobased matrix



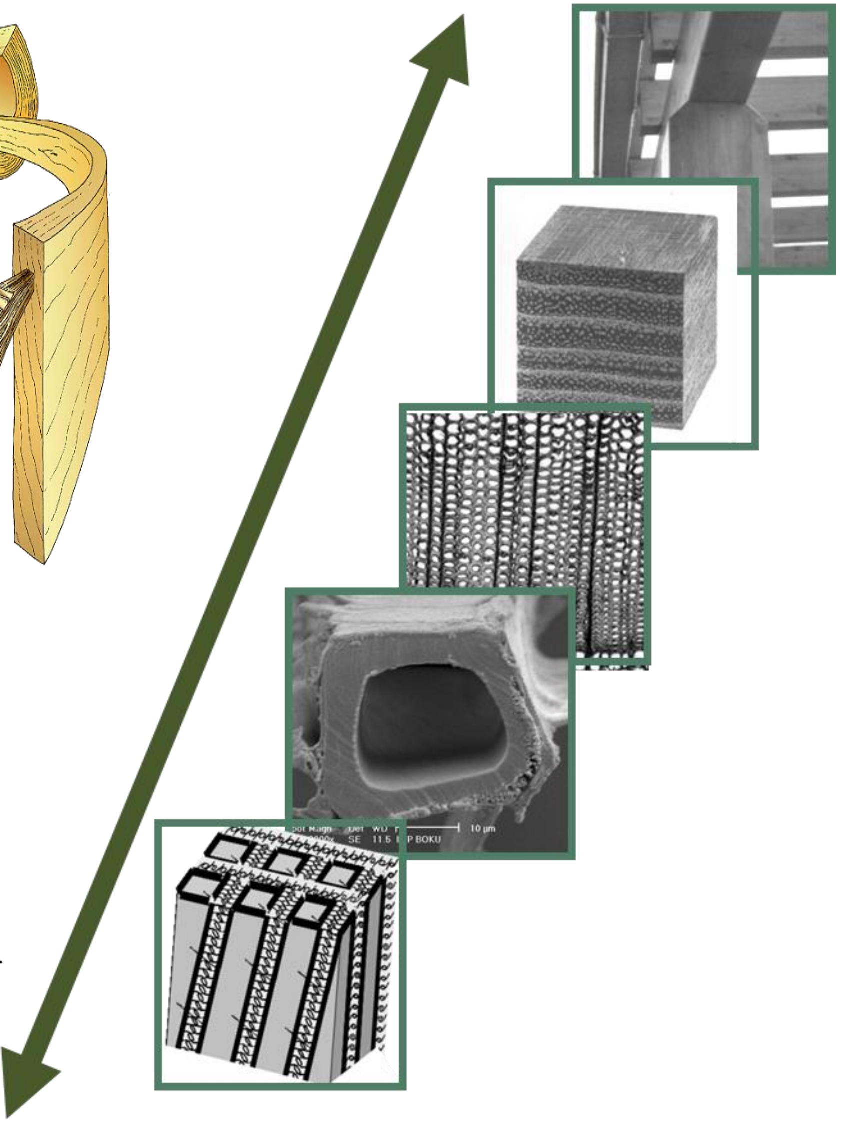
Digital Wood
Machine learning techniques

- Wood grading
- Process optimization
- Quality determination
- Resource efficiency

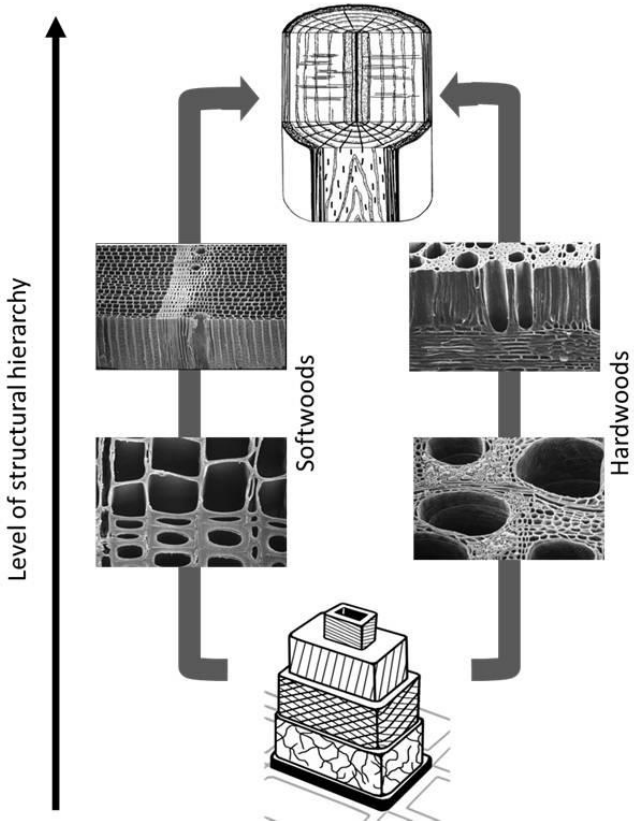


Top-down approach - Hierarchical structure of wood

Thanks to:
M. Harrington, NZ

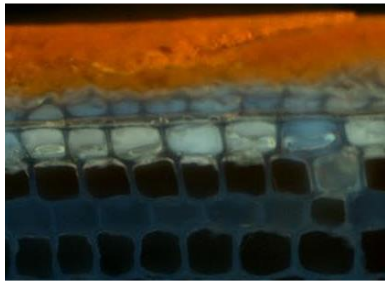
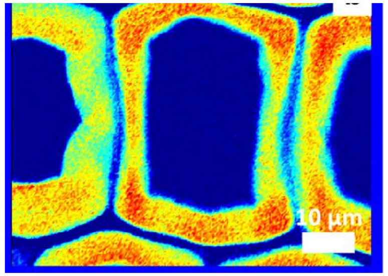


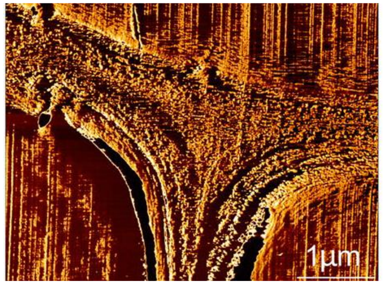
The tree as a «3D-printer»

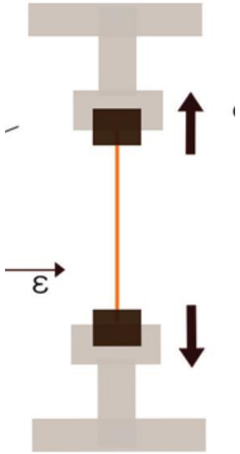


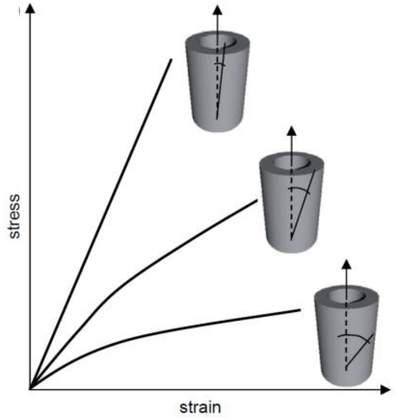
Burgert et al. 2016 IMR

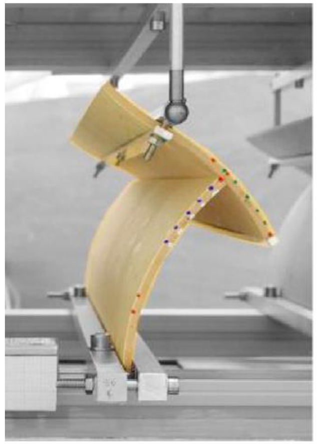
From nano to macro









Empa “NEST”

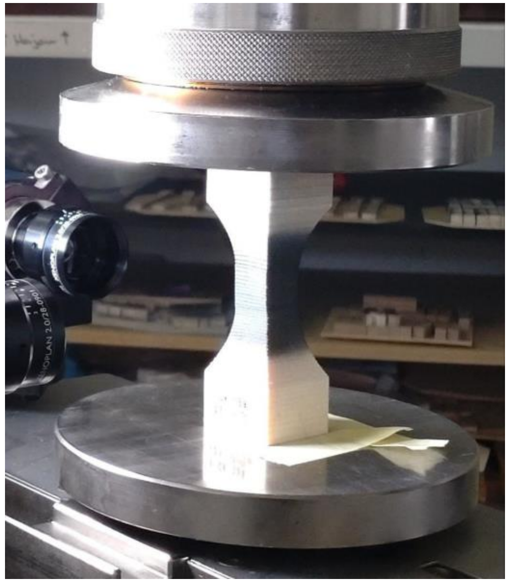
Urbach Tower

From basic research to application

Characterization of wood across scales / macro to micro

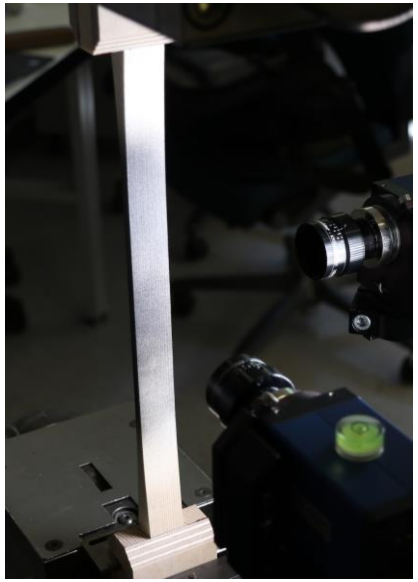
- Obtained data: **elasticity** + **plasticity** for **4RH** in compression/tension/shear
- **Cyclic testing** with stress increase per cycle
- Camera measurements from **two sides**
- Strain analysis with **DIC**

Falk Wittel
Jonas Maas
Alessia Ferrara
Julio Ortiz

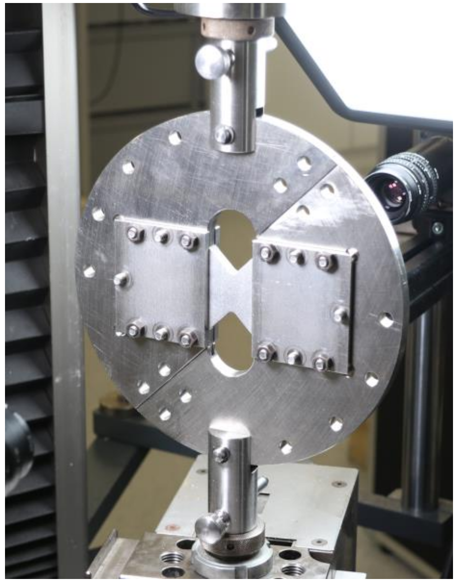


3D dogbone compression test

3D dogbone tension test



DIN 52188 tension test



Arcan shear tests

➢ *Reference to Peter Niemz et al.*

Characterization of wood - Mechanical anisotropy

Automatization of high number of creep tests: The Computer Controlled Climatized Creep Rack (C4)

Jonas Maas
Falk Wittel

- Plane stress state for **12 samples**: 3 tension, 3 compression, 6 shear
- **Front + back side** measurements
- Load controlled
- **Automatic** climate control and photo acquisition for strain analysis by **Digital Image Correlation**

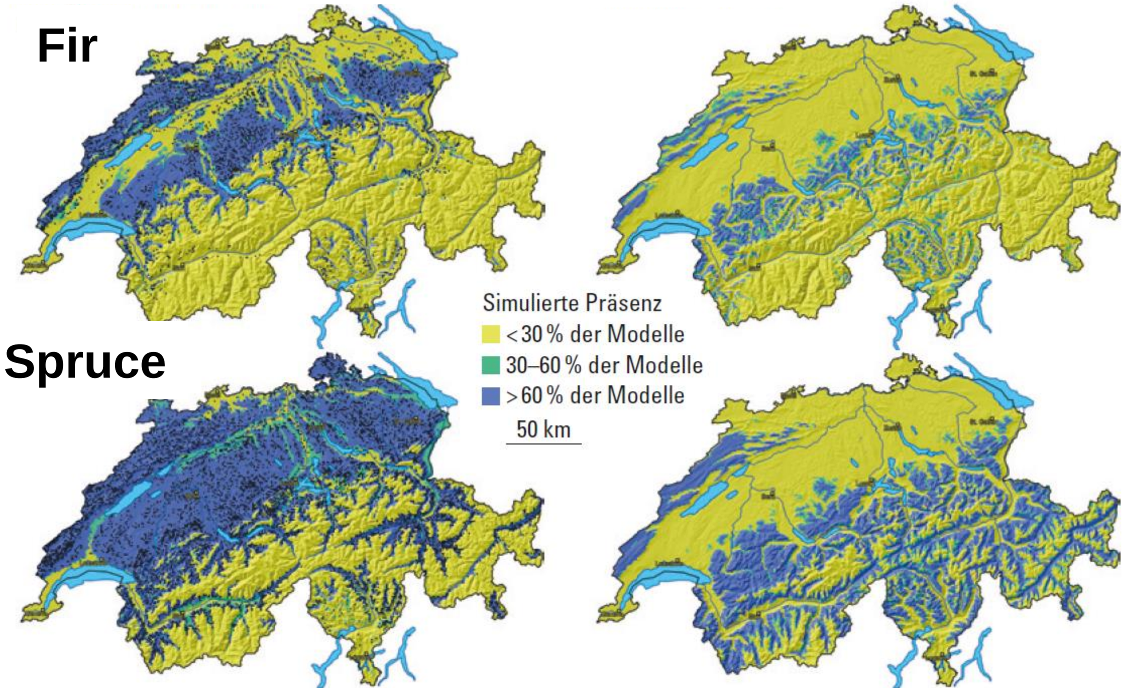
Resource availability

Site suitability

Climate 1981-2010 Climate 2051-2080

Fir

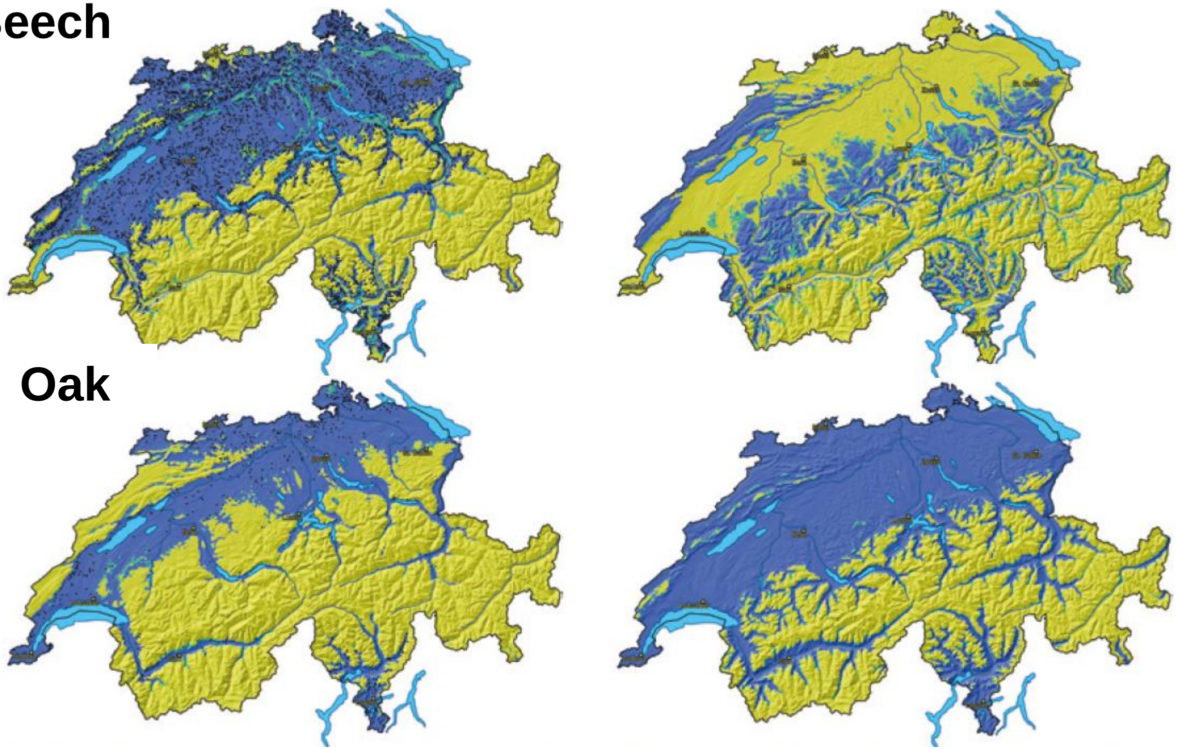
Spruce



Climate 1981-2010 Climate 2051-2080

Beech

Oak



Niklaus E. Zimmermann, Dirk R. Schmatz, Laure Gallien, Christian Körner, Barbara Huber, Monika Frehner, Meinrad Küchler und Achilleas Psomas, 2016. Baumartenverbreitung und Standorteignung. In: Pluess, A.R.; Augustin, S.; Brang, P. (Red.), Wald im Klimawandel. Grundlagen für Adaptationsstrategien. Bundesamt für Umwelt BAFU, Bern; Eidg. Forschungsanstalt WSL, Birmensdorf; Haupt, Bern, Stuttgart, Wien. 199-221.

Resource availability

Availability of spruce wood in Central Europe will decline

- In the future more mixed forests with diversity in terms of age and quality
- Strong impact on the future timber resource provision

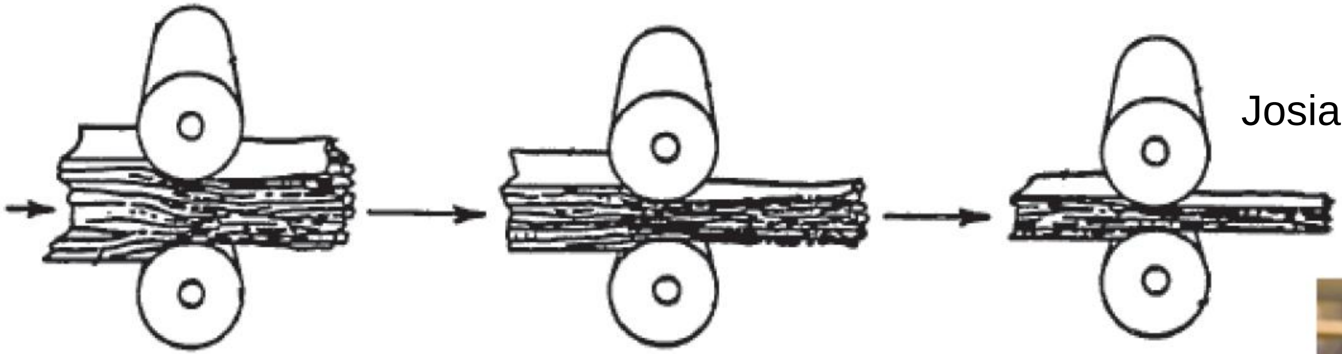
In Switzerland only ~60% of the cut round wood ends up in sawn trimber. Most probably, using more hardwood species will further reduce the material gain

We need a new perspective for handling more hardwoods / natural diversity in the wood value chain

Alternative separation techniques

➢ *Reference to Alfred Teischinger et al.*

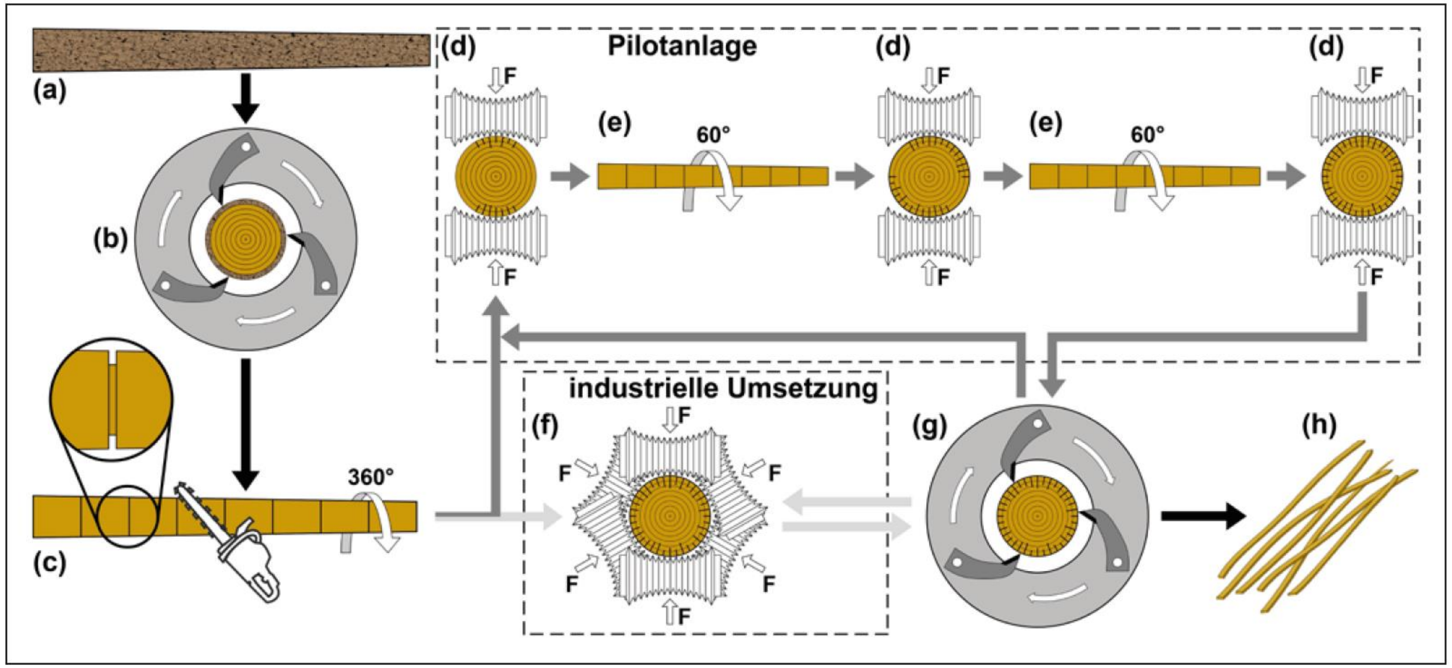
Scrimber



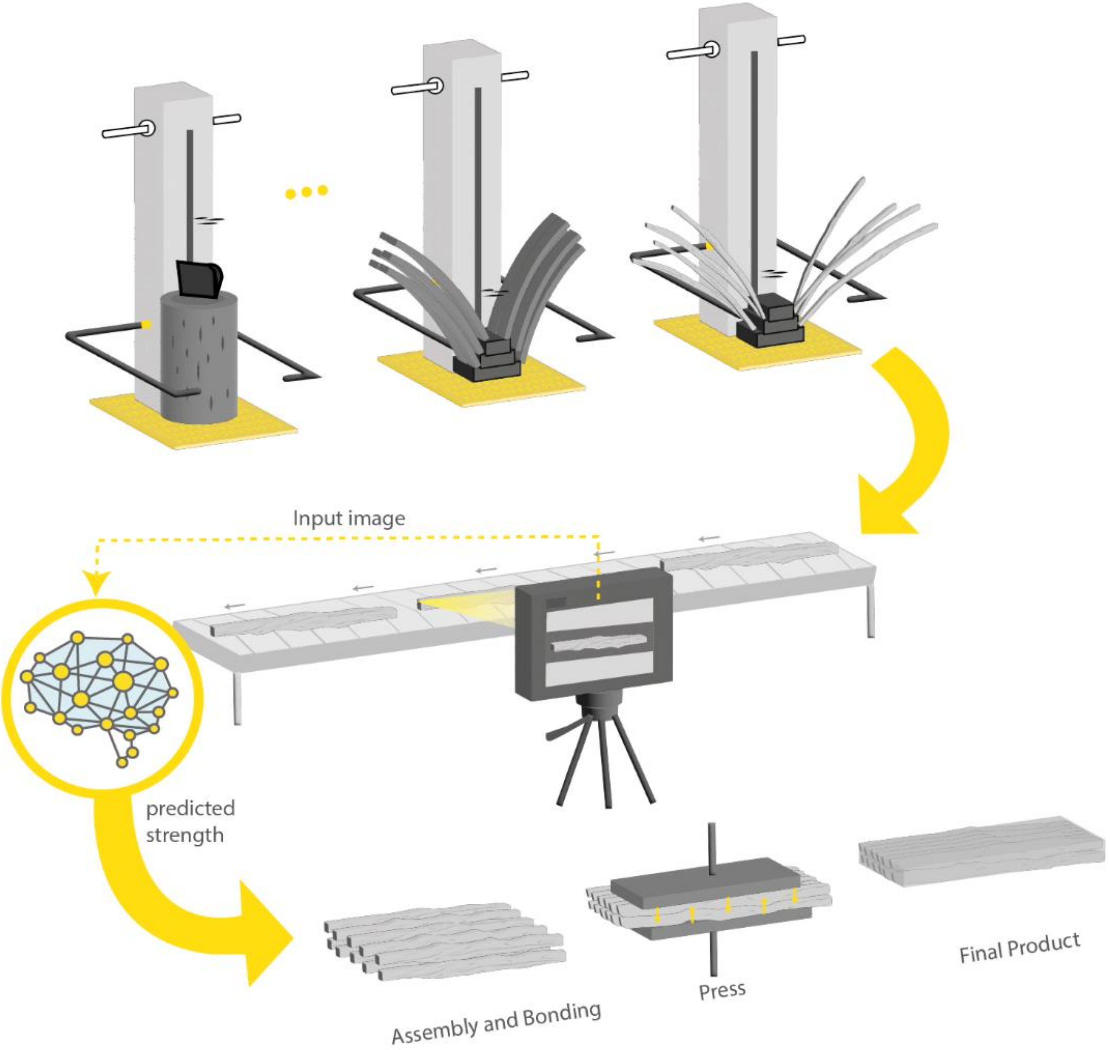
Josiak et al. (2006) Wood Research

Macrofibres – Boku, Vienna

Bliem et al. (2020) Holztechnologie



Split rod wood composites



Burgert et al. (2024) RILEM

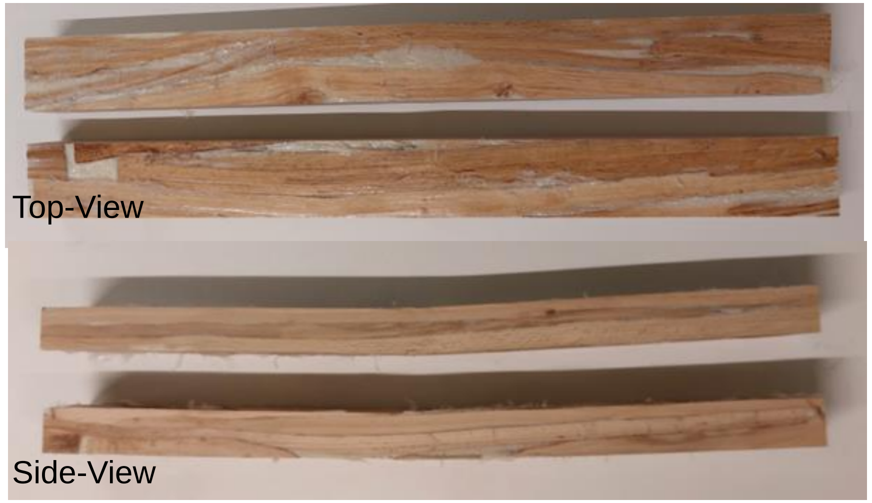
- Using Machine Learning algorithms to deal with the complexity of higher resource diversity.

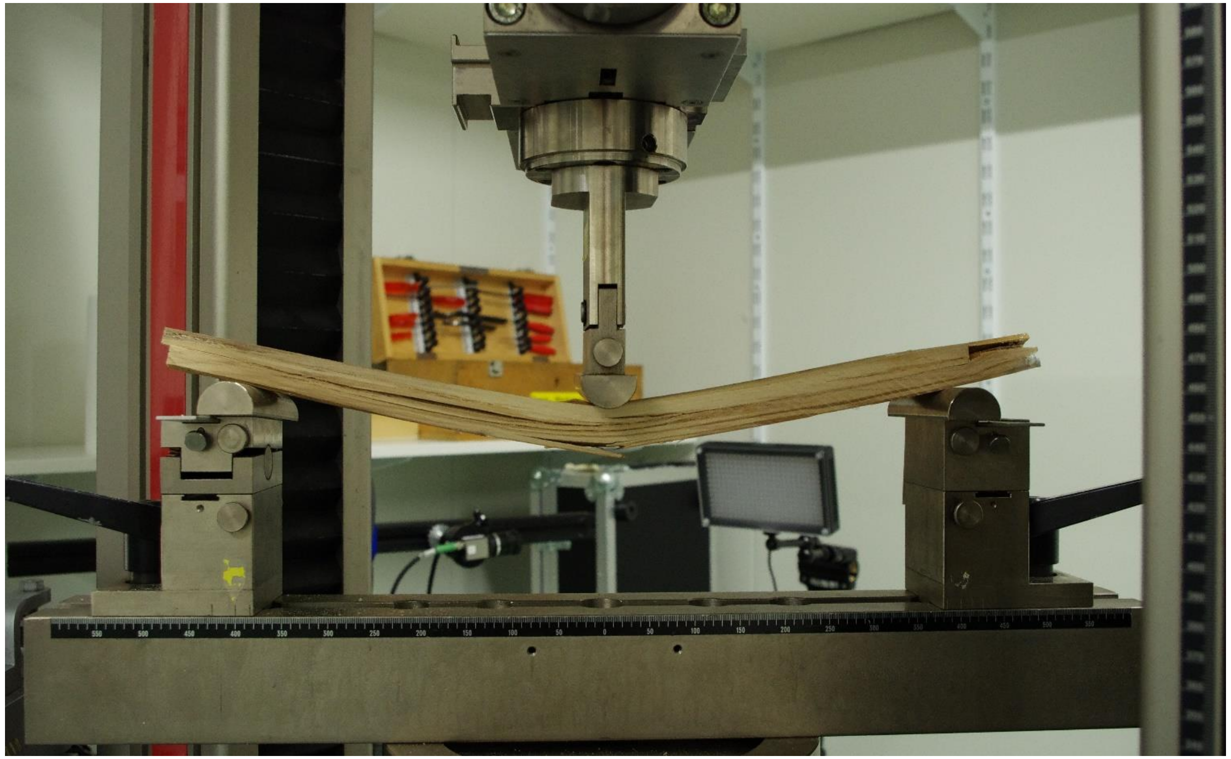
Sandro Stucki, Julia Achatz, Sebastian Kegel, Mark Schubert

Sub-project in the ETH Domain - Joint Initiative: MainWood - Together with Mark Schubert, Empa

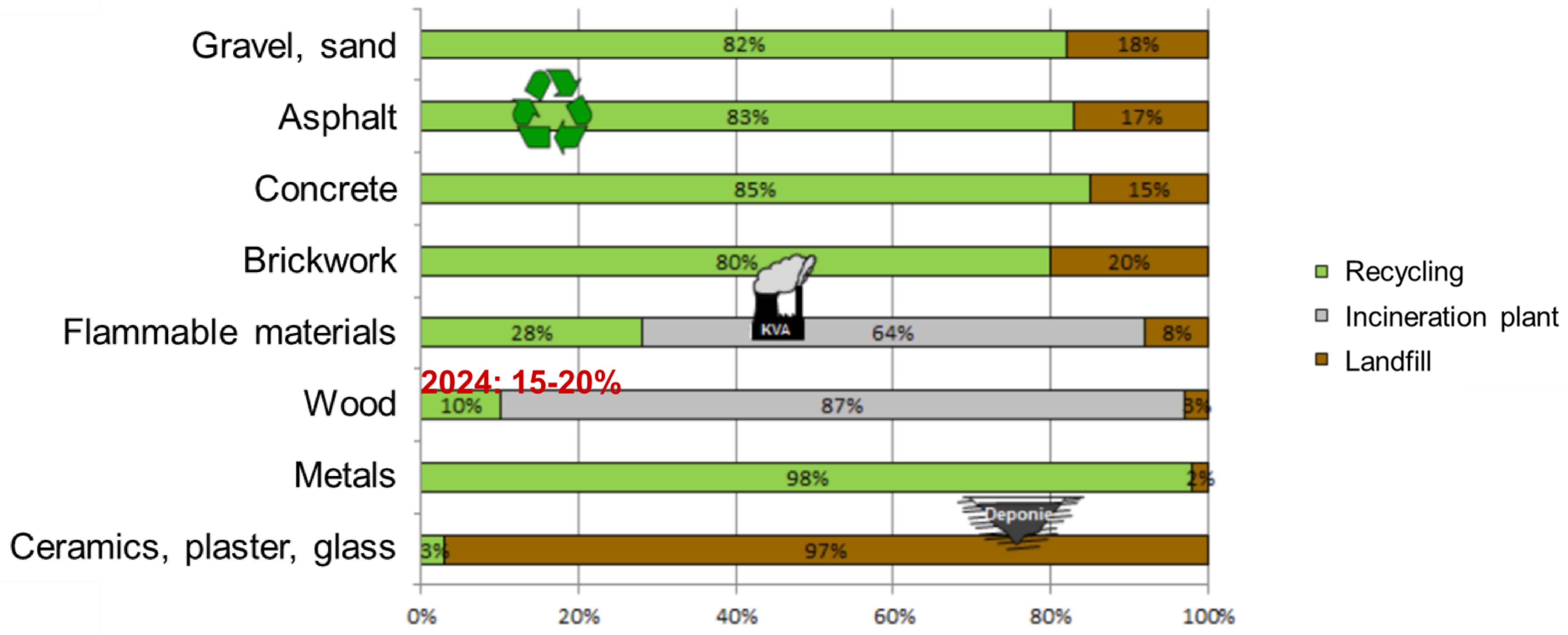
Split rod wood composites

- Bending tests on beech wood elements cut from produced split rod boards





Circularity - Recycling



Project MatCH – Bau: Empa, by order of BAFU (2016) modified

Wood gluing – bio-adhesives

Bio-adhesives for timber engineering applications

RSC Advances

ROYAL SOCIETY OF CHEMISTRY

REVIEW

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Cite this: *RSC Adv.*, 2017, 7, 38604

Development of sustainable bio-adhesives for engineered wood panels – A Review

Venla Hemmilä,*[a] Stergios Adamopoulos, *[a] Olov Karlsson[b] and Anuj Kumar [a]

Received 13th June 2017
Accepted 22nd July 2017

DOI: 10.1039/c7ra06598a

rsc.li/rsc-advances

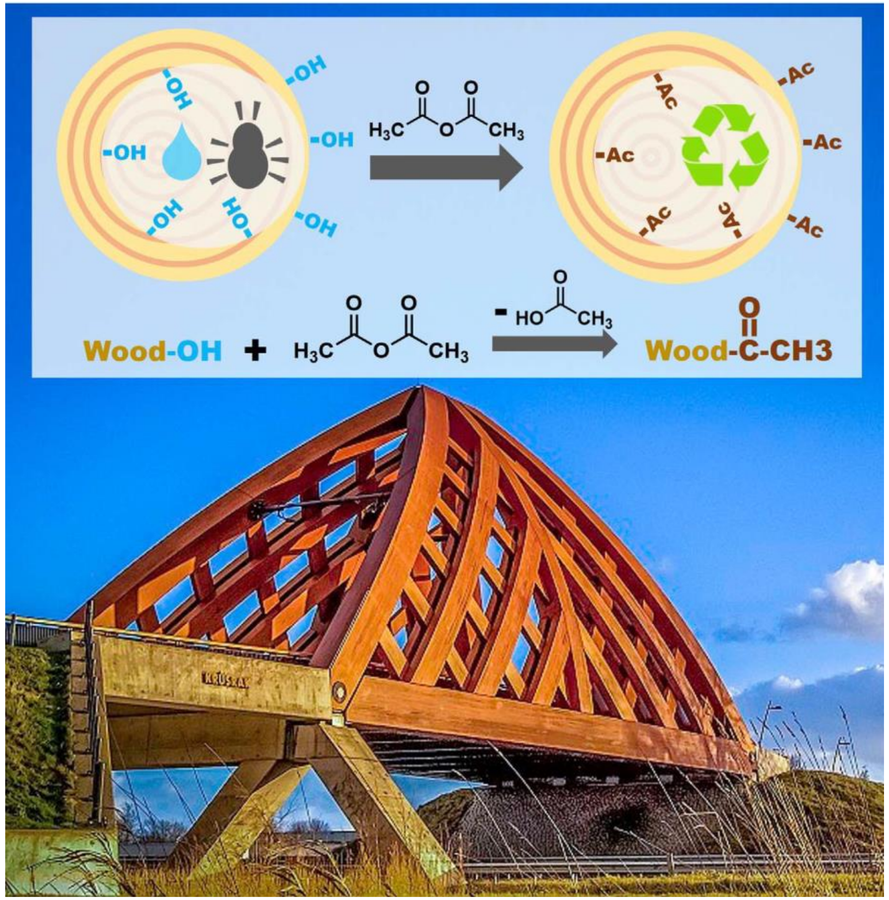
Changes in both formaldehyde legislations and voluntary requirements (*e.g.* Germany RAL) are currently the driving factors behind research on alternatives to amino-based adhesives; moreover, consumer interest in healthy and sustainable products is increasing in bio-based adhesives. Sources of formaldehyde emissions in wood-based panels as well as different emission test methods have been discussed, and the main focus of this review is on the research conducted on sustainable bio-based adhesive systems for wood panels. Lignin, tannin, protein, and starch have been evaluated as both raw materials and adhesive alternatives to existing amino-based thermosetting adhesives. Adhesion improving modifications of these bio-based raw materials as well as the available and experimental crosslinkers have also been taken into account.

Glue joints "debonding on demand"?

Stimulus, crosslink density in thermosets…

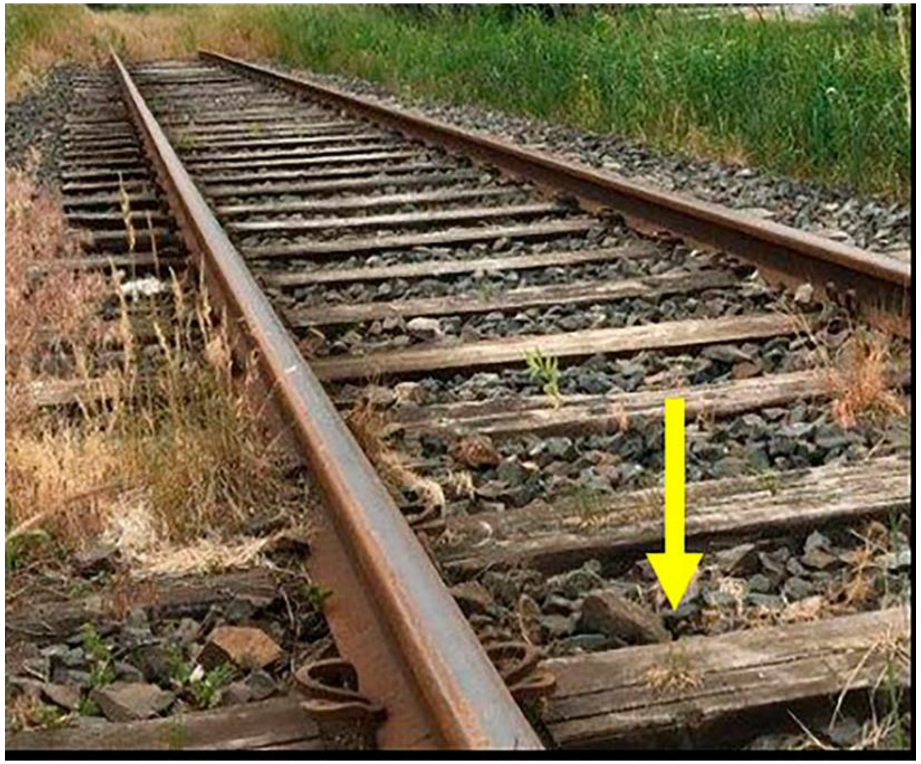
Circularity

Wood modification treatments



Ramage et al. (2017) Renewable & Sustainable Energy Reviews

Replacement of biocides in wood protection?



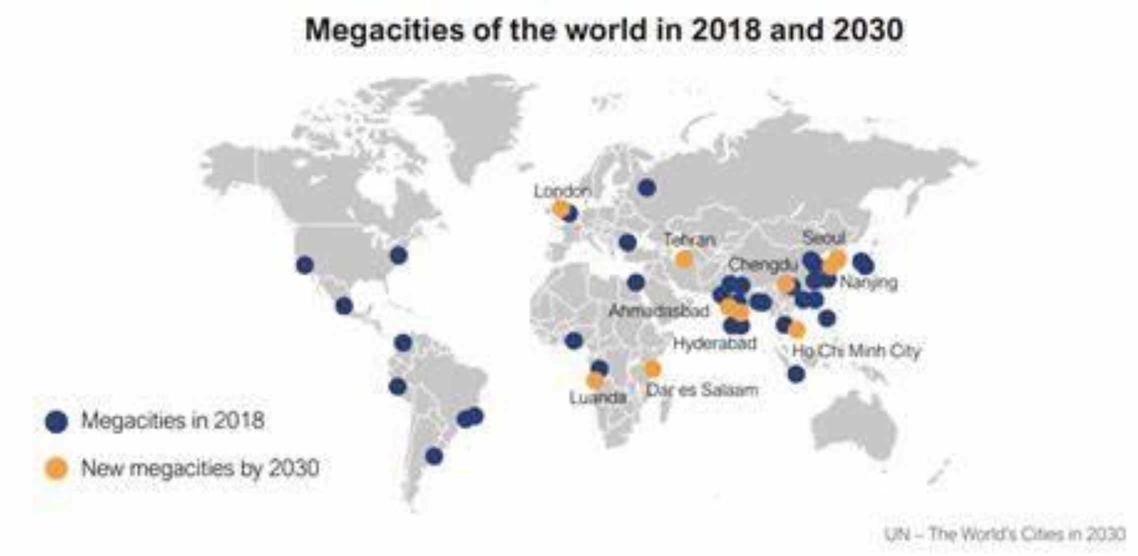
Marais...Militz (2020) Wood Materials Science & Engineering

- *Reference to Holger Militz, Jeff Morrell, Callum Hill, Roger Rowell*

Green and energy-efficient wood processing techniques

Circularity – Recycling - Reuse

- **Raw wood is sustainable, but current wood products are only partly, and this restricts circularity**

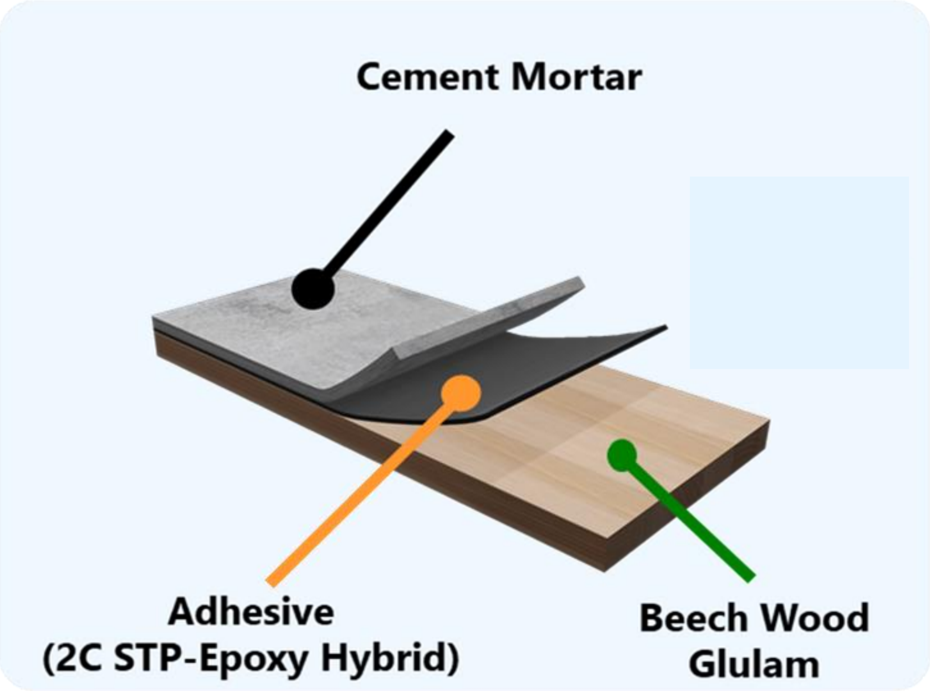


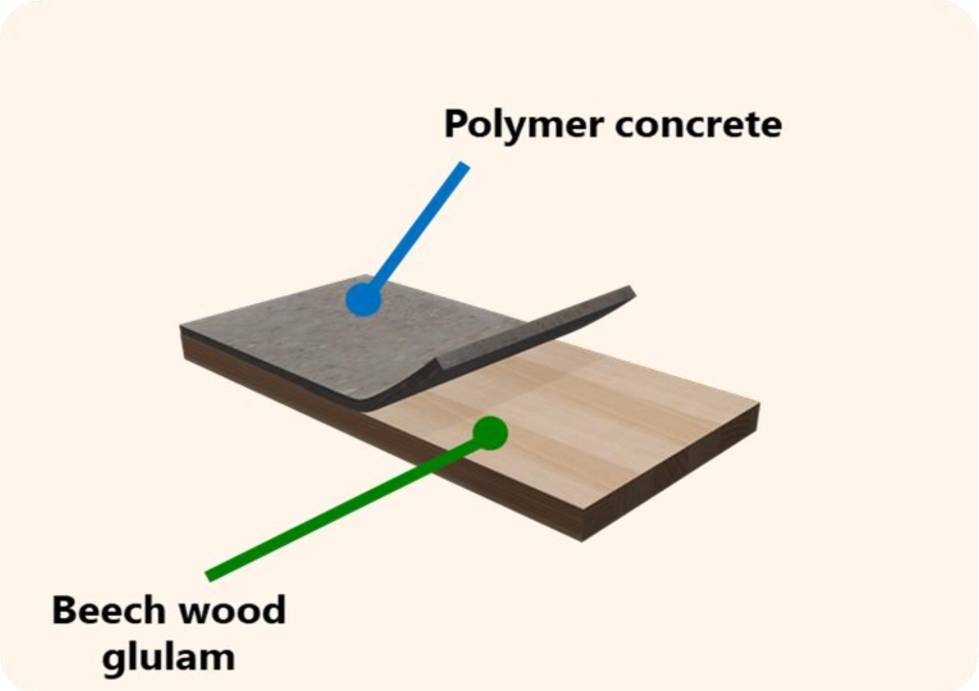
Required research and development

- Improved sorting techniques (ML)
- Replace fossil-based adhesives with bio-based ones and/or debonding on demand
- "Green" coatings and bulk modifications to improve flame retardance, dimensional stability, UV protection
- **Durable wood without biocide treatments**

Termites

Wood Hybrid Products– Adhesive-bonded Timber-Concrete Composites

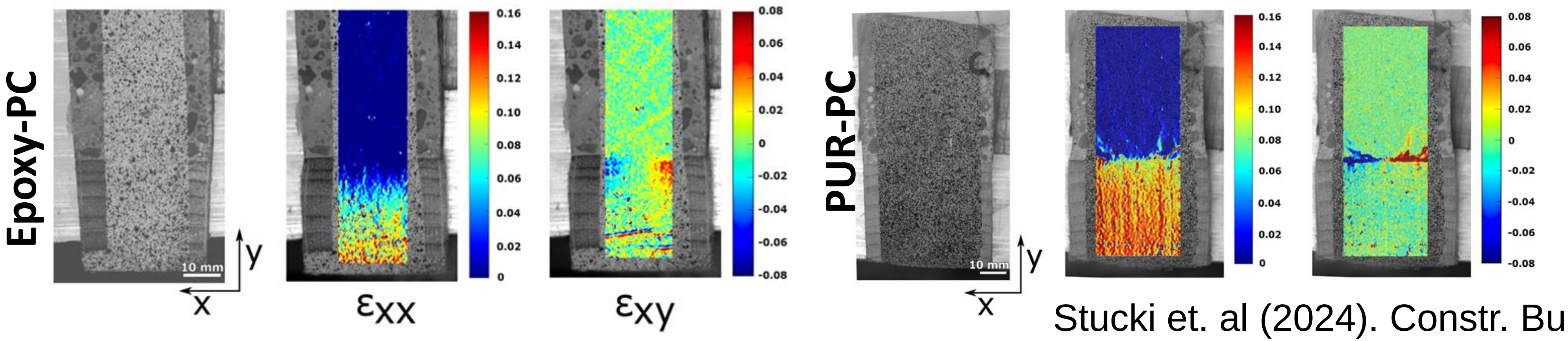




Sandro Stucki

BUILDING TRUST Sika

FAGUS SUISSE

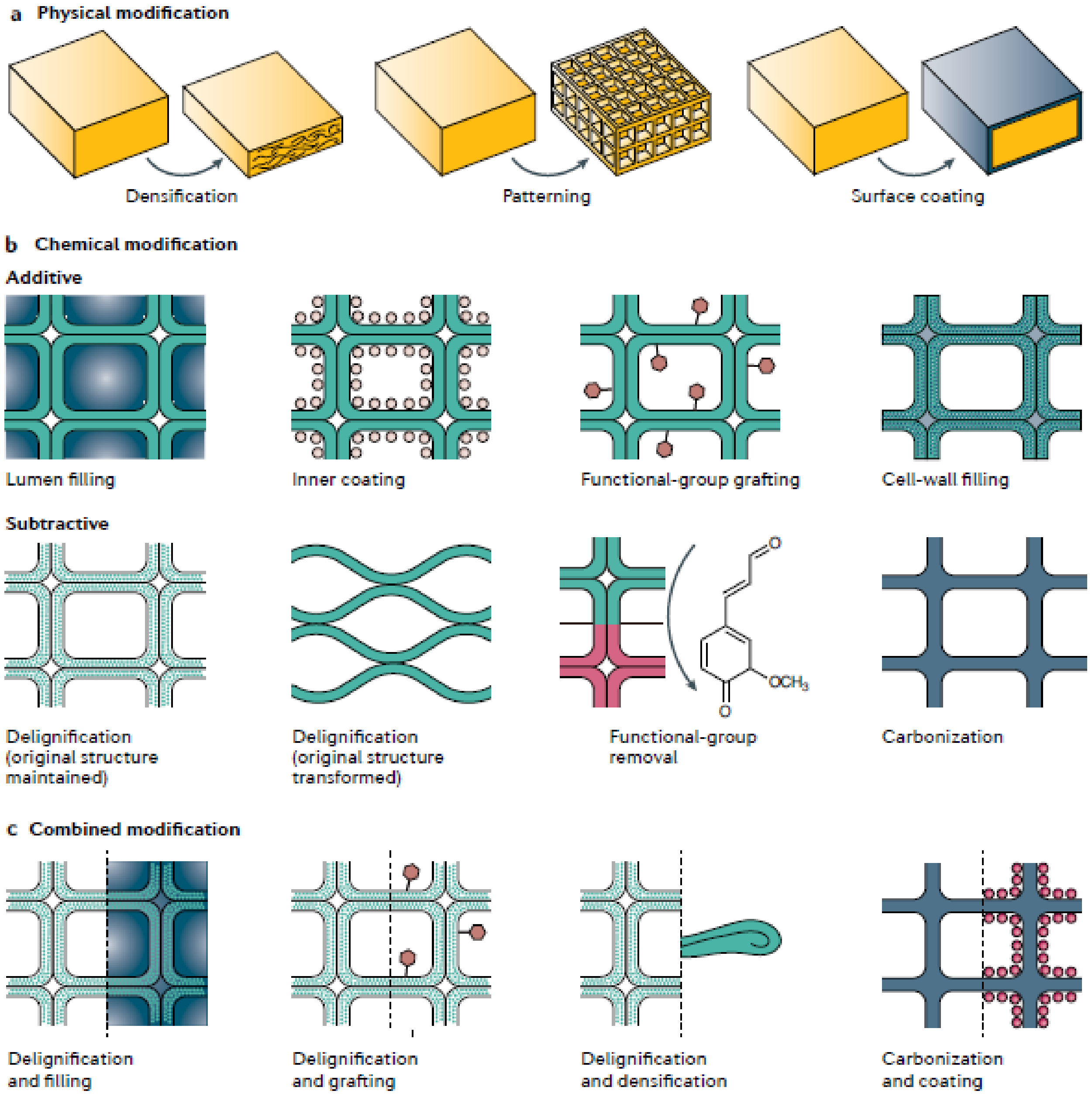


Visualization of Swelling Strains by Digital Image Correlation (DIC)

Stucki et. al (2024). Constr. Build. Mater. 411

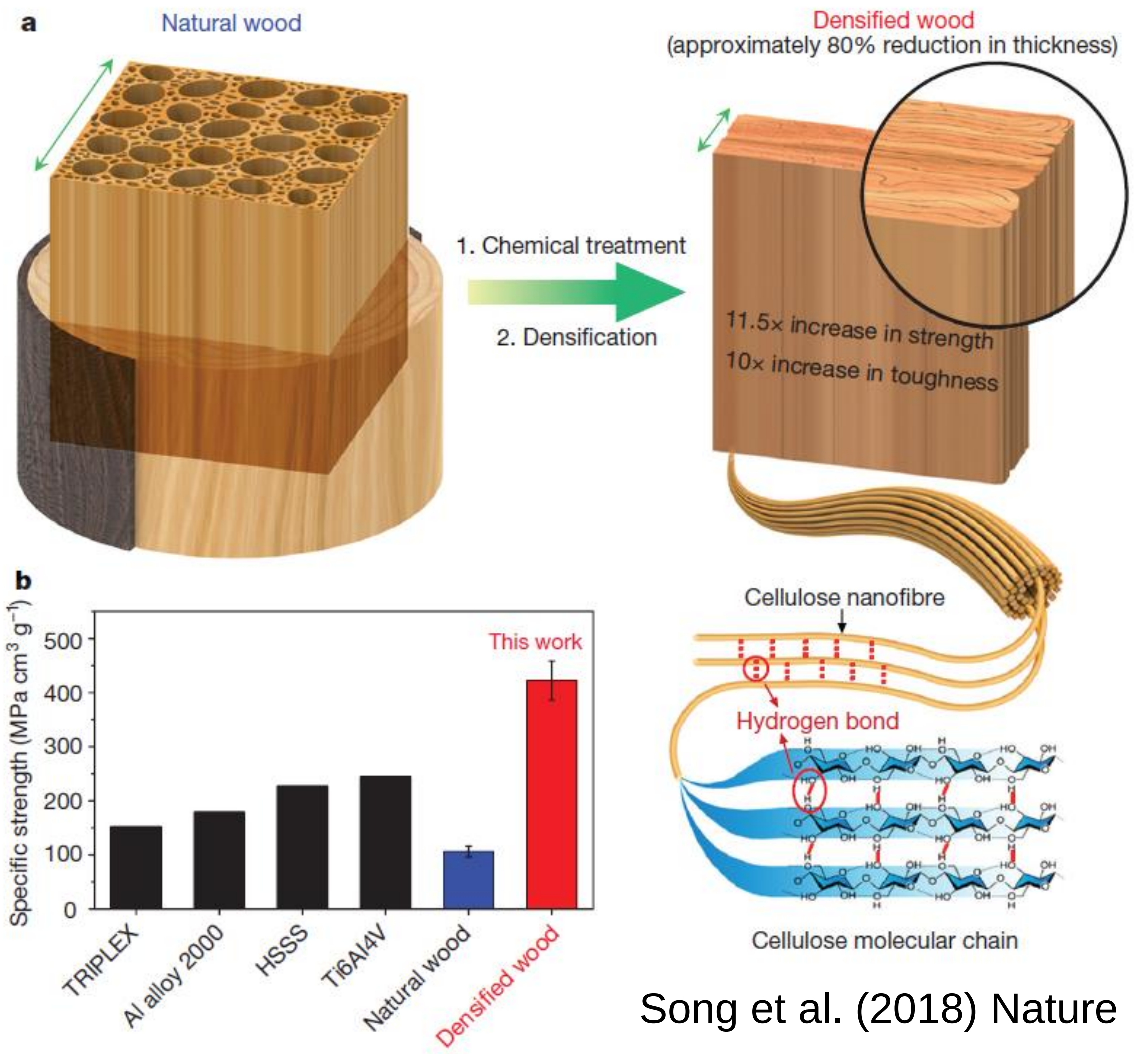
Circularity

Wood modification and functionalization



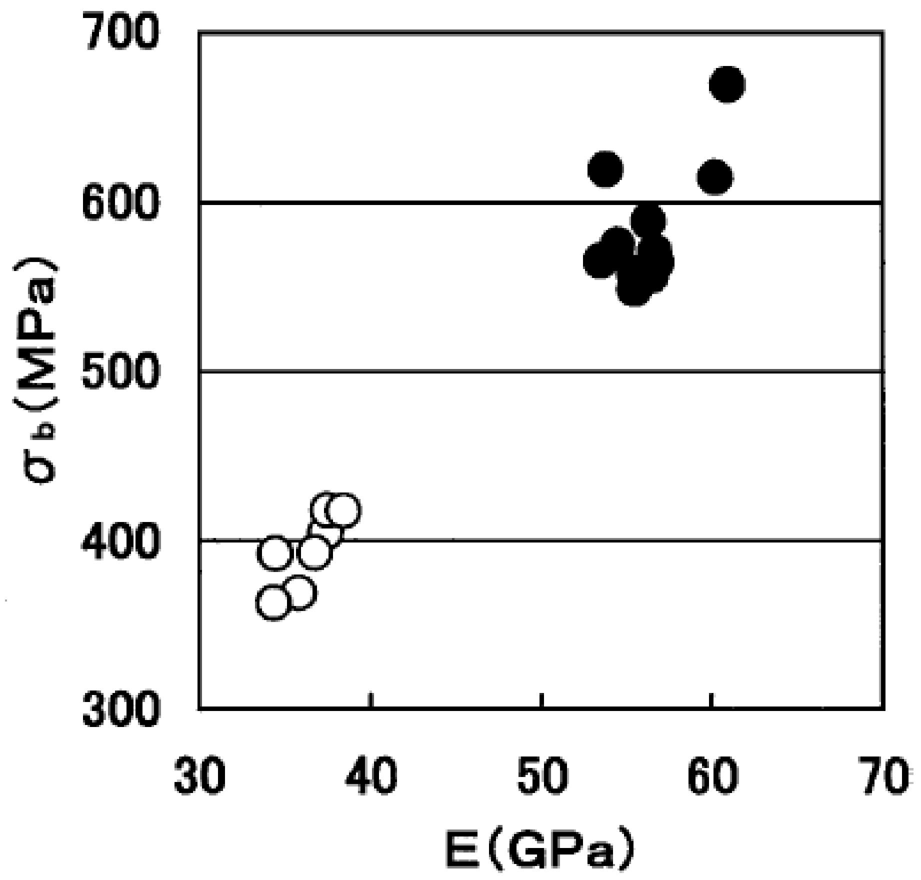
Chen et al (2020) Nature Reviews Materials

High-strength cellulose composites



Song et al. (2018) Nature

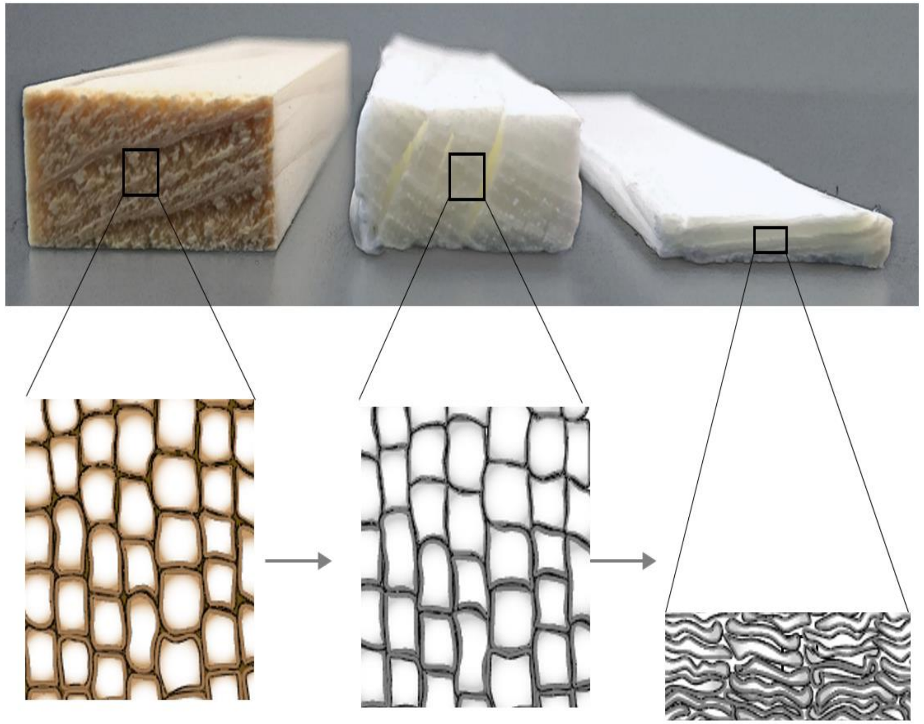
Partly delignified, PF resin impregnated and densified veneers

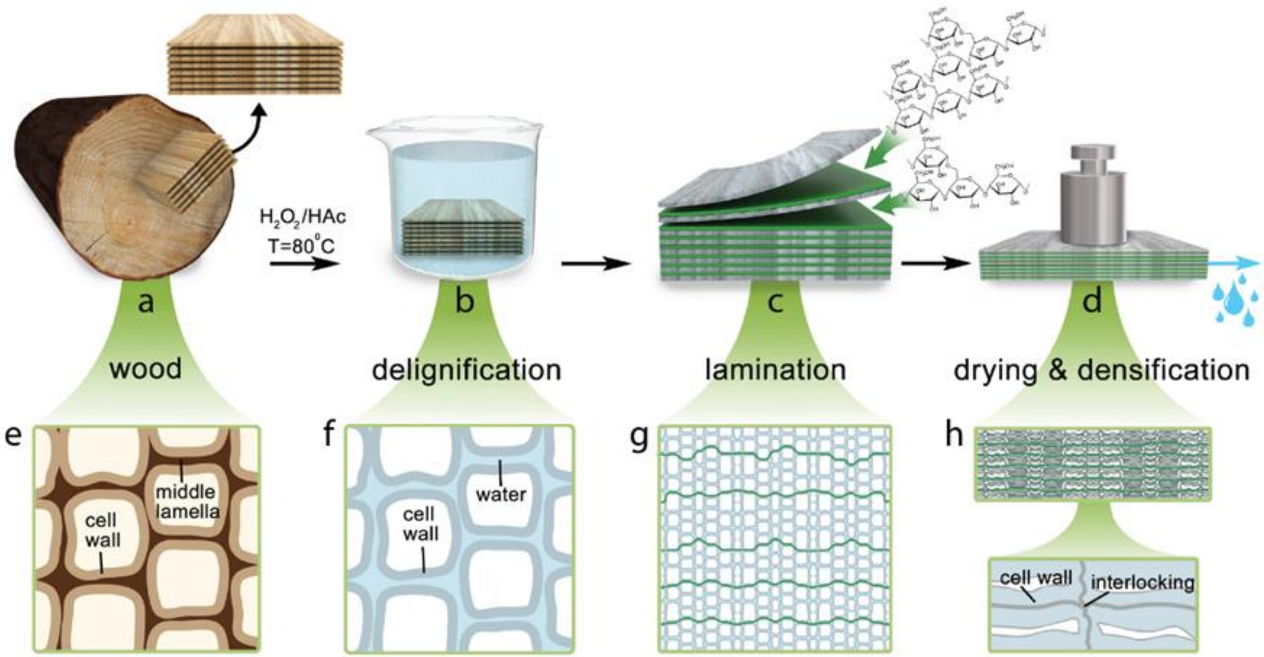


Yano (2001) J Materials Sci Letter

High-strength cellulose composites

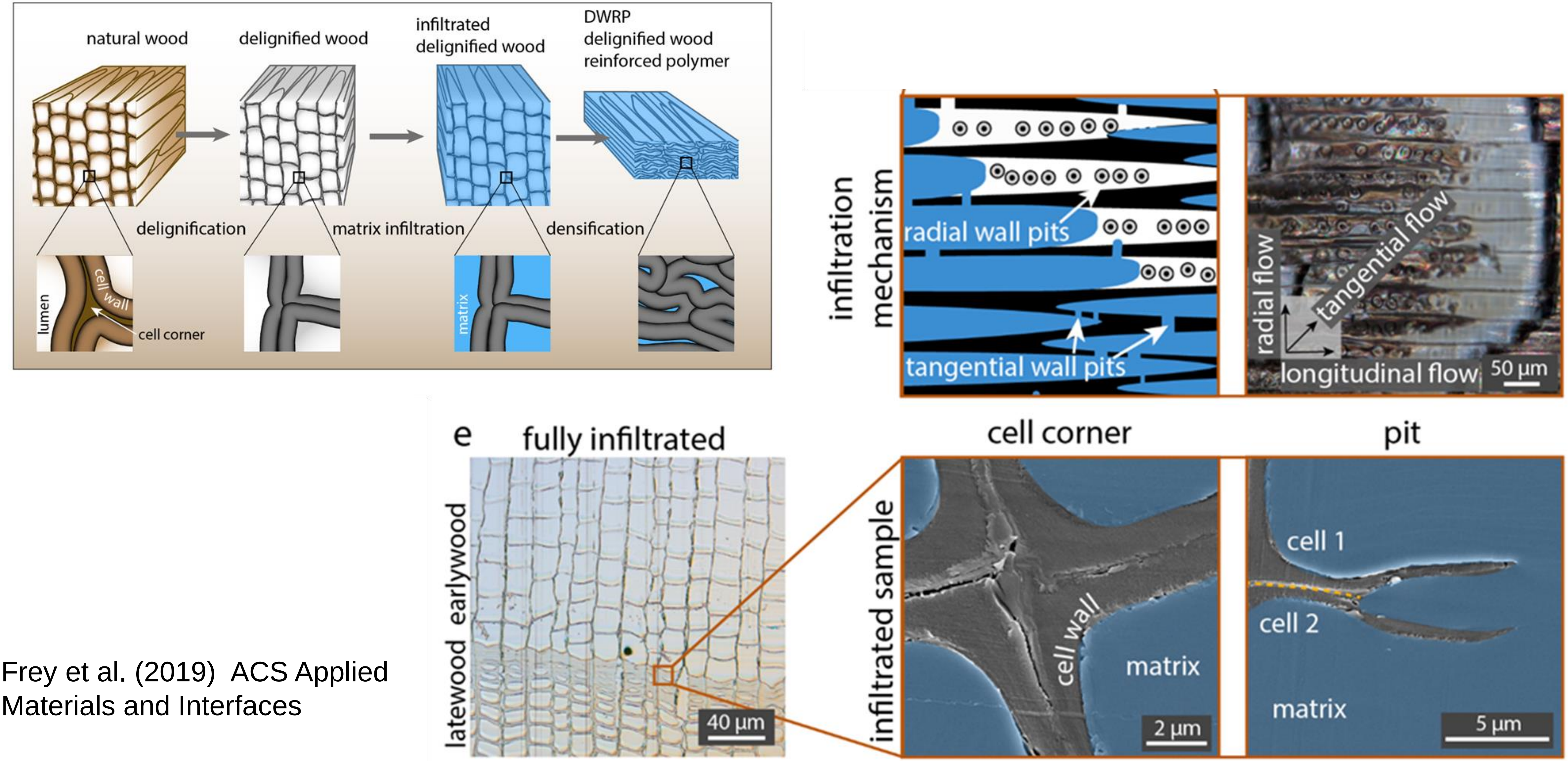
Marion Frey
Tobias Keplinger





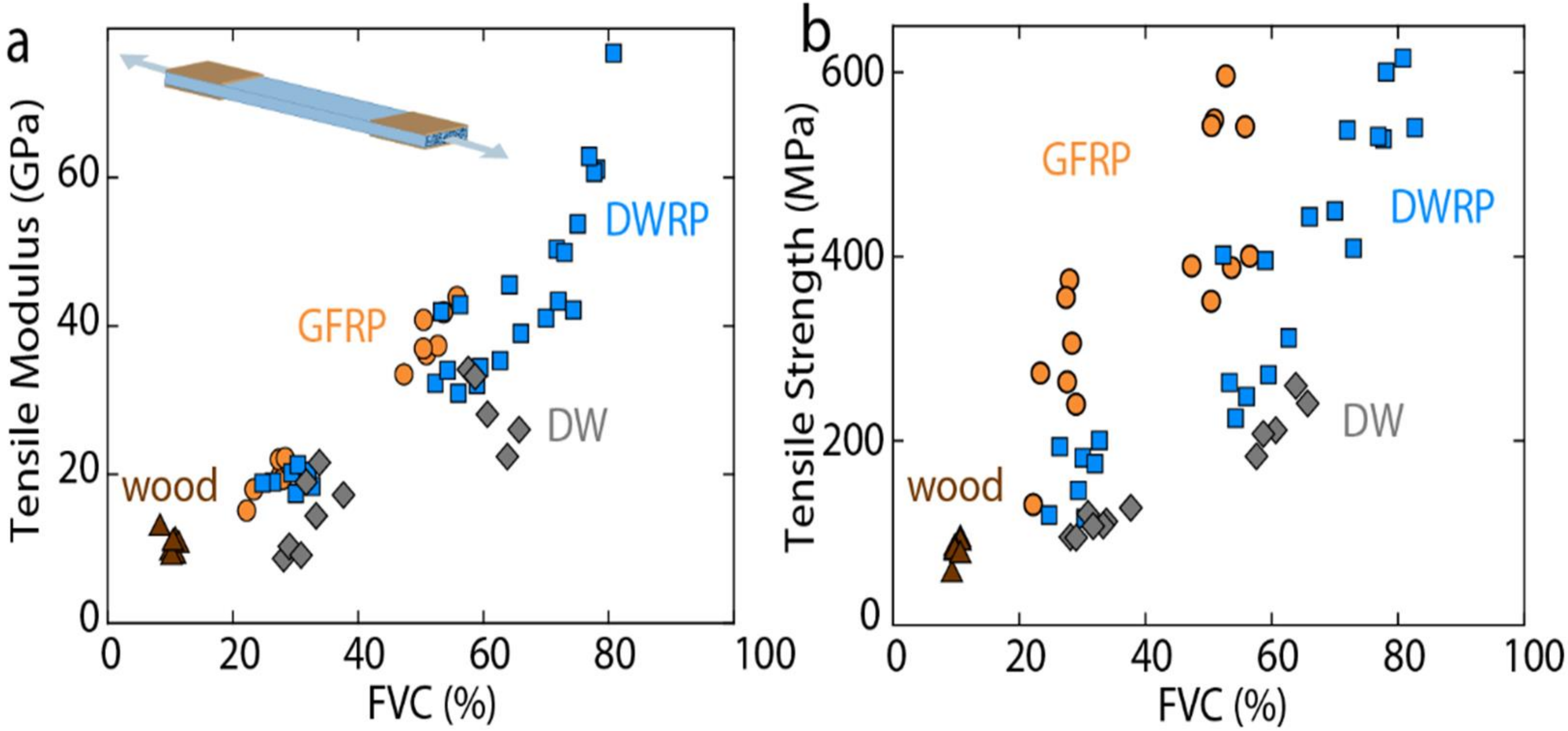
Frey et al. (2018) ACS Applied Materials and Interfaces

Delignified wood-polymer interpenetrating composites



Frey et al. (2019) ACS Applied Materials and Interfaces

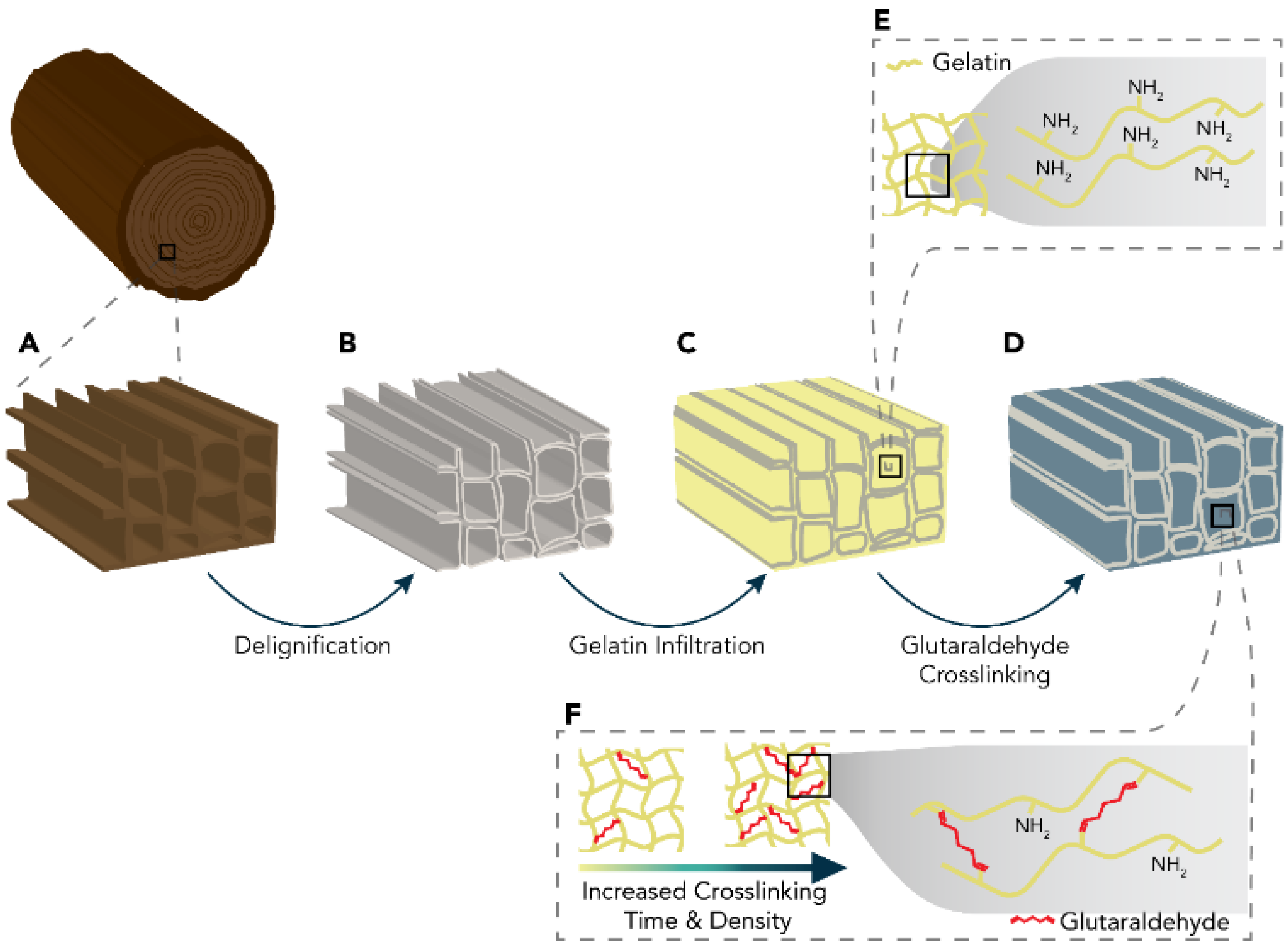
Delignified wood-polymer interpenetrating composites



Frey et al. (2019) ACS Applied Materials and Interfaces

Delignified wood-gelatin composites

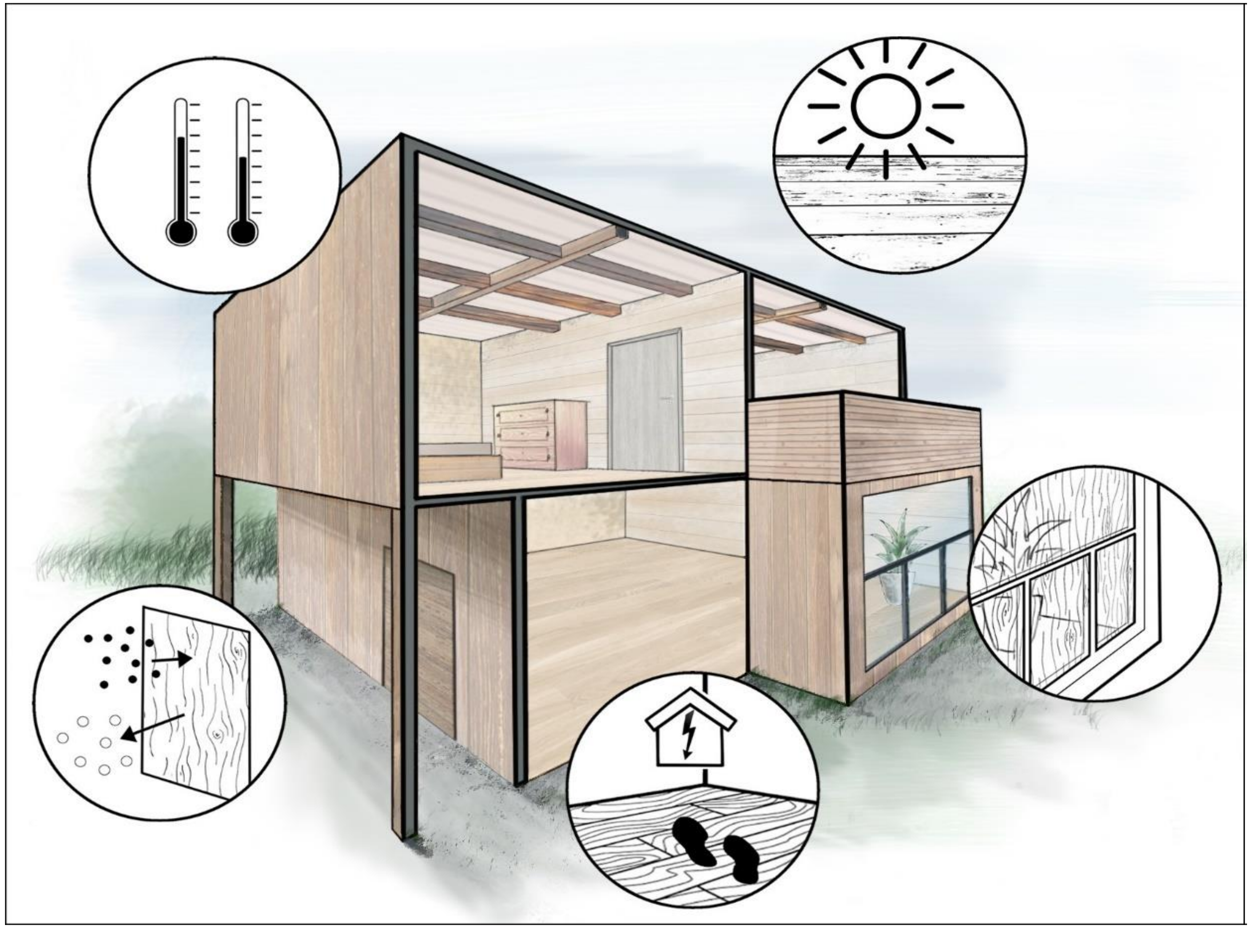
Sophie Koch



Koch et al. (2023) Materials Today Bio

Connection to Smart Building Technologies

Functional wood materials



Panzarasa & Burgert (2021) Holzforschung

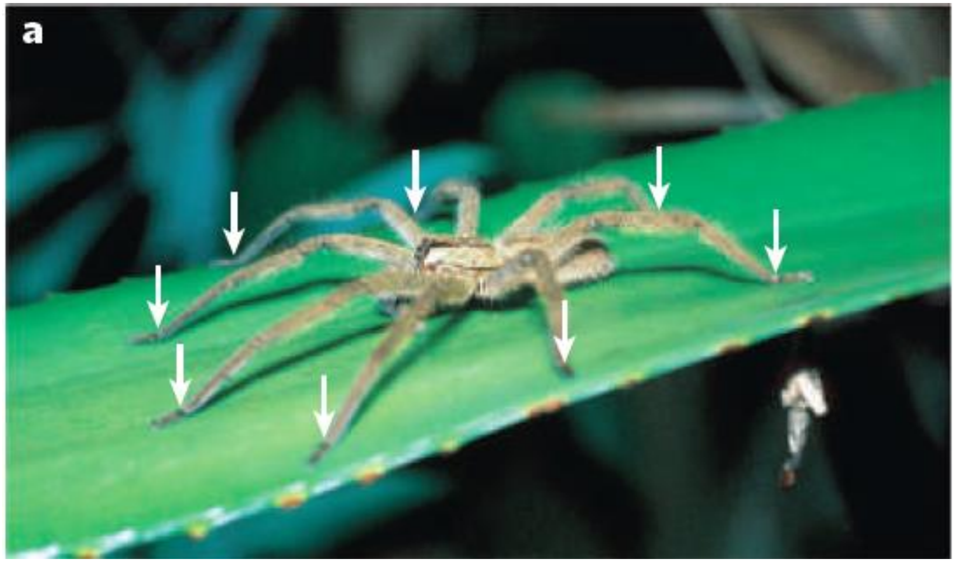
From passive structural members to active materials

- Control of room climate
- Sensing
- Energy harvest / savings
- Light management
- Acoustics
- Self-shaping building elements

Wood with new functions has the potential to reach new fields of application

Organisms with “embedded sensors” as source of bio-inspiration

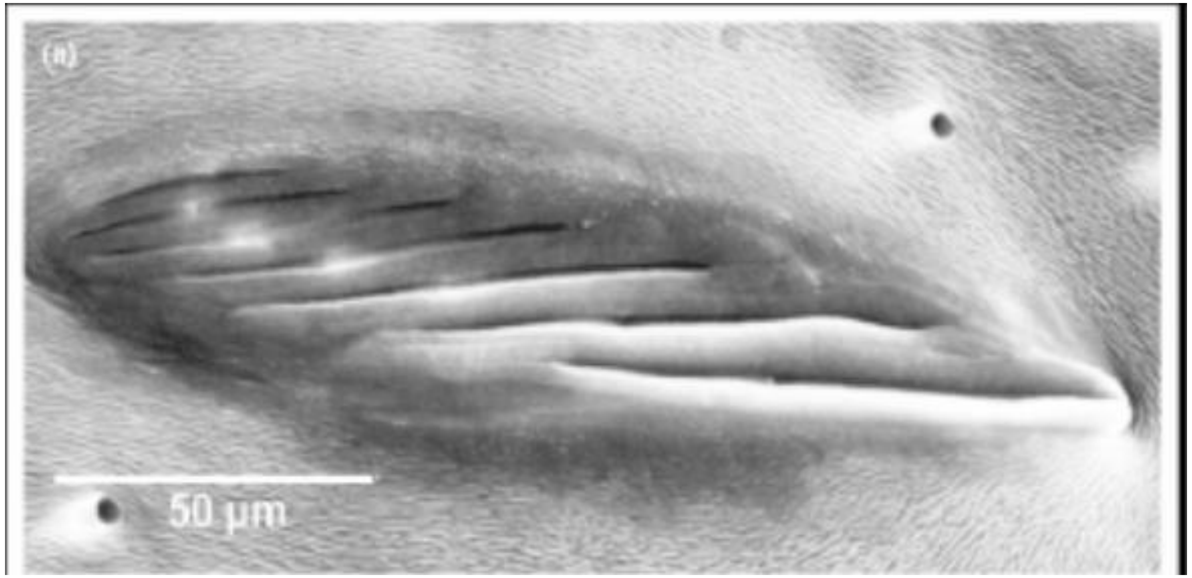
Tiger wandering spider
(*Cupiennius salei*)



Vibration sensors

Fratzl and Barth (2009) Nature

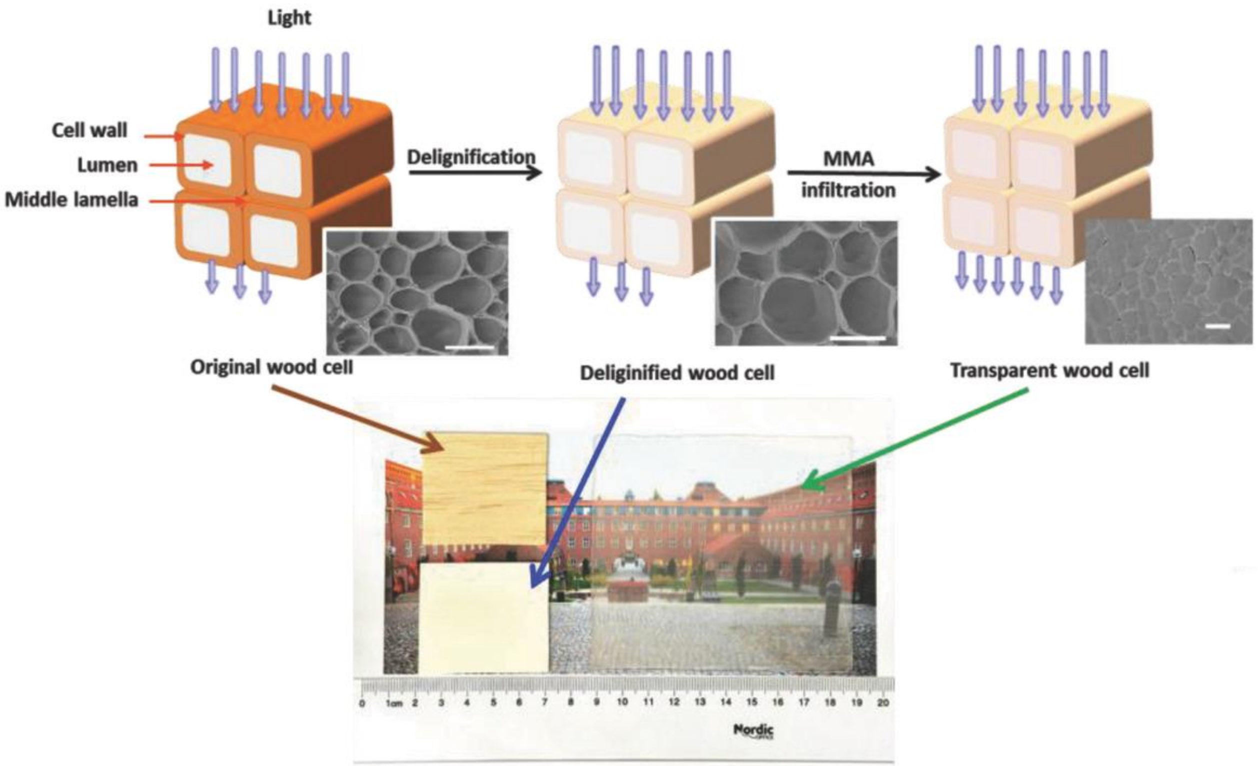
Slit sensilla in the cuticular exoskeleton of spiders



Barth (2004) Current Opinion in Neurobiology

Transparent wood

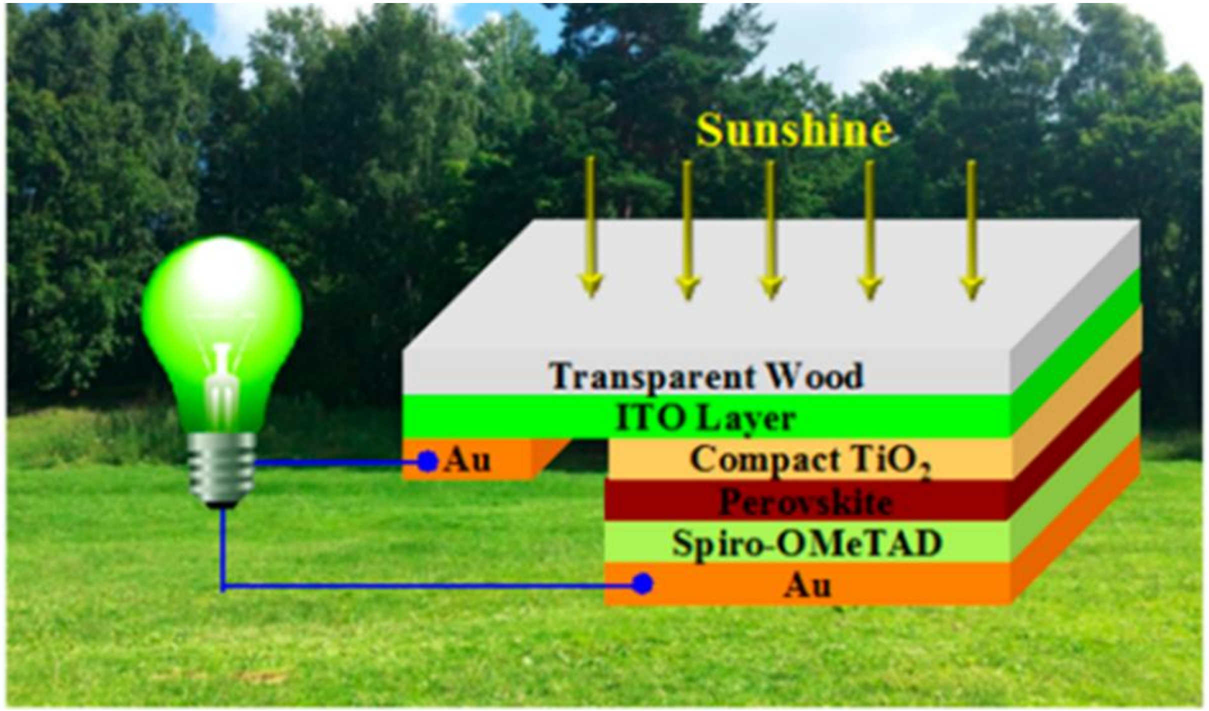
Polymer Infiltration for Refractive Index Matching



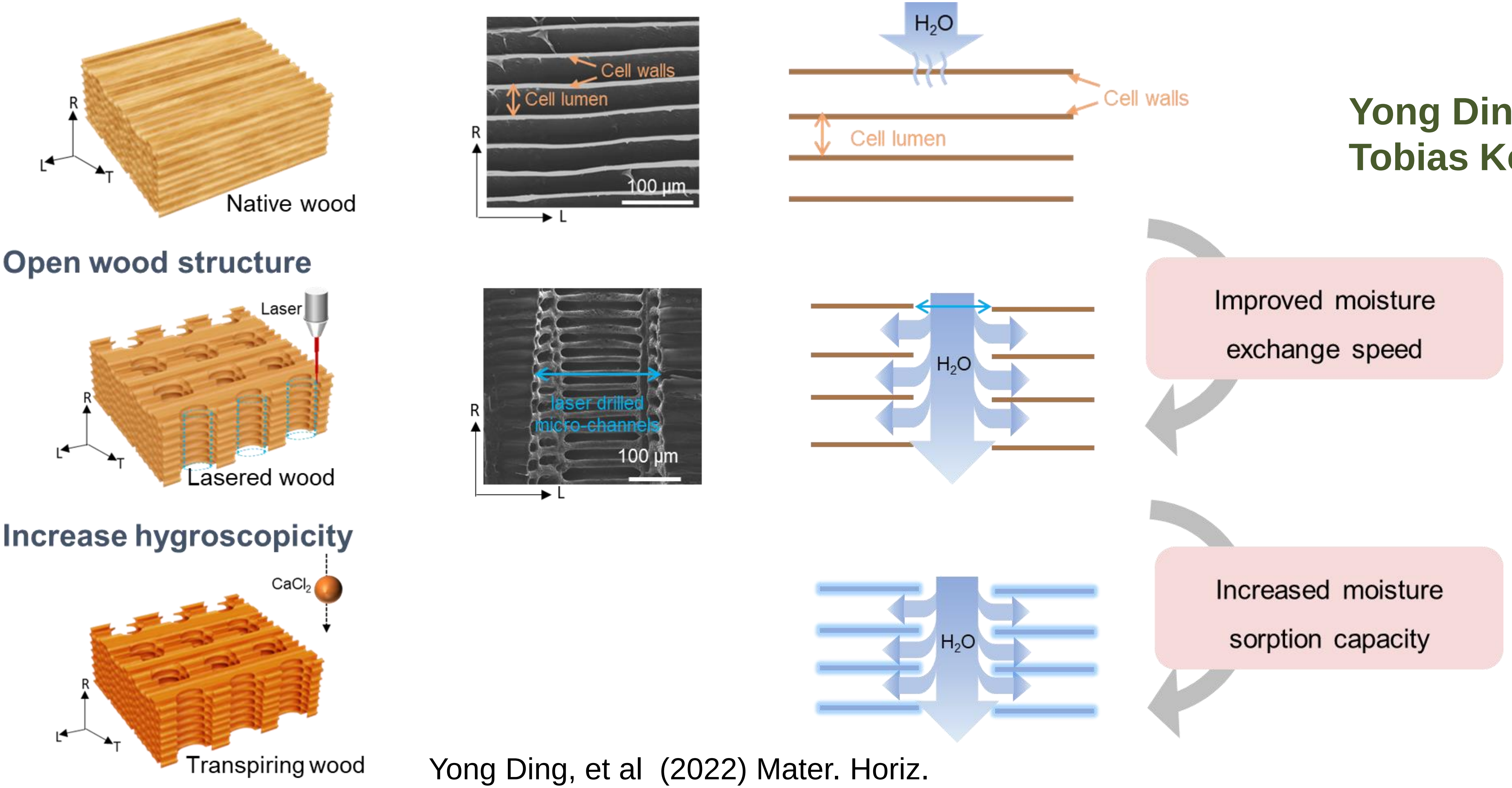
Y. Li et al. (2018)
J. Mater. Chem. A

Transparent Wood for Solar Cells

- mechanical properties
- insulation (low thermal conductivity)
- light scattering (haze)



Passive Indoor Climate Regulation with Wood/$CaCl_2$ Composites

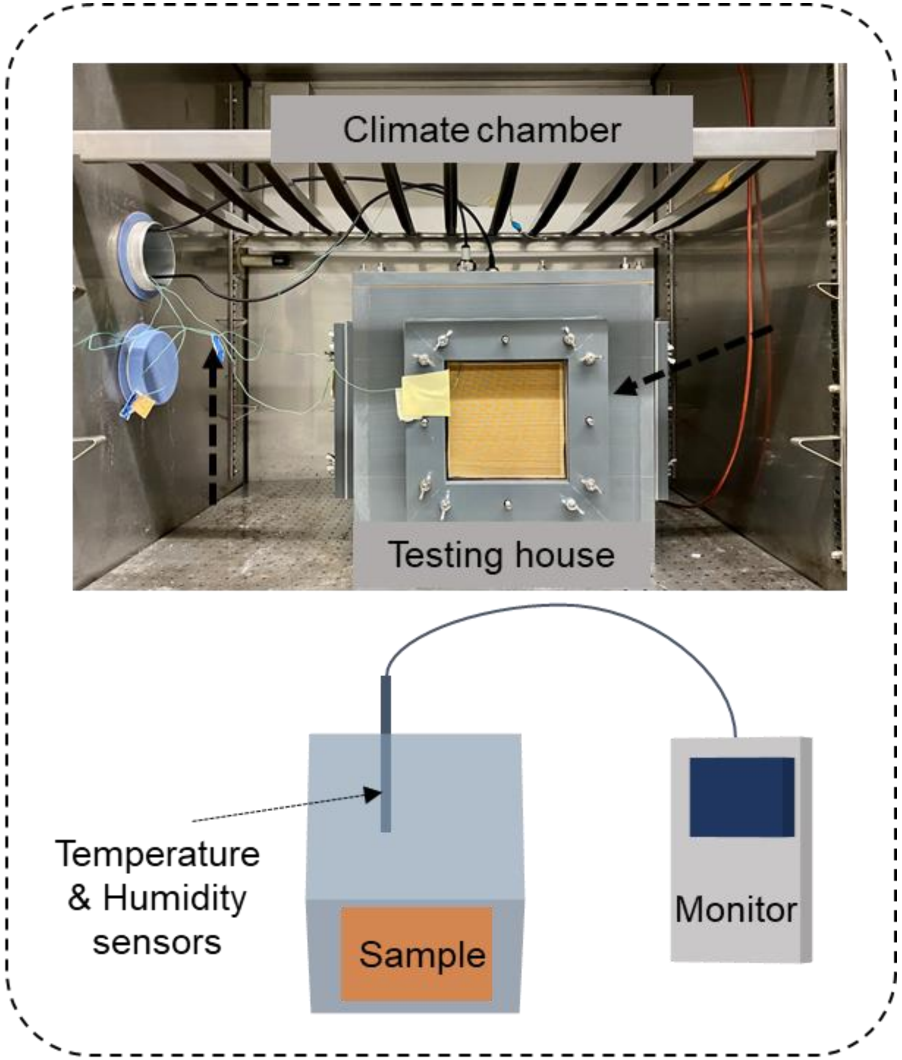


Yong Ding
Tobias Keplinger

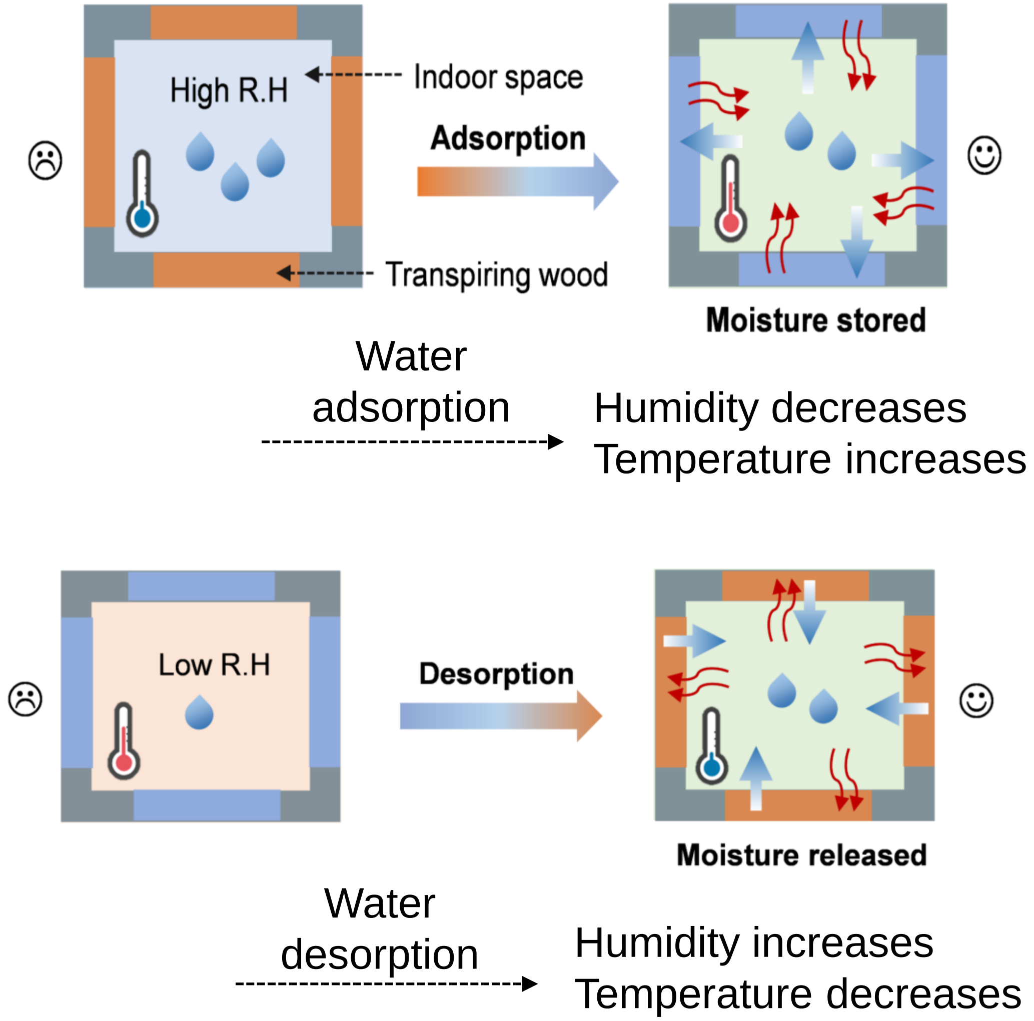
Yong Ding, et al (2022) Mater. Horiz.

Passive Indoor Climate Regulation with Wood/$CaCl_2$ Composites

- Setup for climate regulation measurement



- Climate regulation mechanism

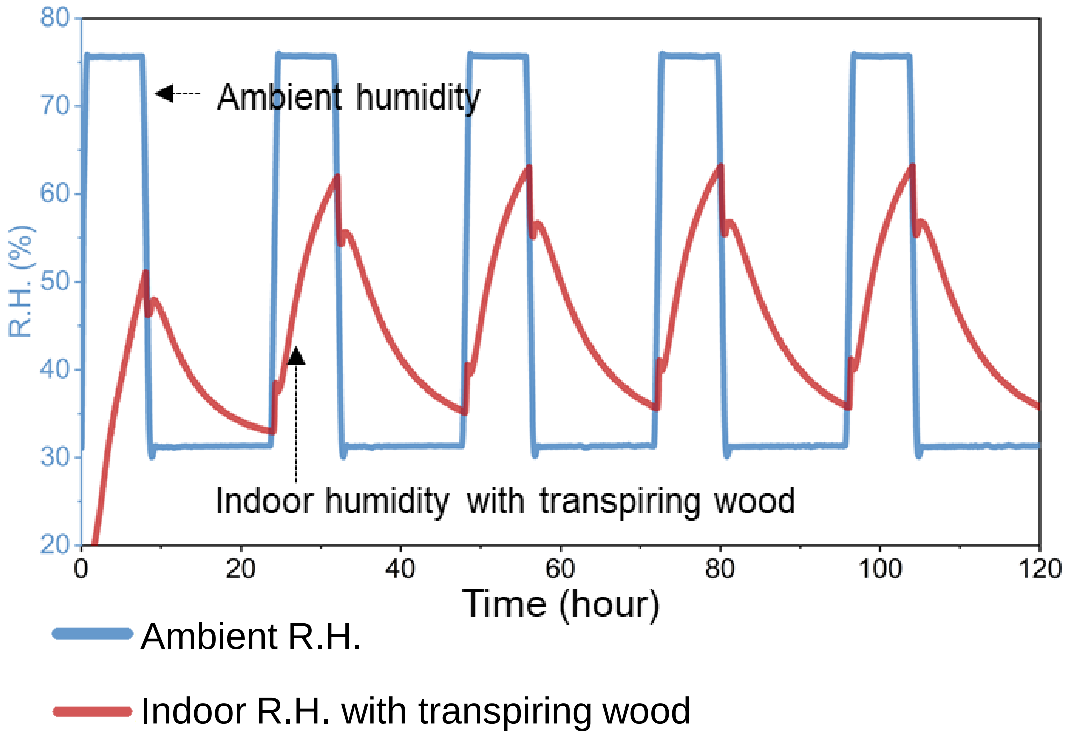


Ding et al. (2022) Mater. Horiz.

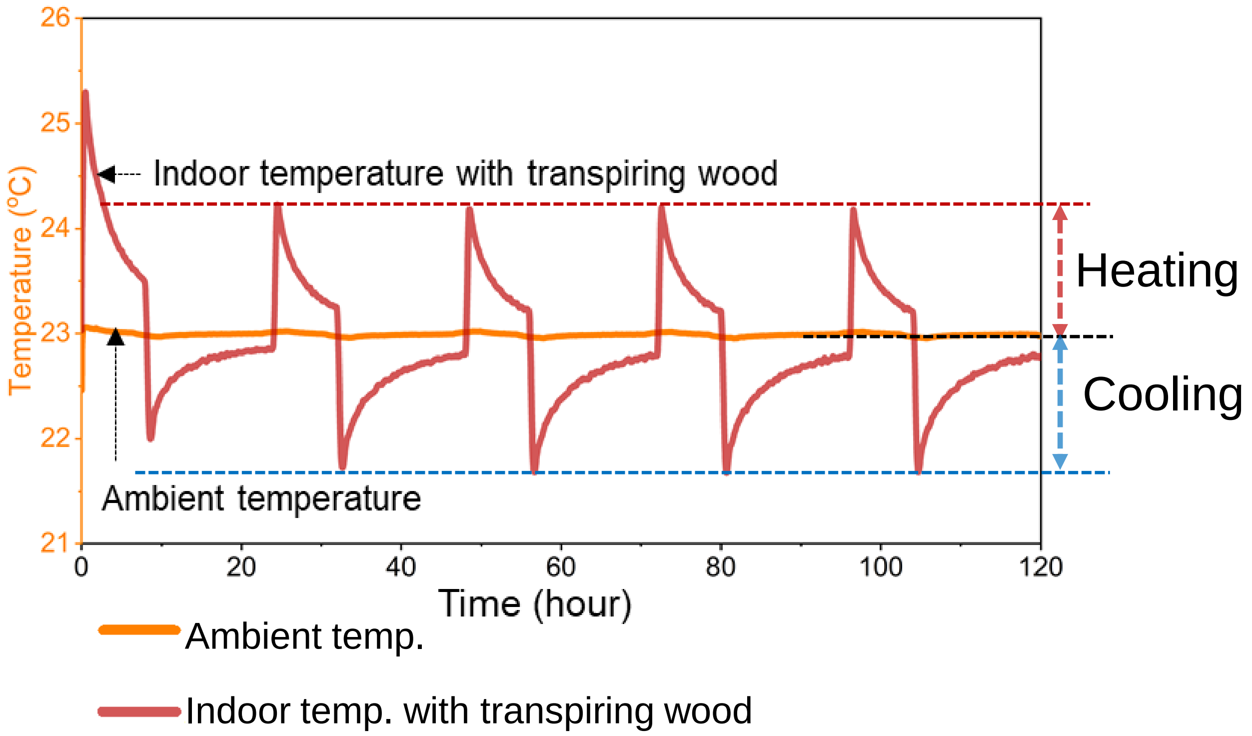
Passive Indoor Climate Regulation with Wood/$CaCl_2$ Composites

- 23°C, **75**% R.H., 8 hours
- 23°C, **30**% R.H., 16 hours

- Humidity regulation



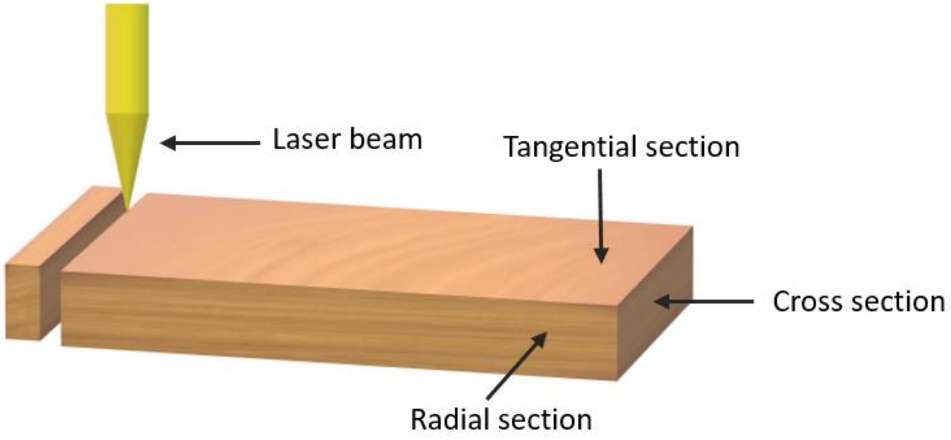
- Thermal regulation

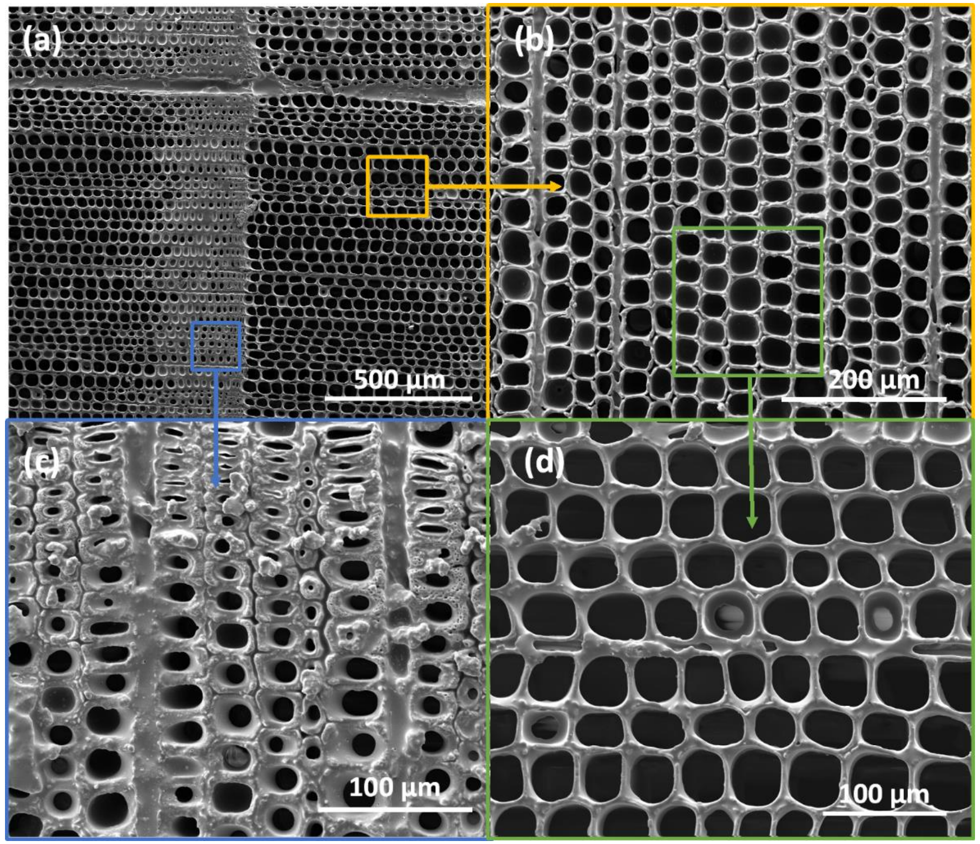


Yong Ding, et al (2022) Mater. Horiz.

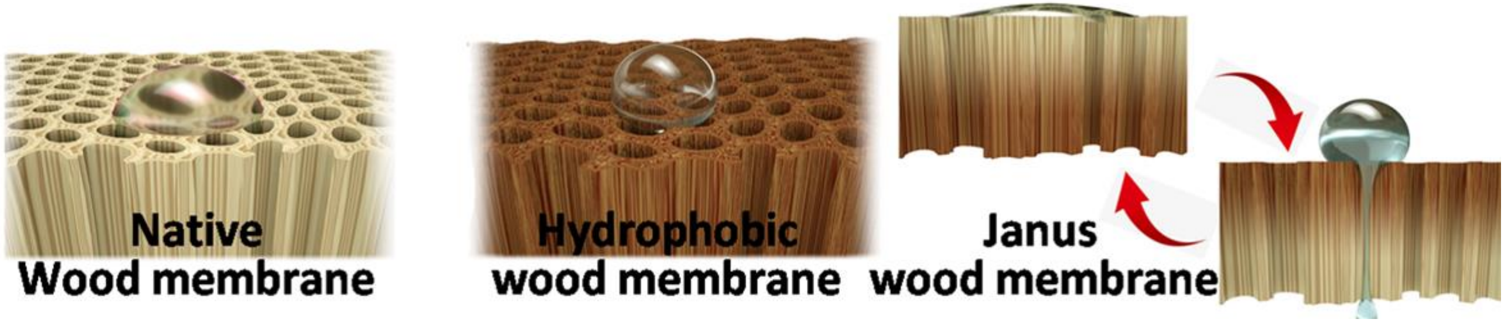
Controlled directional water transport

Laser cutting





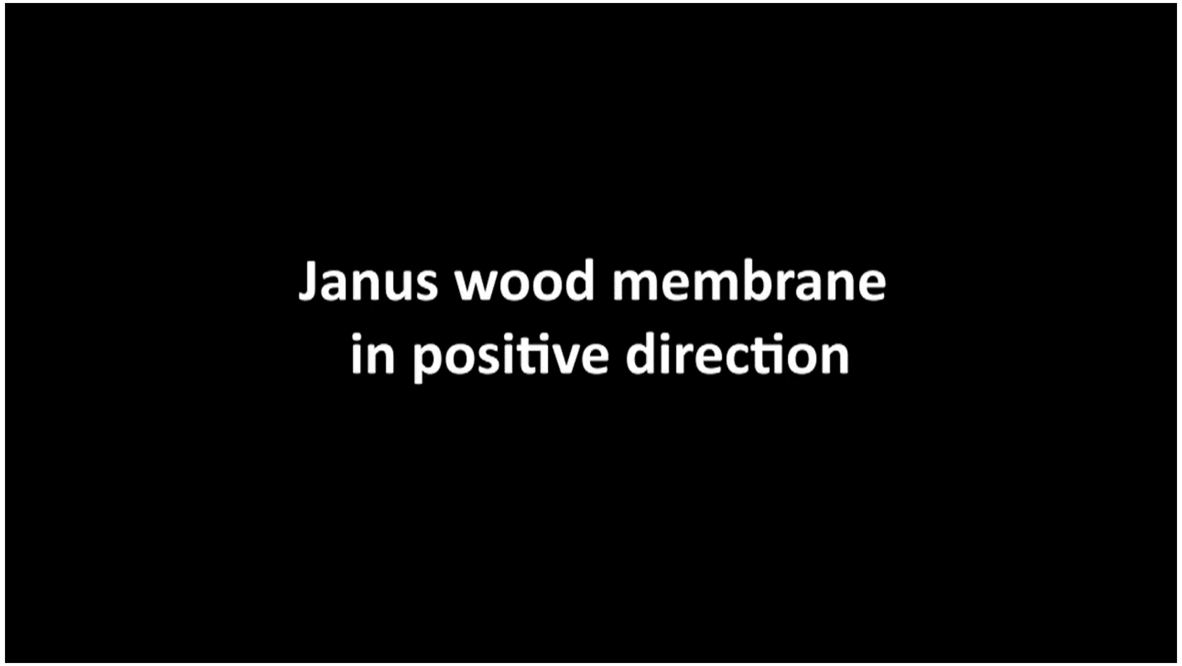
Introducing a wettability gradient into wood membranes

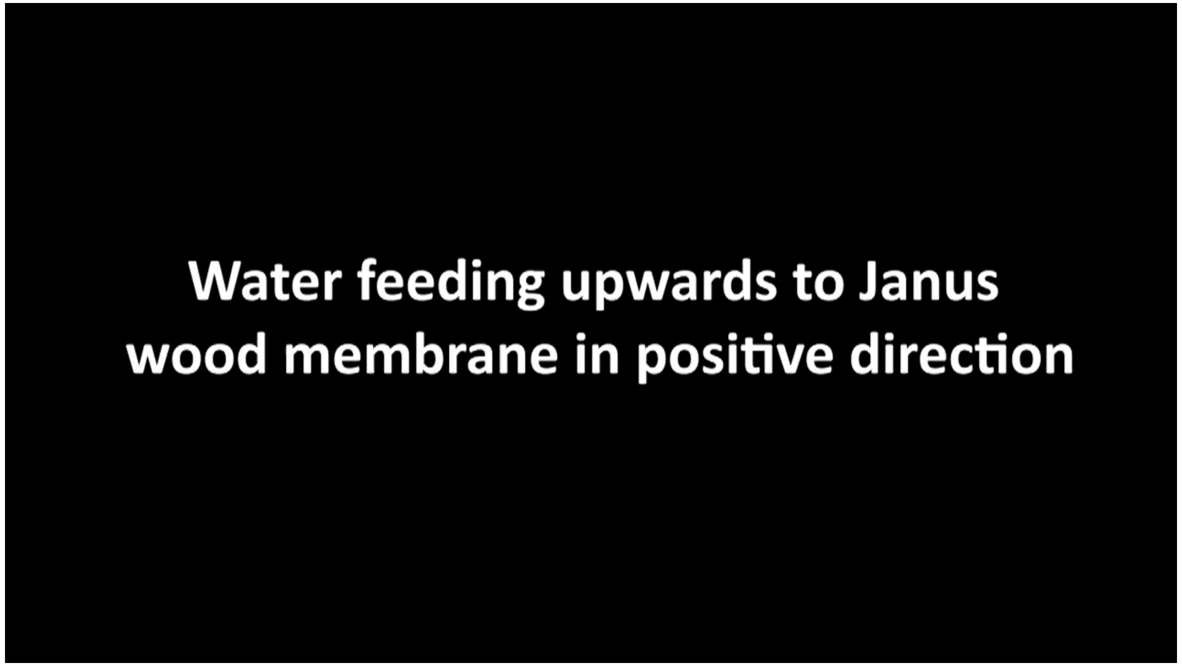


Yong Ding
Tobias Keplinger

Ding et al. (2020)
J. Mater. Chem. A

Controlled directional water transport

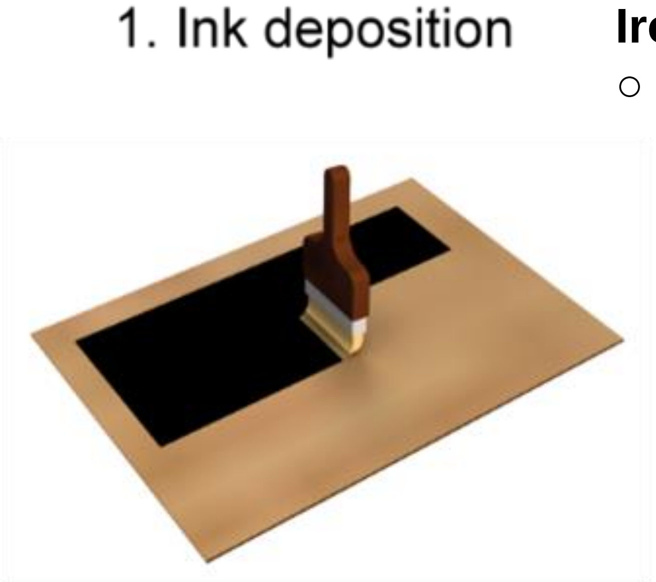




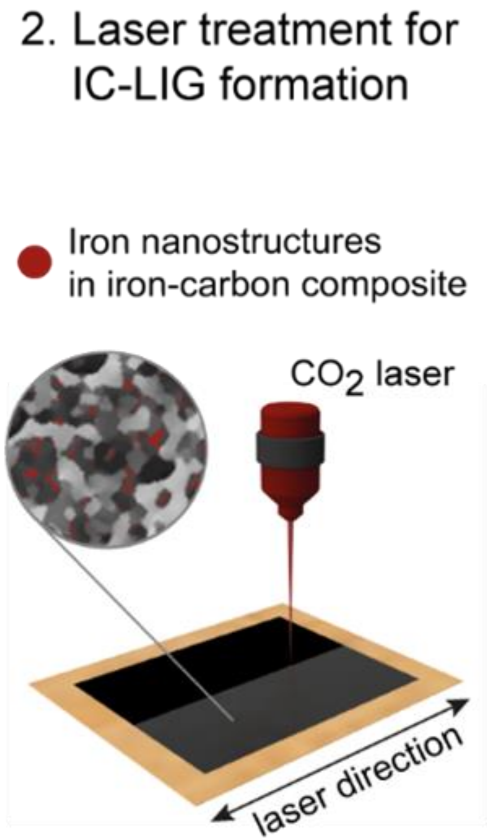
Ding et al. (2020) J. Mater. Chem. A

Electric conductivity by laser-induced graphitization of wood

Christopher Dreimol
Guido Panzarasa



Iron-tannin ink
○ Bio- and water-based

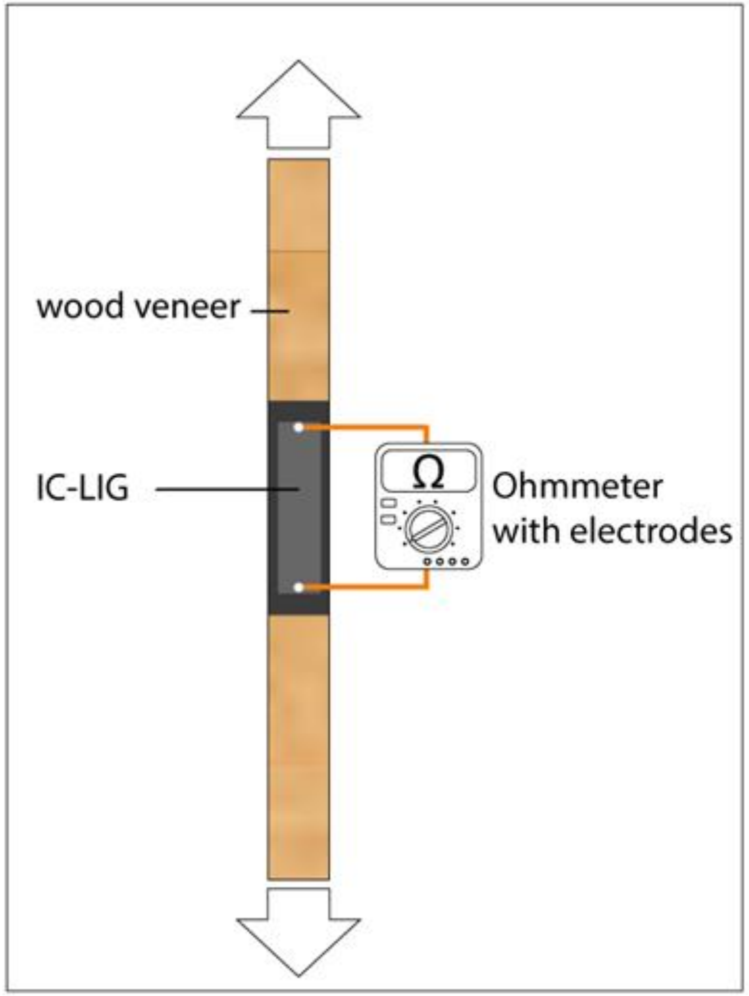


Optimized laser treatment
○ CO_2 laser
○ Ambient atmosphere
○ Single lasing step

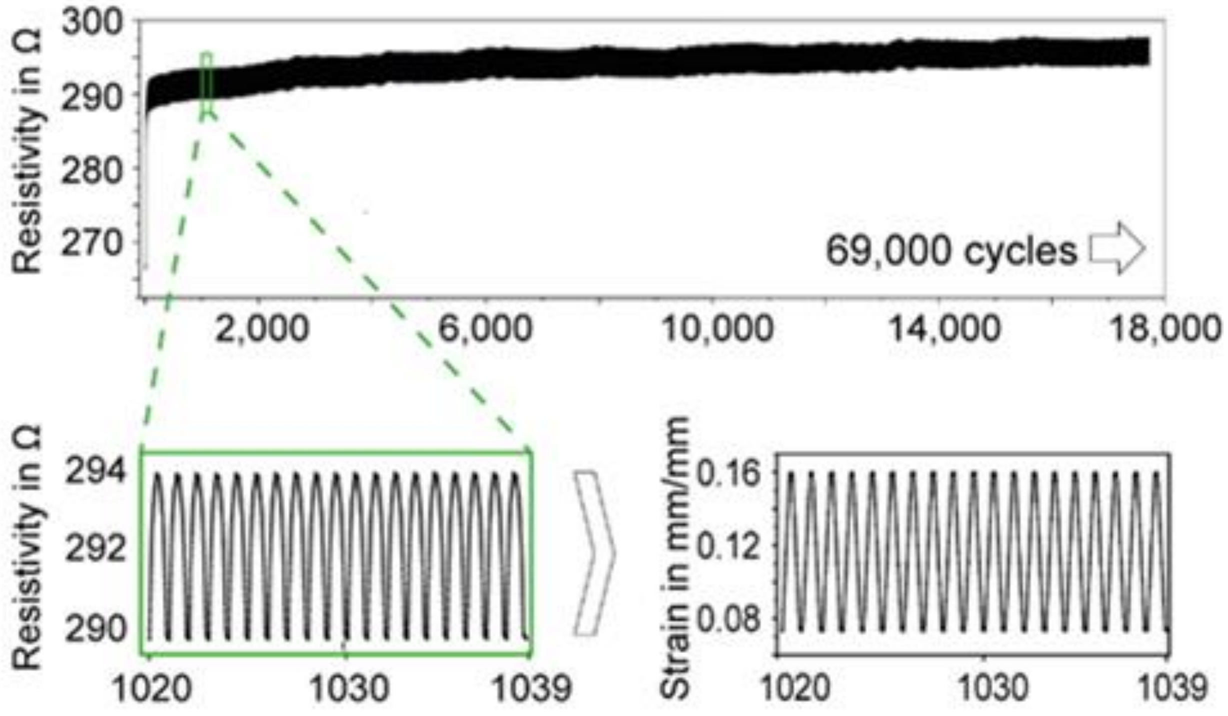
Capacitive touch panel

Dreimol et al. (2022) Nature Communications

Electric conductivity by laser-induced graphitization of wood



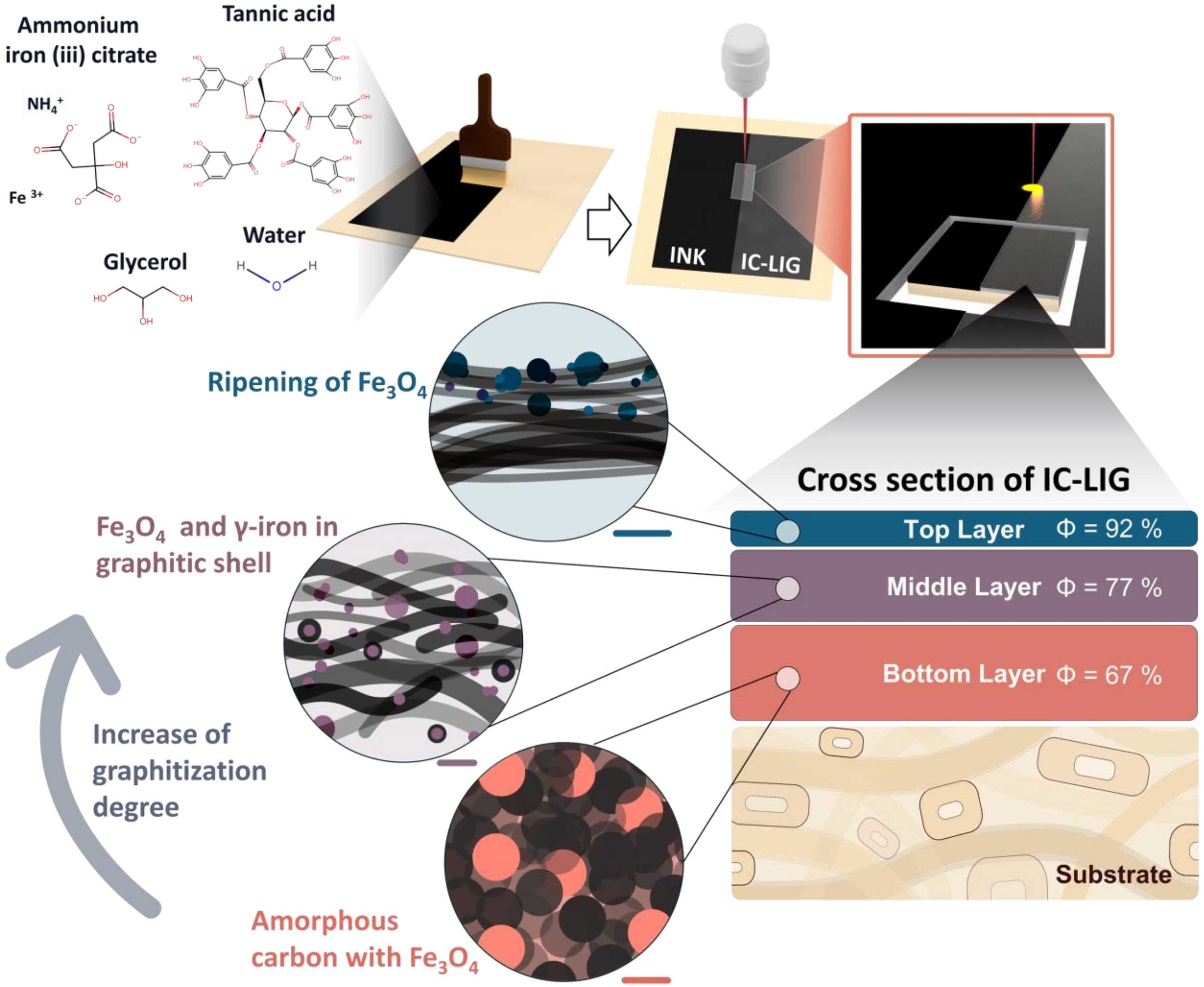
Strain sensor

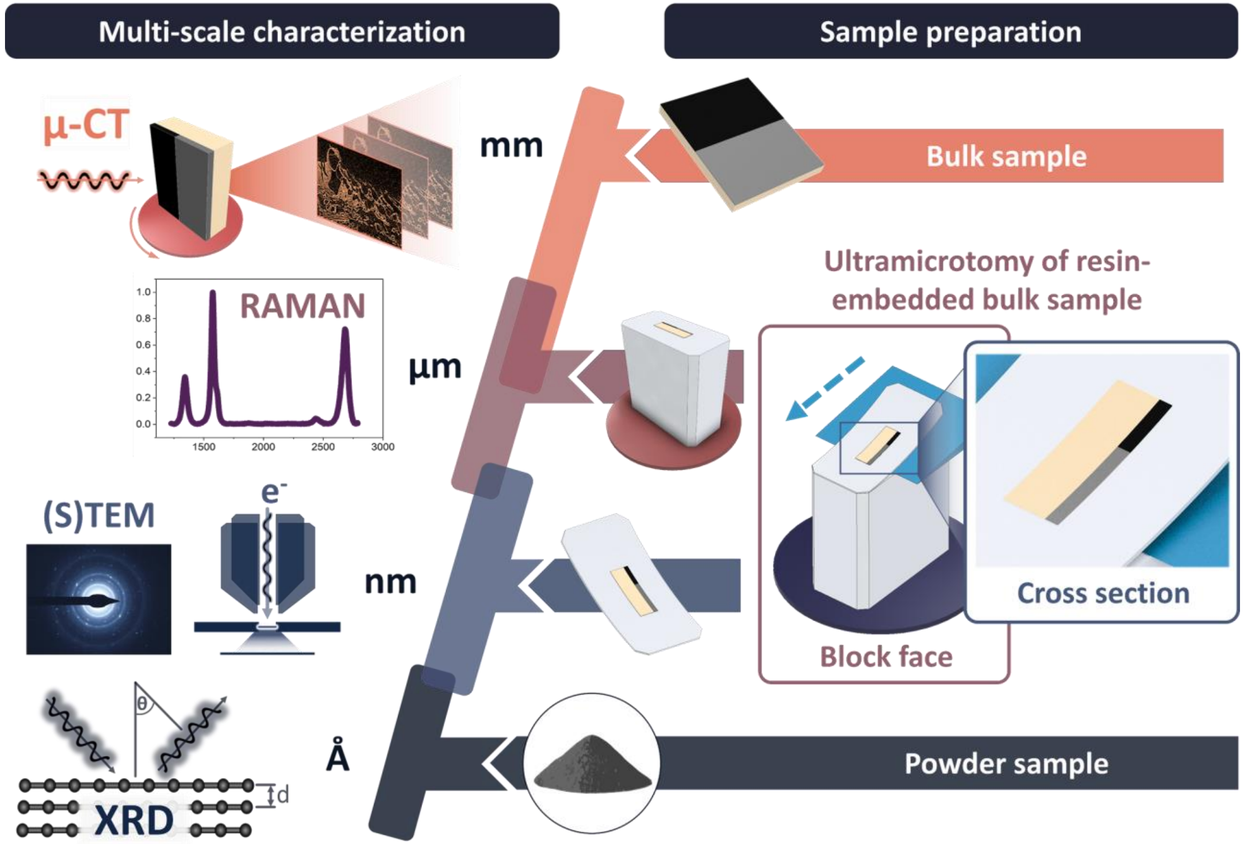


Dreimol et al. (2022) Nature Communications

Electric conductivity by laser-induced graphitization of wood

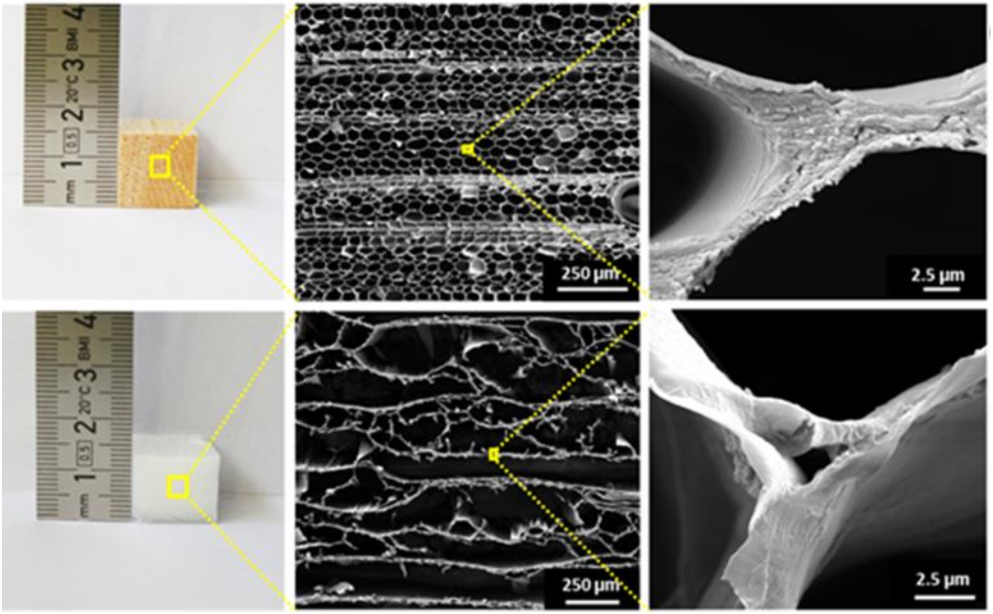
Structural evolution and catalytic graphitization

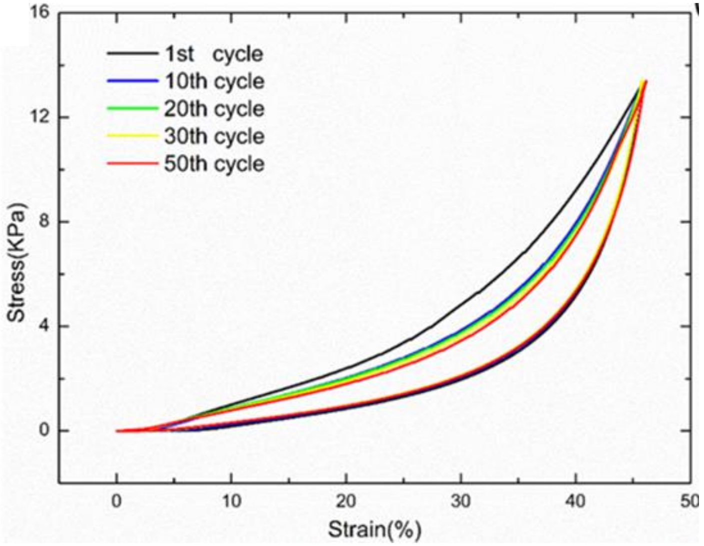


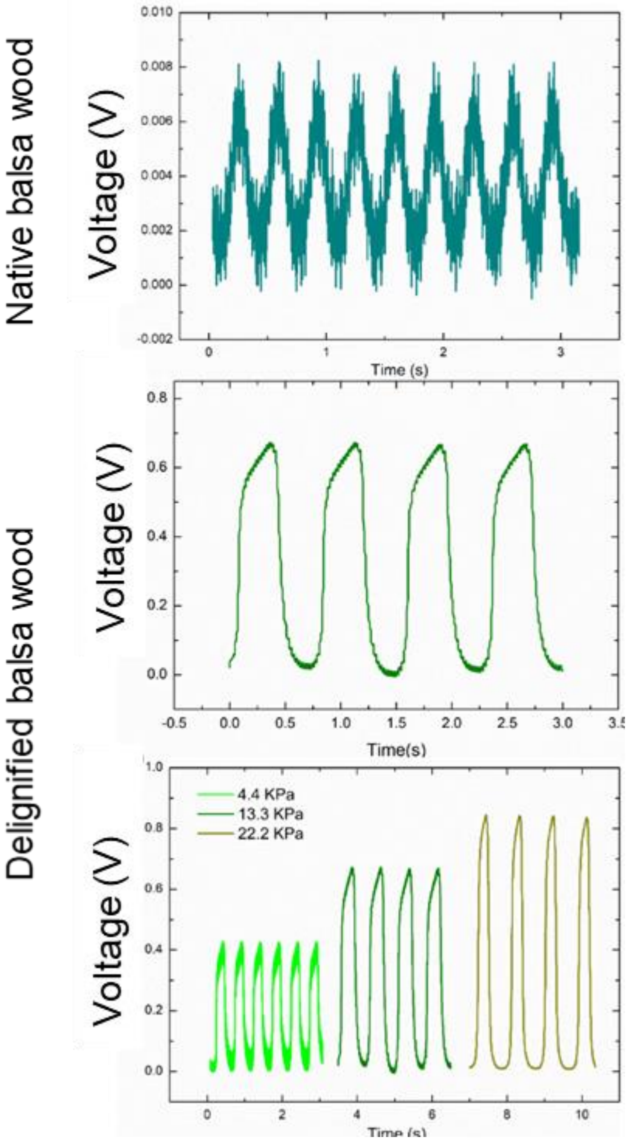


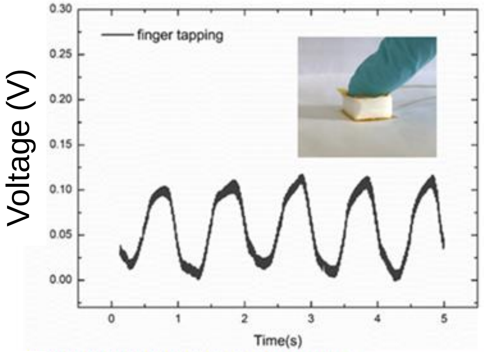
Dreimol et al. (2024) Small

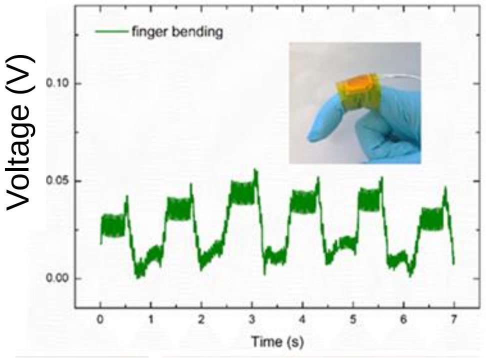
Enhanced voltage output of wood by delignification

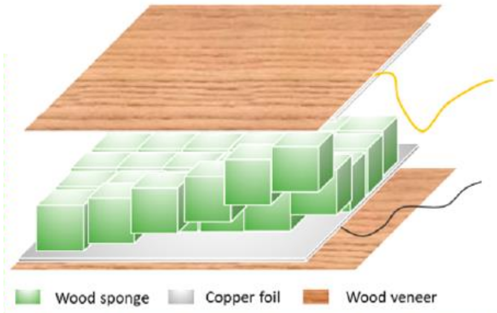








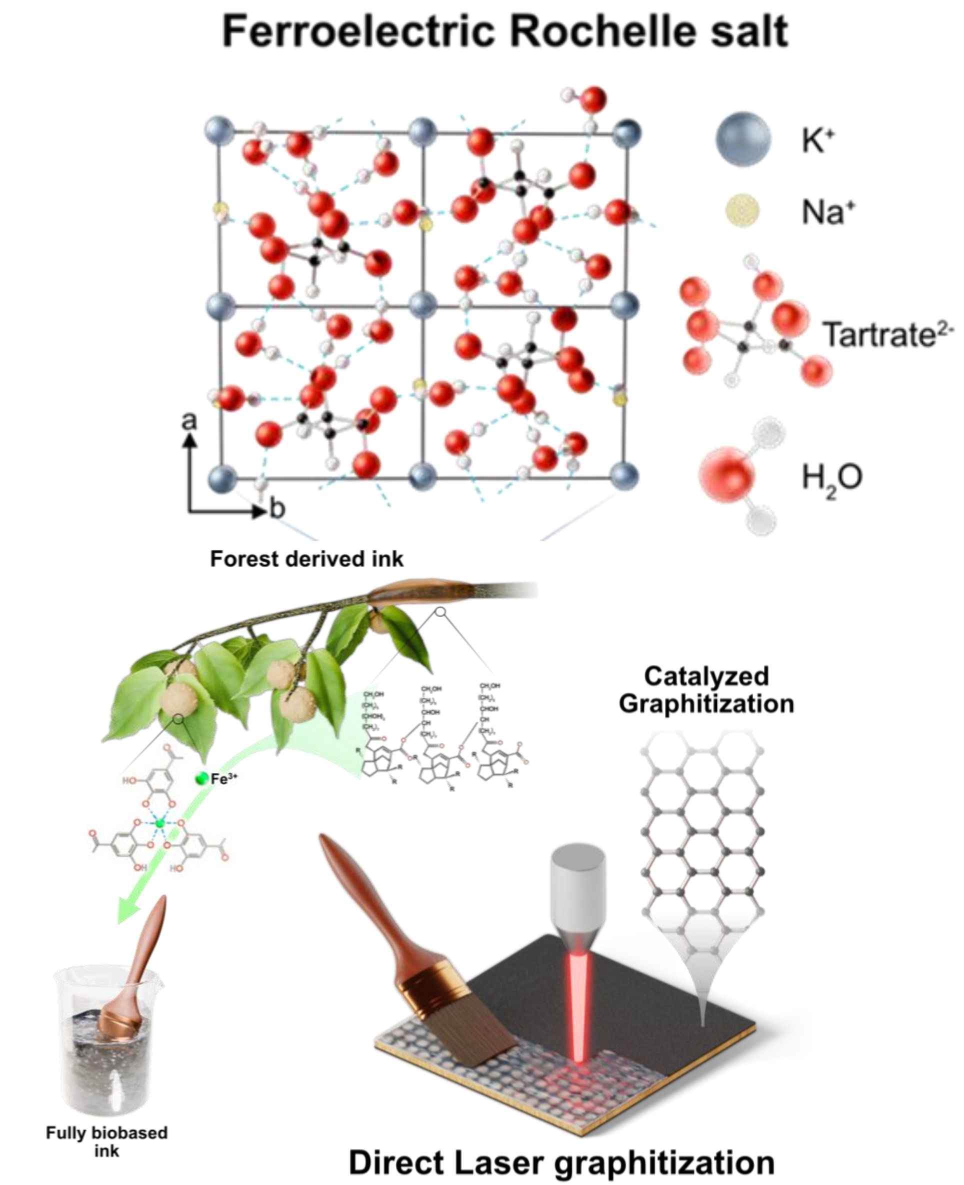


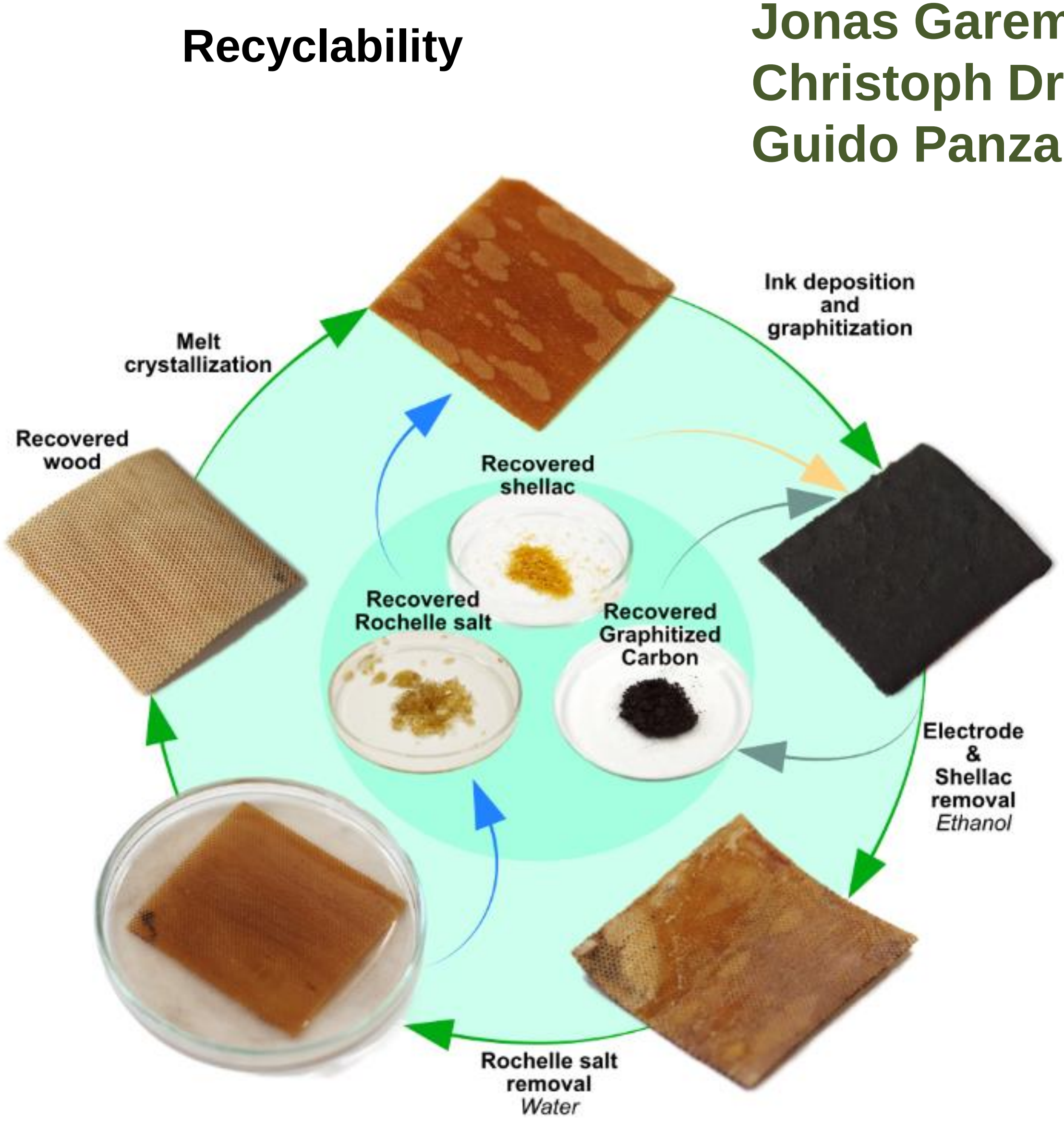


Sun et al. (2020)
ACS Nano

Green piezoelectric devices

Jonas Garemark
Christoph Dreimol
Guido Panzarasa





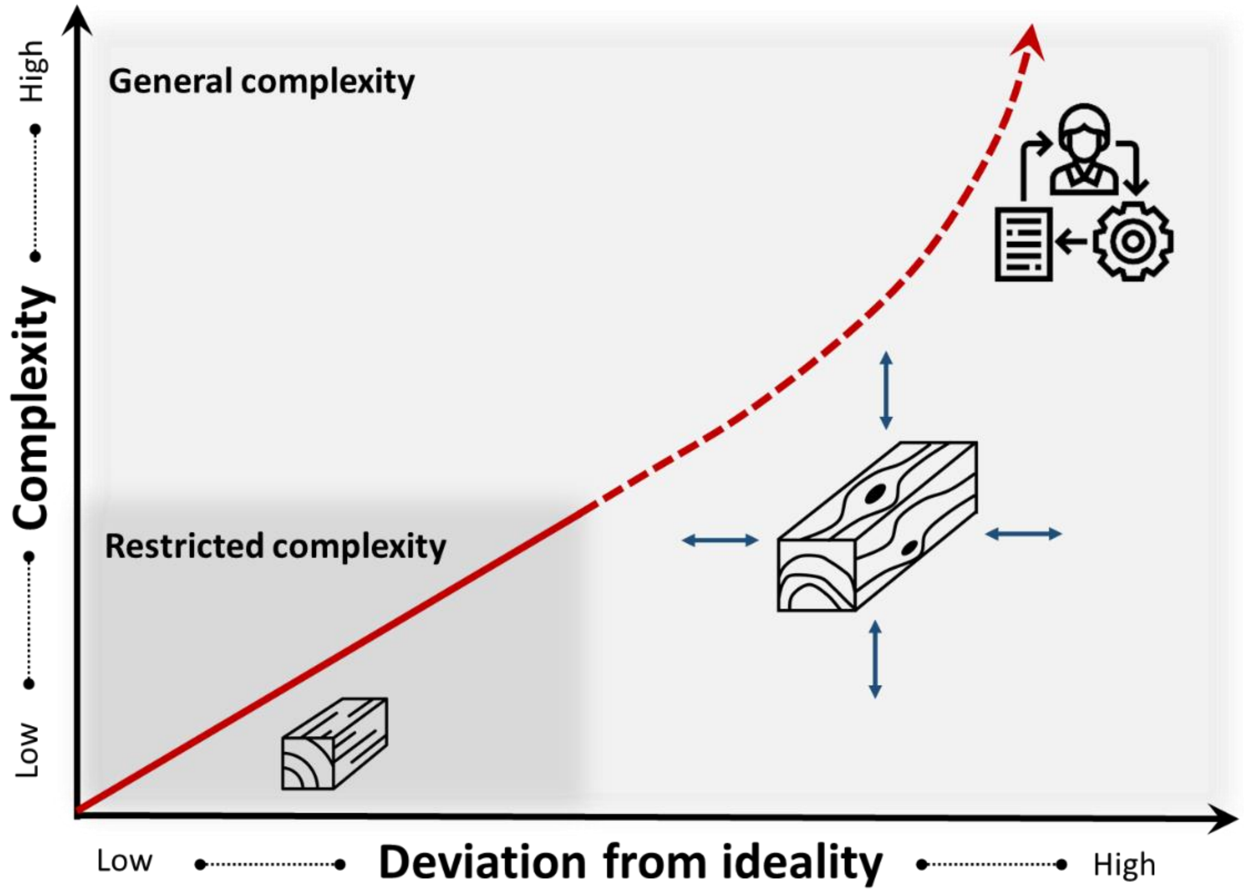
Garemark et al. (2025) Advanced Functional Materials

AI in wood science

➢ We are forced to adapt the wood value chains with strong impact on wood processing and wood products (more heterogeneity, lower quality of the resource).

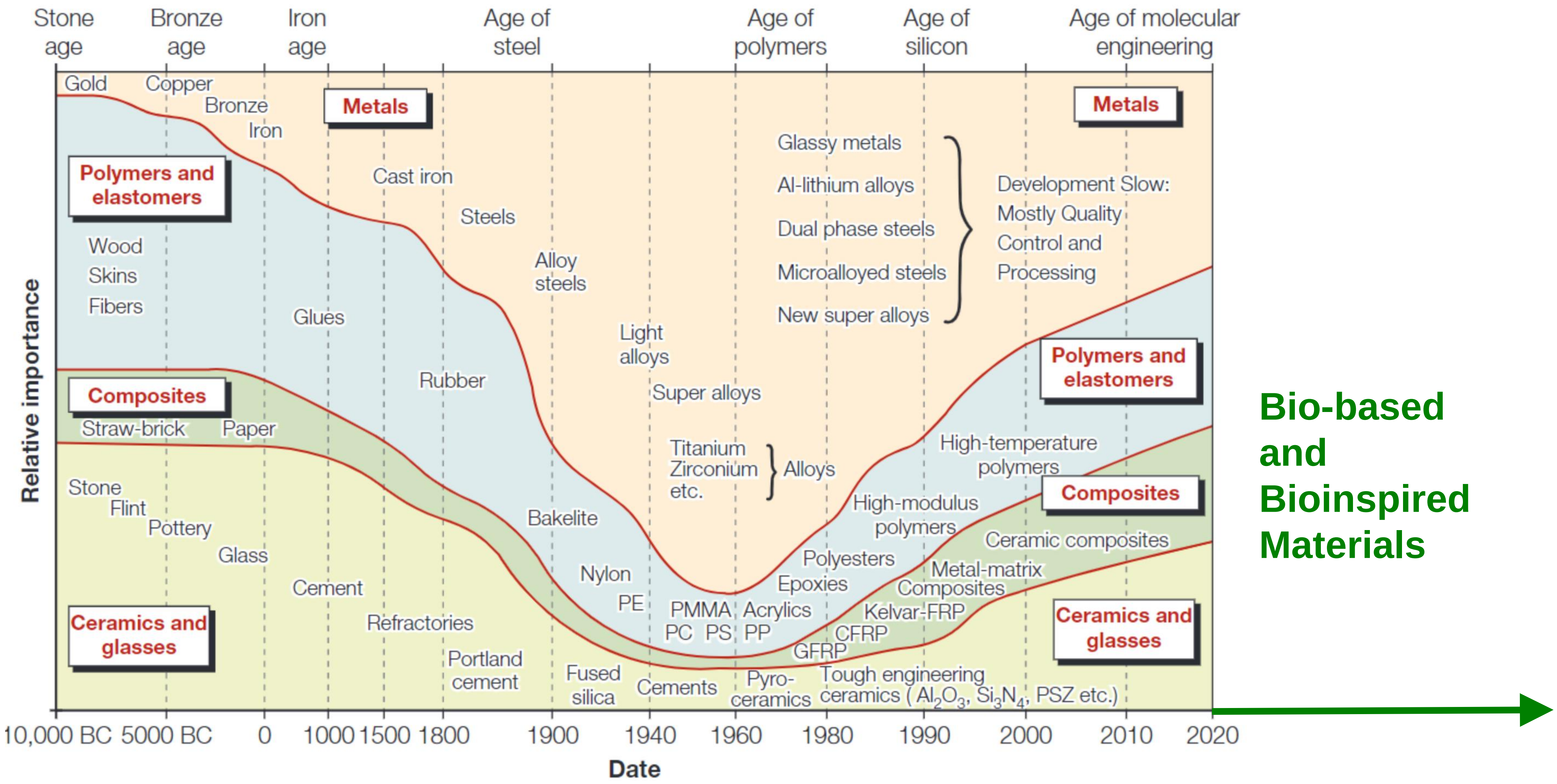
Research on:

➢ Machine learning techniques to better predict wood properties and handle or even appreciate (bio)diversity of the natural resource



Schubert et al. (2022) Chemical Reviews

Development of materials



Bio-based and Bioinspired Materials

Ashby 2007: Materials Selection in Mechanical Design

Summary & Outlook

Wood has the potential to play a key role in a future circular economy and climate change mitigation efforts

To realize this potential, we need to:

- adapt the entire wood value chain to increase material gains and become more flexible toward resource provision
- become greener and circular in wood modifications and bonding + scalable + Life cycle analysis
- establish recycling and reuse chains
- develop sustainable functional wood materials that can contribute to energy savings in building operations

Find ways to materialize CO_2 for wood property improvements "Double Carbon Storage"

Thanks

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Collaboration partners and co-authors

Wood Materials Science

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Former group members

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