The emerging trends in sustainable construction materials

Dr. Karol Sikora

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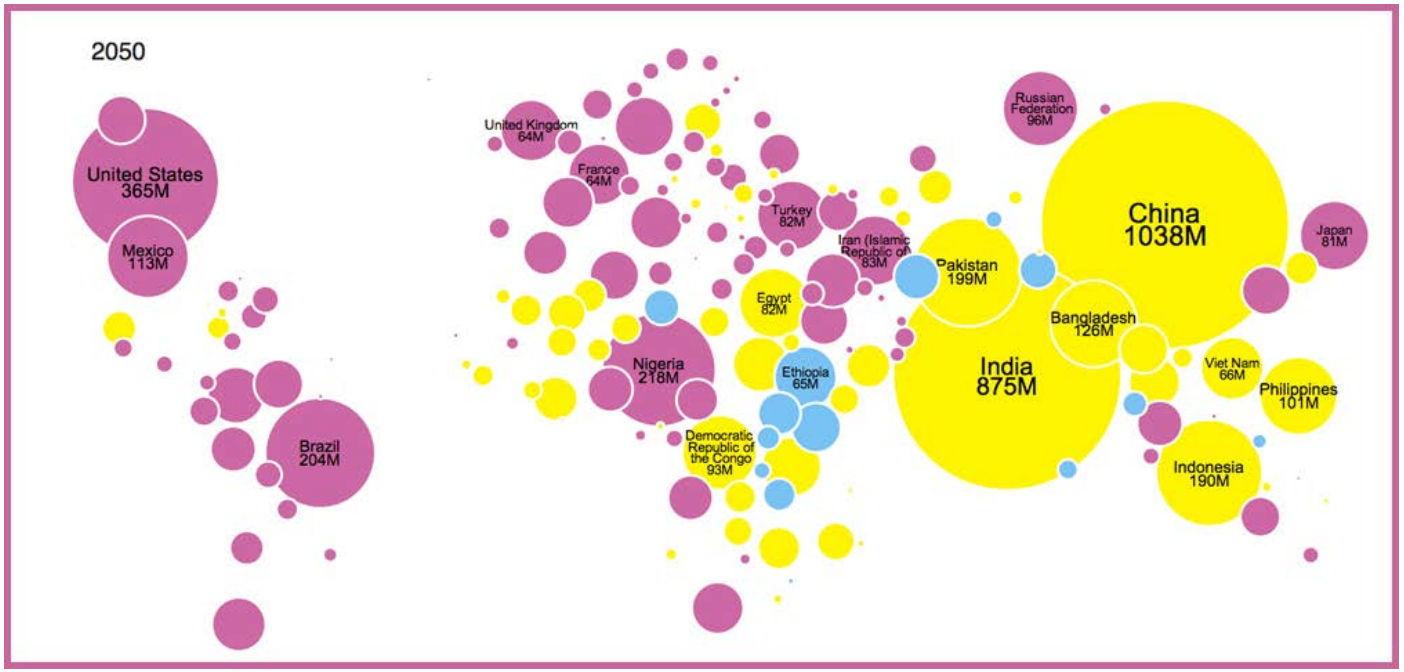
Population of urban areas in 1950

[businessinsider.com]

Population of urban areas in 2000

[businessinsider.com]

Population of urban areas in 2050



[businessinsider.com]

Chinese Golden Week
G4 Beijing-Hong Kong-Macau Expressway

[topgear.com]

Diwali
Nagpur

[www.prokerala.com]


2.5 billion
extra in urban areas by 2050

20 billion tones of concrete annually

>25,000 x

Every 20 minutes new Burj Khalifa

An Olympic pool of cement is used

every 15 seconds.

Source : PC Alcin & S. Mindness, *Écostructures en béton, Comment diminuer l'emprunte carbone des bâtiments ?* Eyrolles Paris 2013.

Demand for sand has led to the emergence of illegal mining of the material – here, a police officer stands guard in a quarry near Bogota, Colombia

[www.aljazeera.com]


“We are using resources as if we had two planets, not one. There is no “Plan B” because we do not have a “Planet B”. We have to work and galvanize our action.
Ban Ki-moon
The former UN Secretary-General

[www.cart-away]

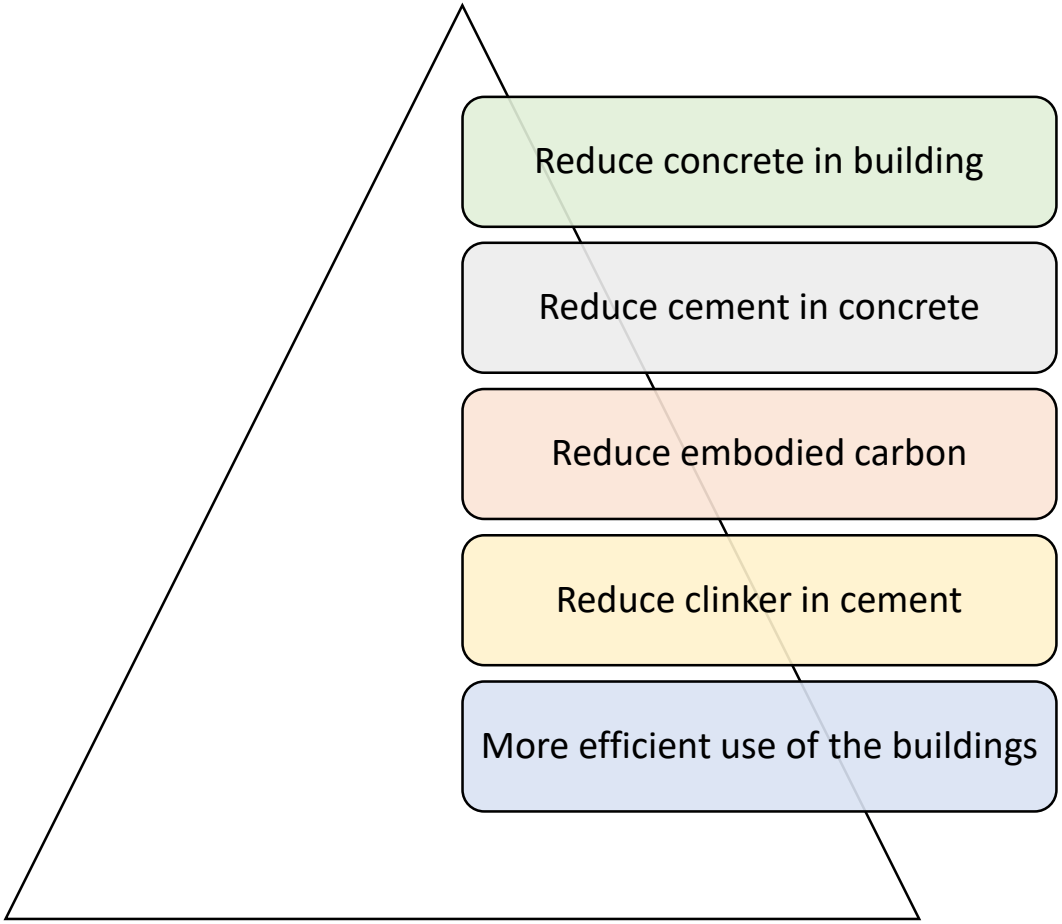
Concrete

Material of 20th century

Sources of greenhouse gases

Source: FORTUNE, 2021

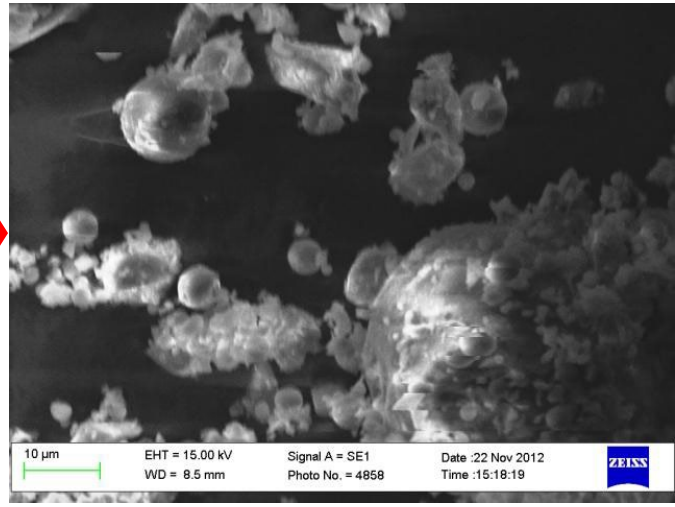
R levels


Reduce concrete in building
Reduce cement in concrete
Reduce embodied carbon
Reduce clinker in cement
More efficient use of the buildings

Reduce clinker in cement

[www.cement.org]

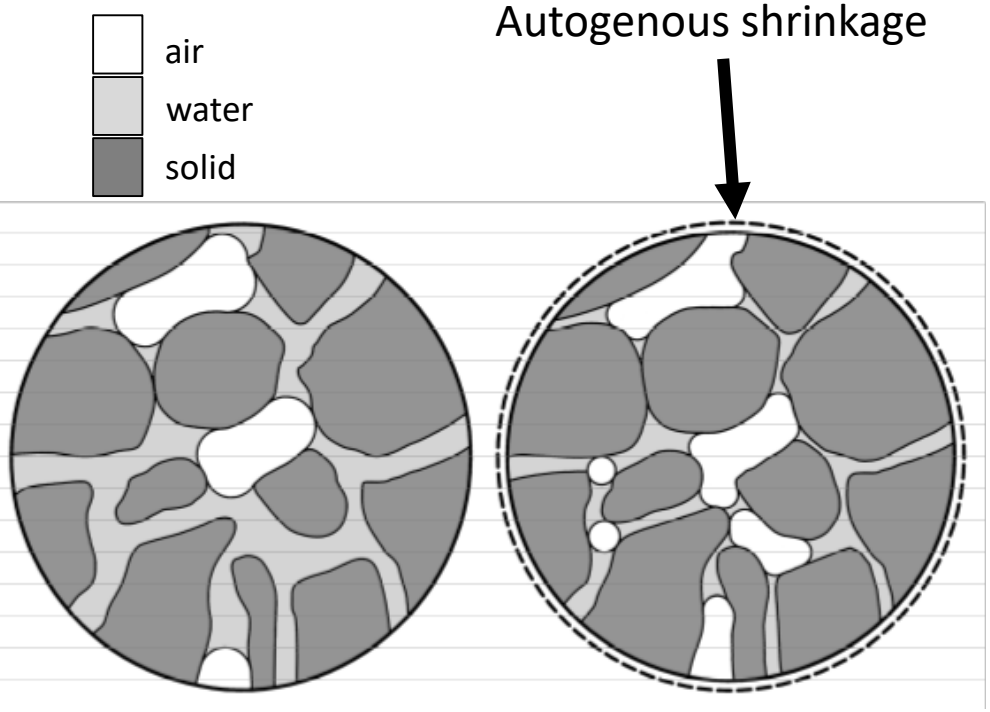
[www.nrdc.org]



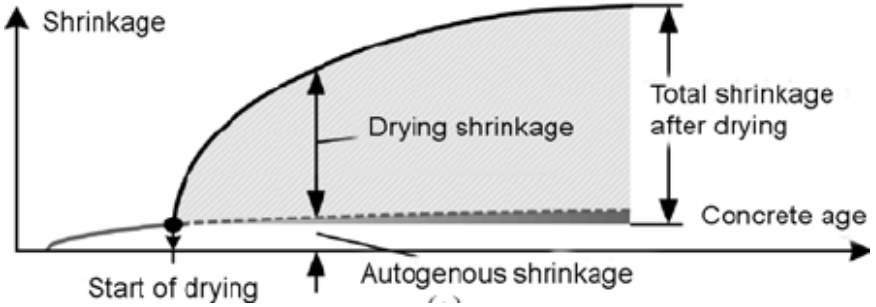
Blended cement

Reduce clinker in cement

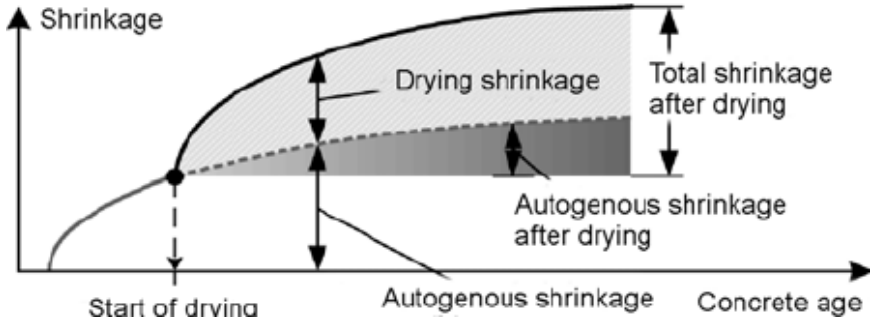
Shrinkage of concrete



[Jansen & Hansen, 2001]



Shrinkage strain components in normal concrete



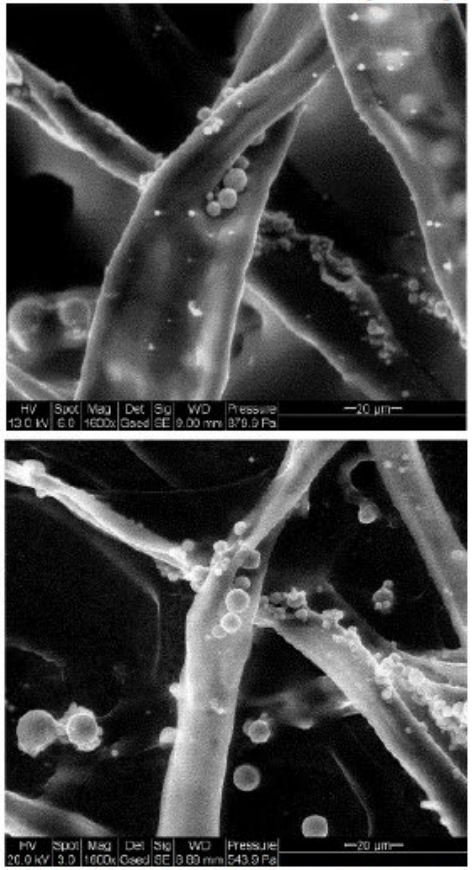
[Sakata & Shimomura, 2004]

Reduce clinker in cement

Internal curing

Saturated lightweight aggregate

Thermomechanical pulp fibers

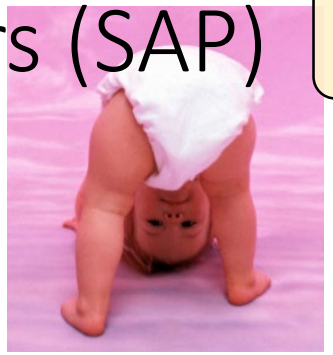


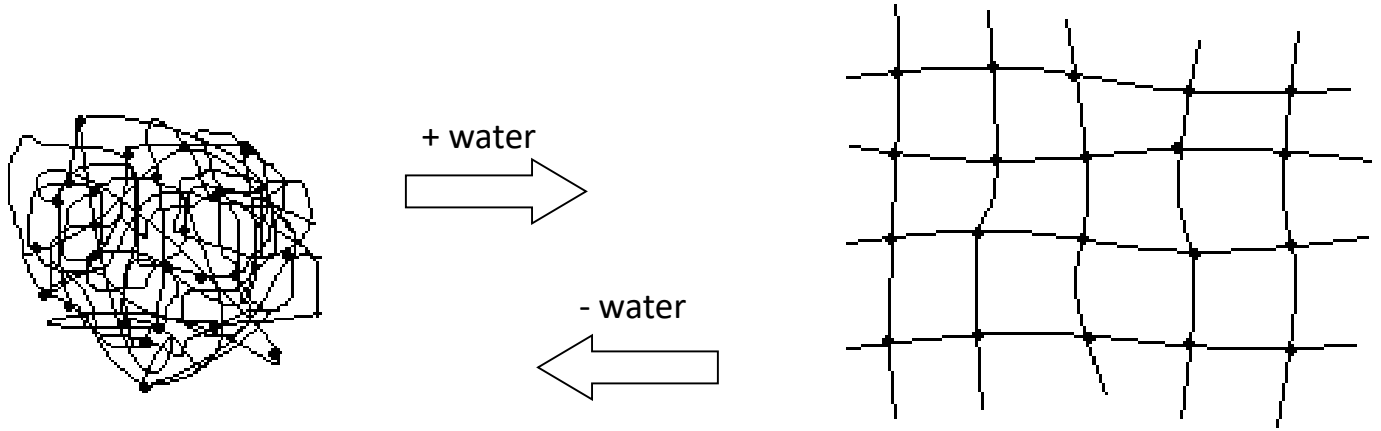
Bentur et al. CCR 2001, Lura et al. RILEM 2004

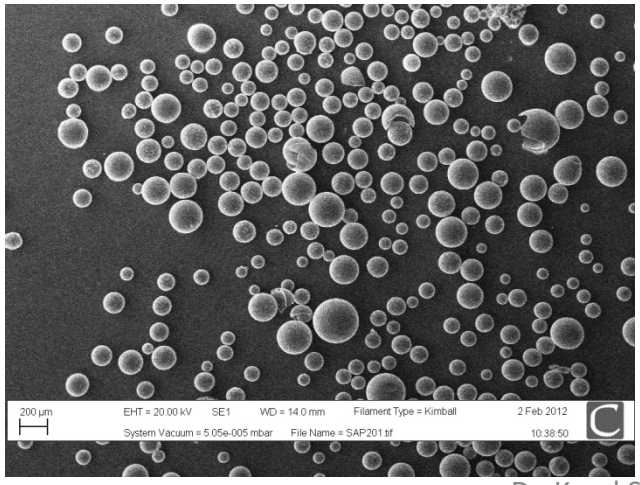
Mohr et al. CCR 2006

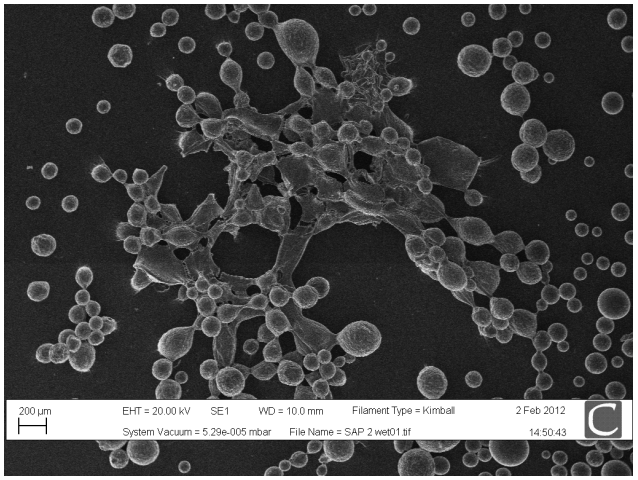
Superabsorbent polymers (SAP) Mechanism of swelling

Reduce clinker in cement





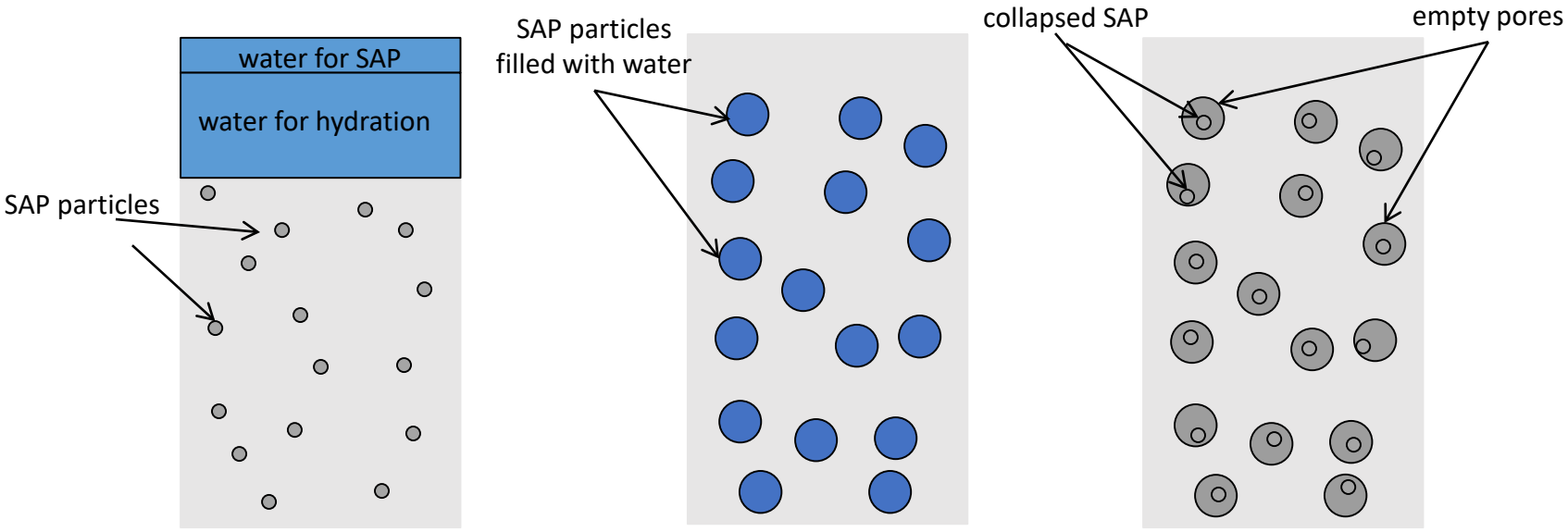




[Sikora & Klemm, 2013]

Reduce clinker in cement

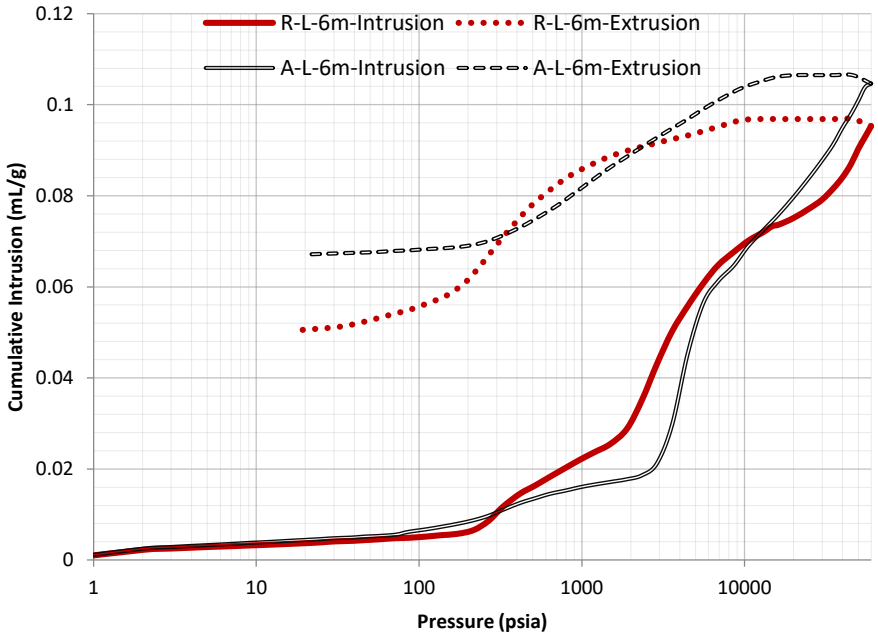
Concrete modifications by SAP

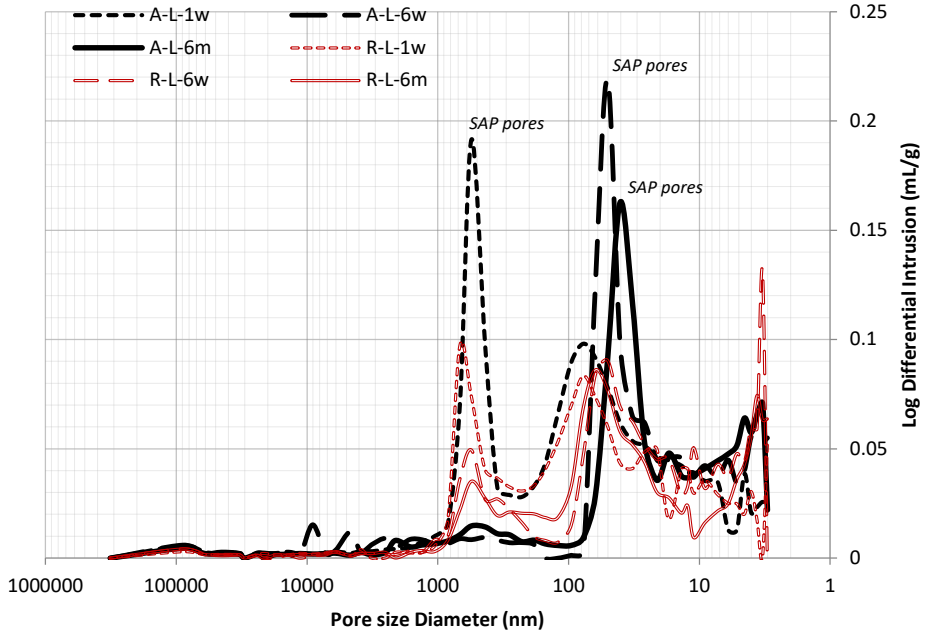


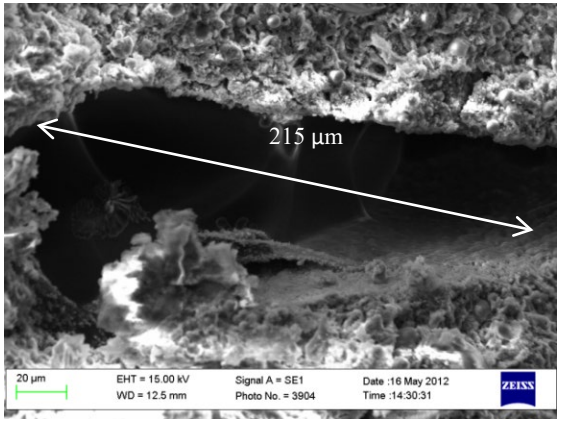
[Sikora & Klemm, 2013]

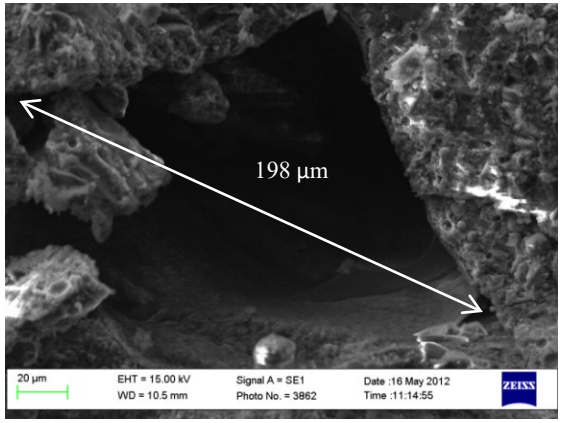
Pores by SAP are ‘ink-bottle’ and/or closed and have a diameter of at least a few thousands nanometres

Reduce clinker in cement









[Sikora & Klemm, 2013]

Reduce clinker in cement

SAP very effective in internal curing
Vary noticeably between different types of SAPs and supplementary cementitious materials

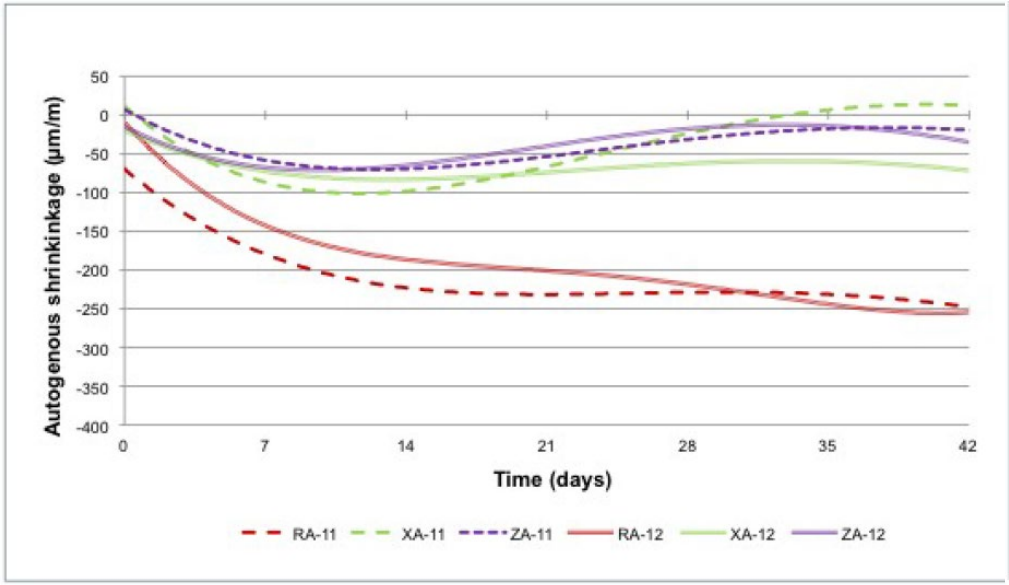


Fig. 8: Autogenous shrinkage for mortars featuring FA

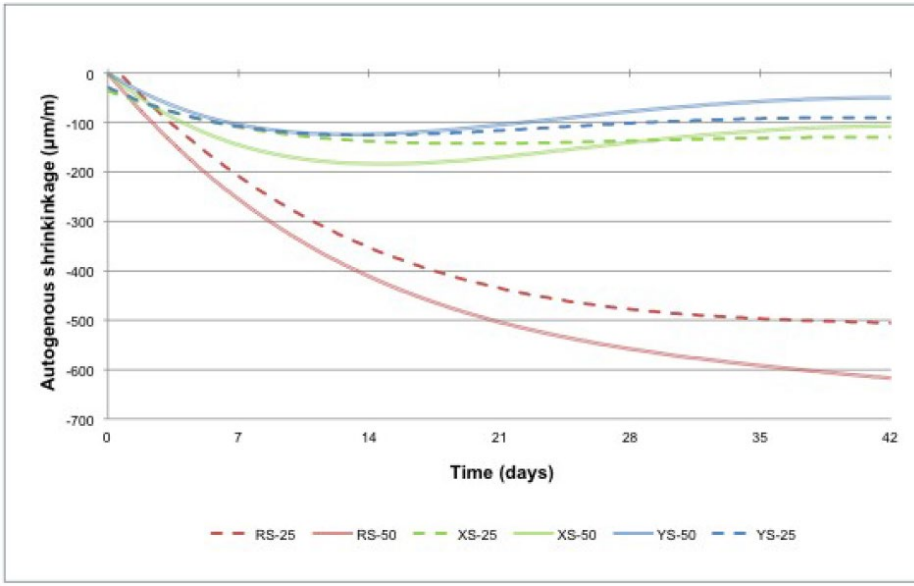
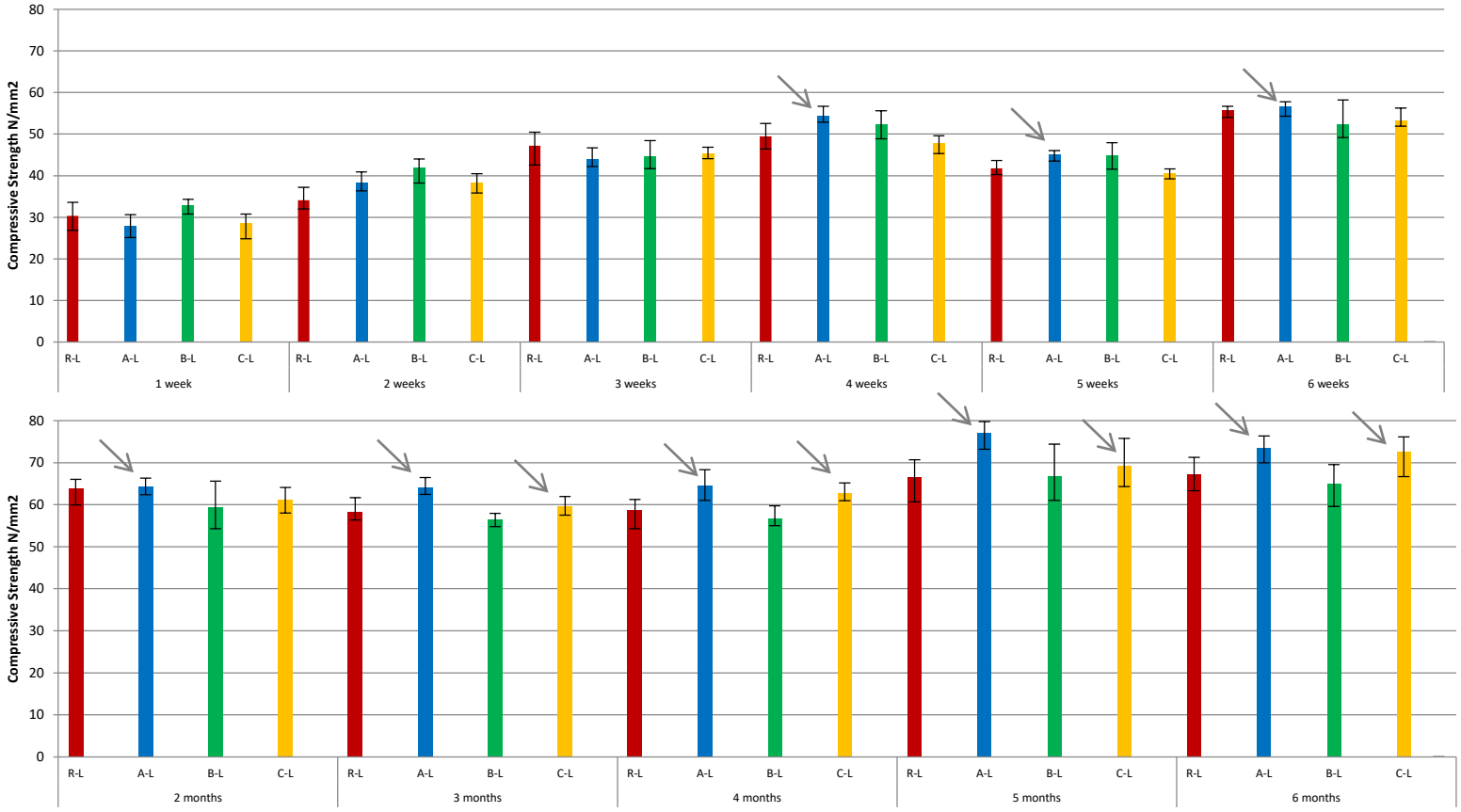


Fig. 5: Autogenous shrinkage for mortars with ground granulated blast furnace slag (GGBS)

[Klemm et al., 2013]

SAPs with high water absorption increase compressive strength, no effect on flexural strength

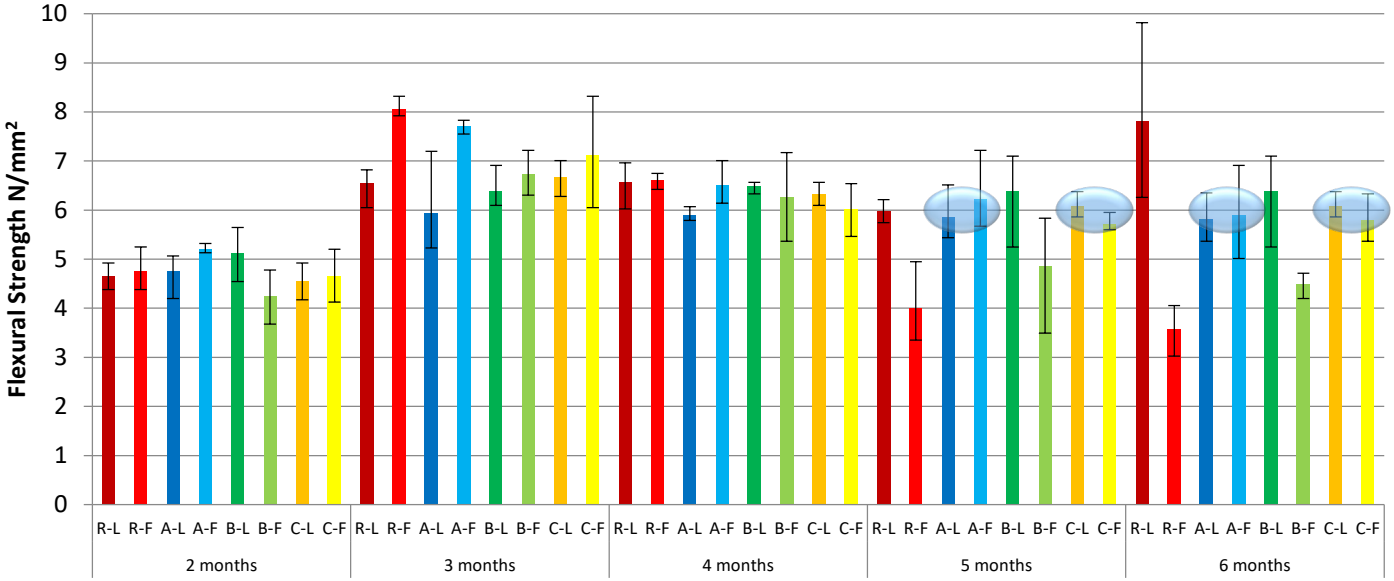
Reduce clinker in cement

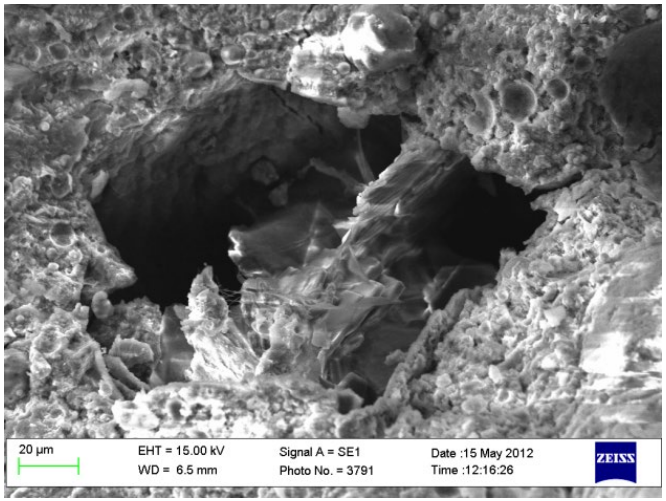


[Sikora & Klemm, 2013]

SAPs with high water absorption capacity prevent flexural strength reduction caused by frost action in cementitious composites

Reduce clinker in cement





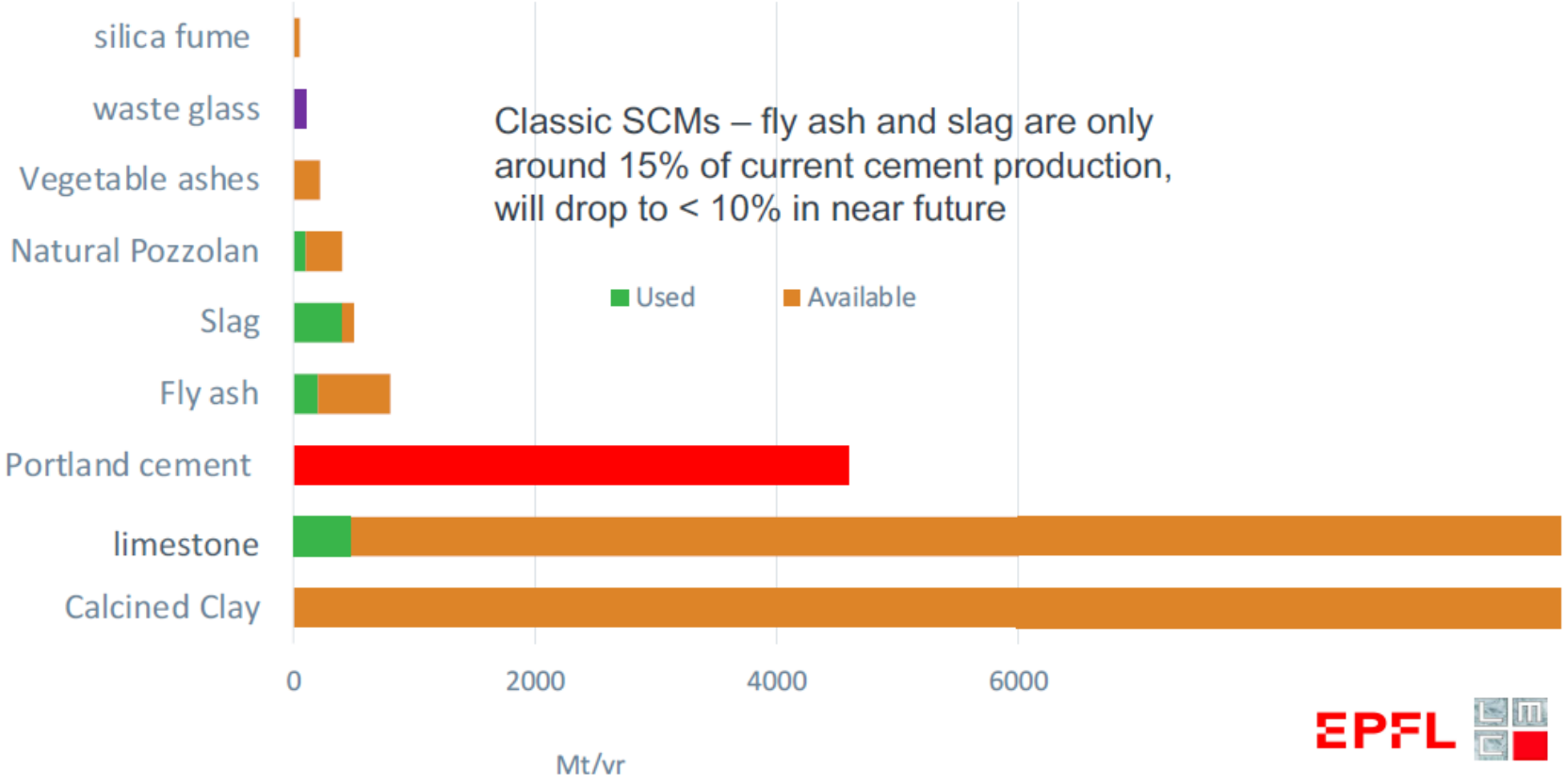
[Sikora & Klemm, 2013]

Reduce clinker in cement

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Availability of SCMs



EPFL

Professor Karen Scrivener, FREng, EPFL, Switzerland
Professor Fernando Martirena, UCLV, Cuba
Alberto Putin, IPIAC, Portugal

Reduce clinker in cement

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

There is no magic solution

- Blended with SCMs will be best solution for sustainable cements for foreseeable future
- **Only material really potentially available in viable quantities is calcined clay**.
- **Synergetic reaction** of calcined clay and limestone allows high levels of substitution:
  EPFL led LC^3 project supported by SDC. **Started 2013**

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

Limestone Calcined Clay Cement LC3

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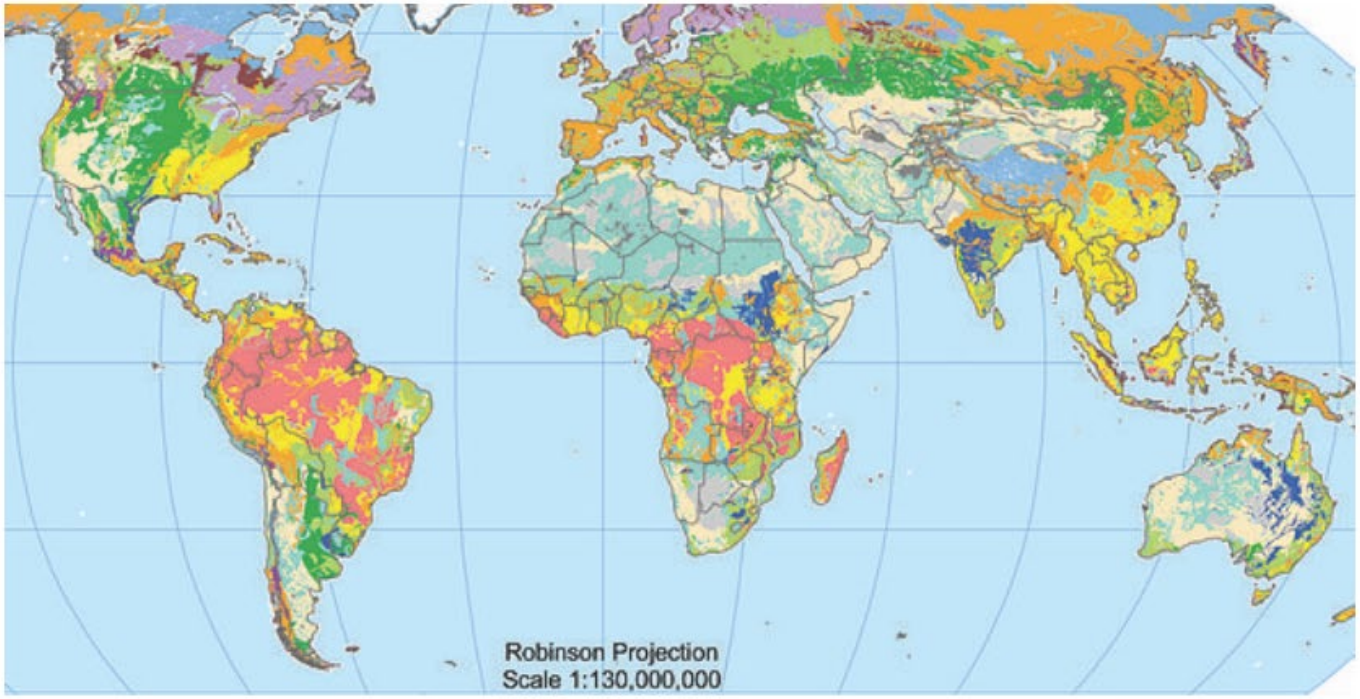
Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

World soil map gives a rough indication, yellow pink and light green regions, very good but other areas have also have good deposits



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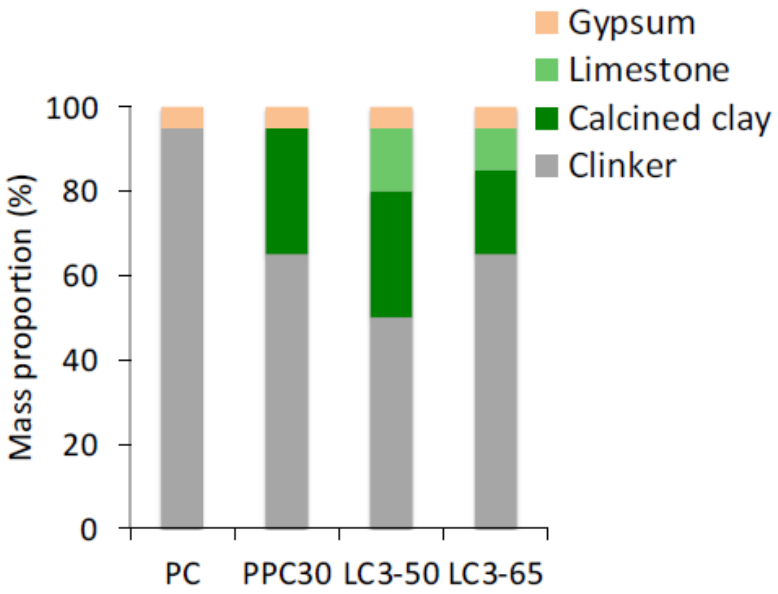
Reduce clinker in cement

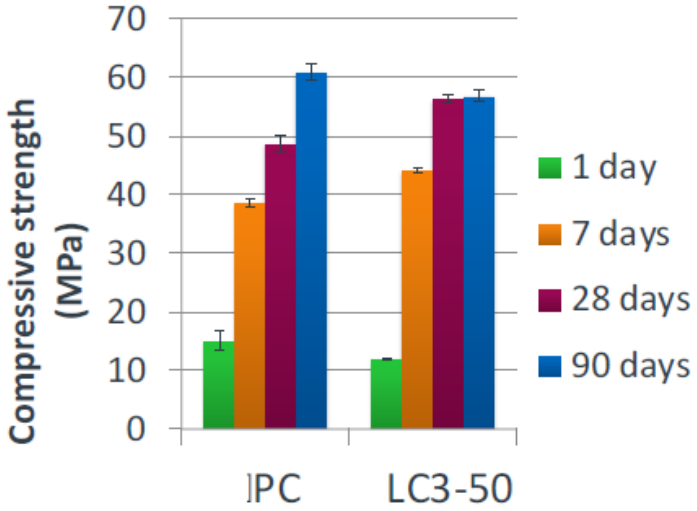
Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

What is LC3



LC3 is a family of cements, the figure refers to the **clinker** content



- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

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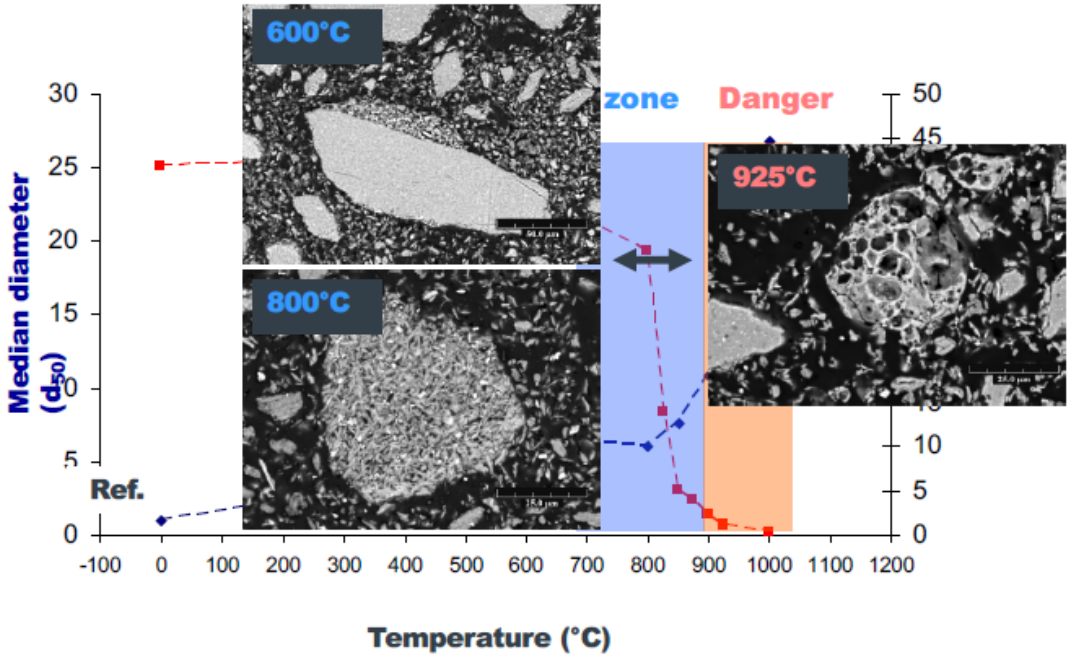
Reduce clinker in cement

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Impact of calcination temperature

- Agglomeration occurs at higher temperatures
- Specific surface decreases (reactivity)
- Above 950 ºC re-crystallization occurs



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Reduce clinker in cement

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Concluding remarks

- Future cements will be based on Portland cement clinker with increasing levels of incorporation of SCMs
- Calcined clays are the only realistic option for extending the use SCMs
- Possible to obtain similar mechanical properties to OPC / CEM I with 50% clinker and clays with >40% kaolinite
- If we are serious about avoiding drastic climate change we need to use cements with lower CO_2 emissions, e.g LC^3 clinker/ calcined clay / limestone blends

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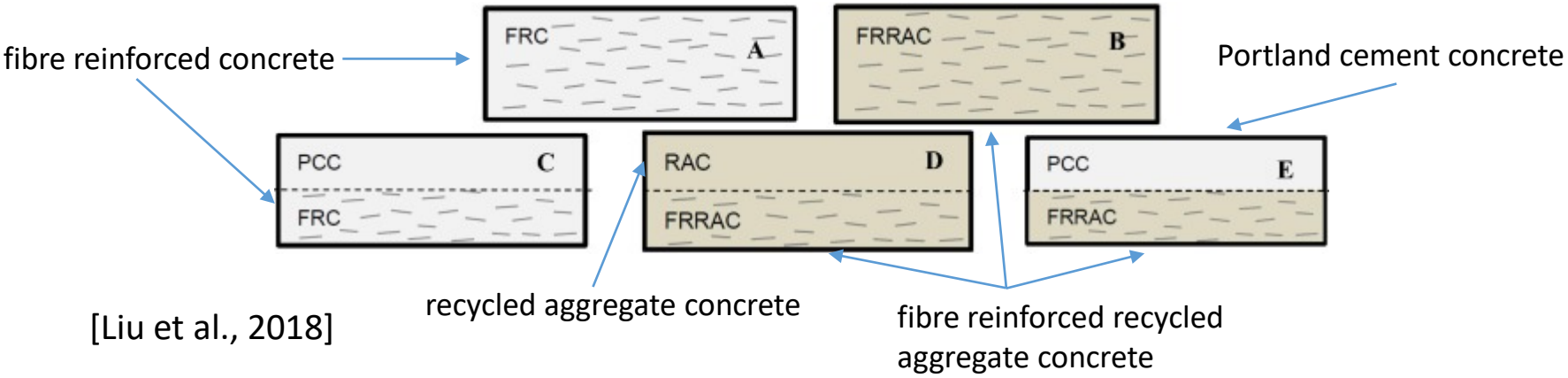
EPFL

Reduce embodied carbon

Functionally graded concrete



[Liu et al., 2018]

- Content of fibres do not have significant effect on the strength
- Type of aggregates used to produce the mixes does

Reduce embodied carbon

Desert sand for concrete

[Neumann & Curbach, 2018]

Reduce embodied carbon

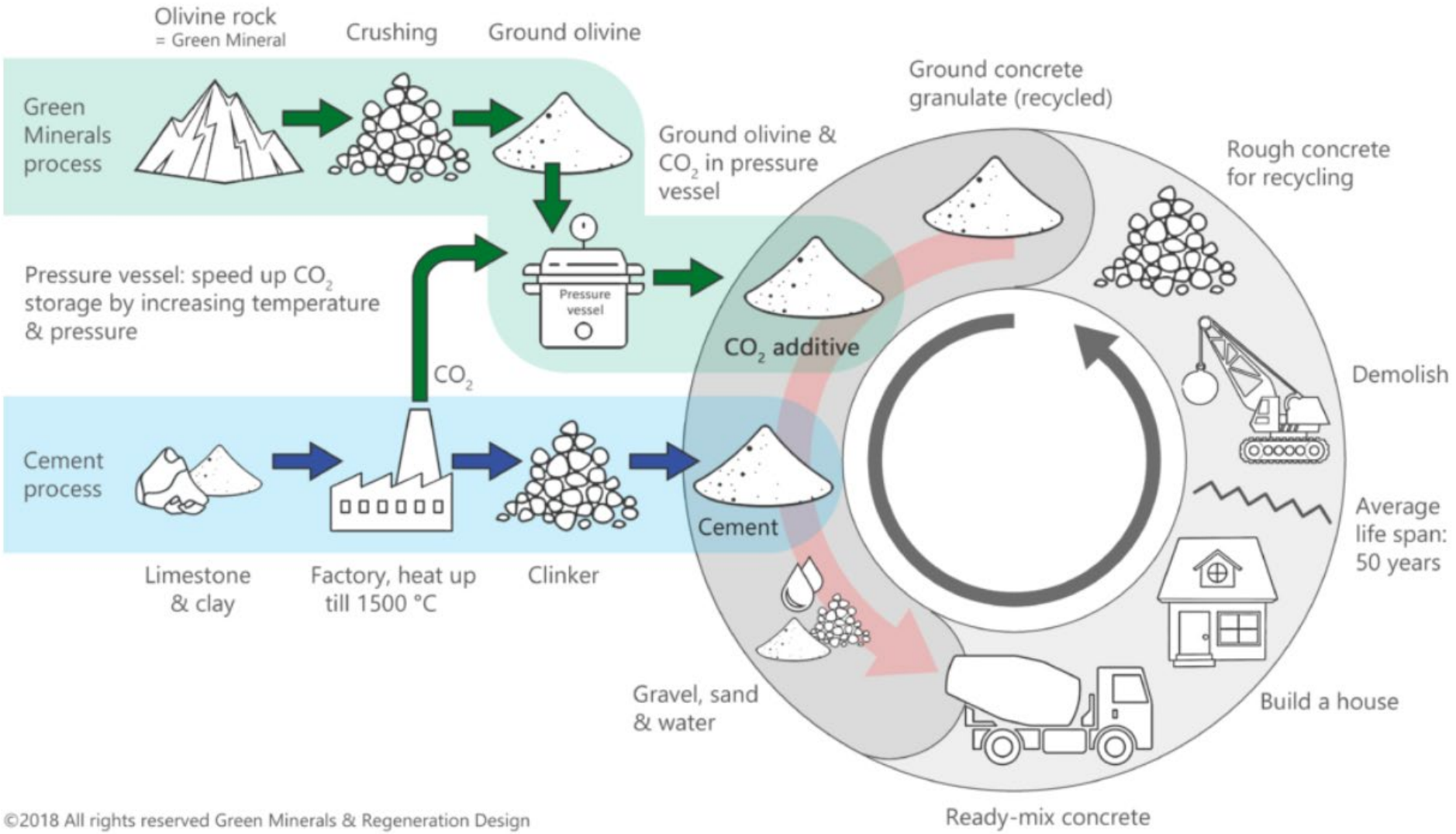
Sea components + basalt

[www.technobasalt.com]

[www.mnn.com]

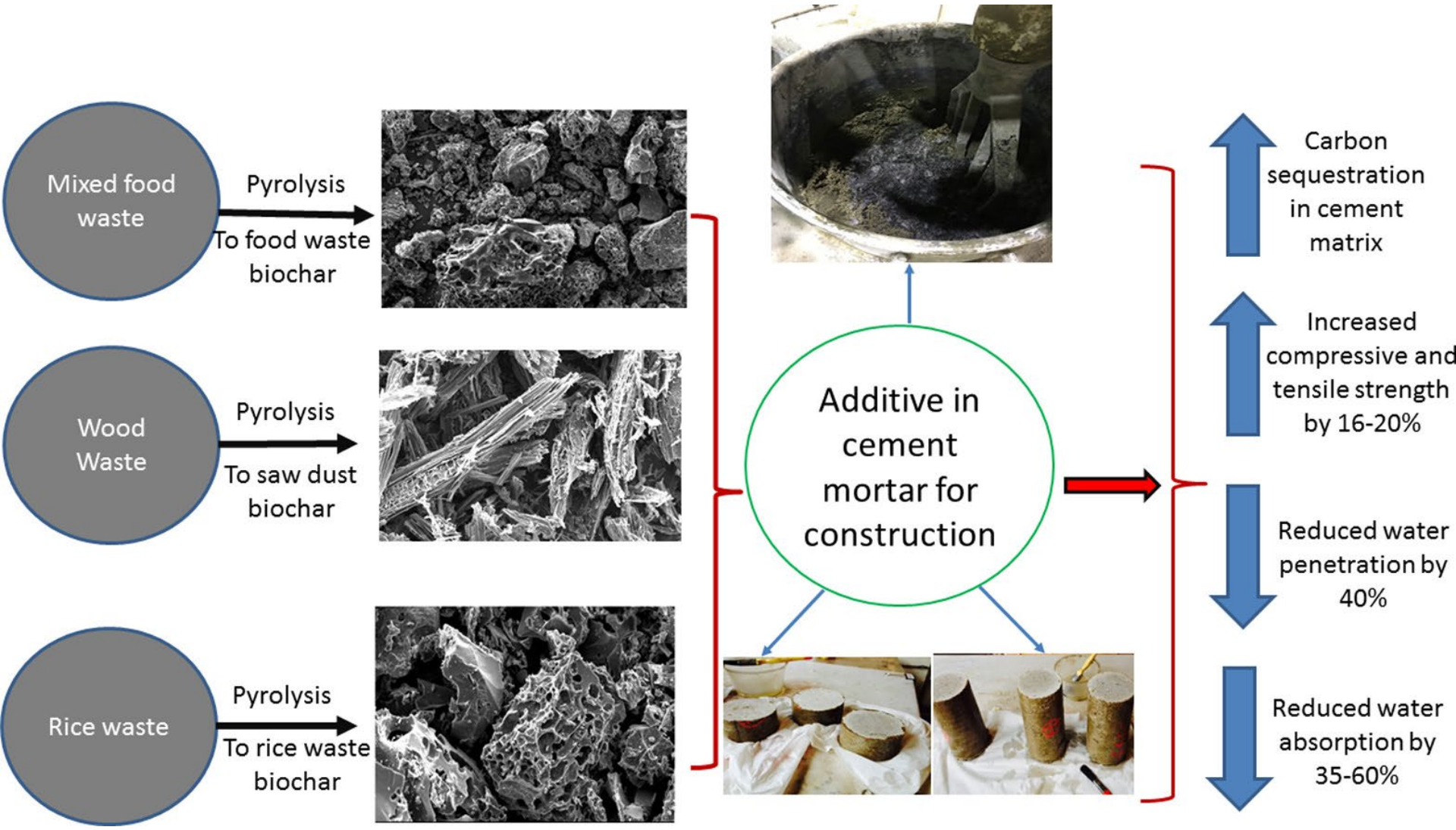
Reduce embodied carbon

Process infographic – CO_2 based concrete & Circular economy



Biochar for concrete

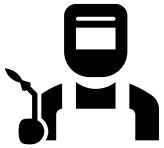
Reduce cement in concrete



[Gupta, S., Kua, H.W. and Koh, H.J., 2018]

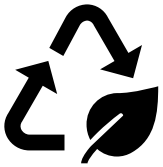
Shift work off-site

The construction supply chain is highly impacted, generating project slippage and/or extra costs



Enhanced focus on worker safety and increased cost pressure

Preassembled in a controlled environment

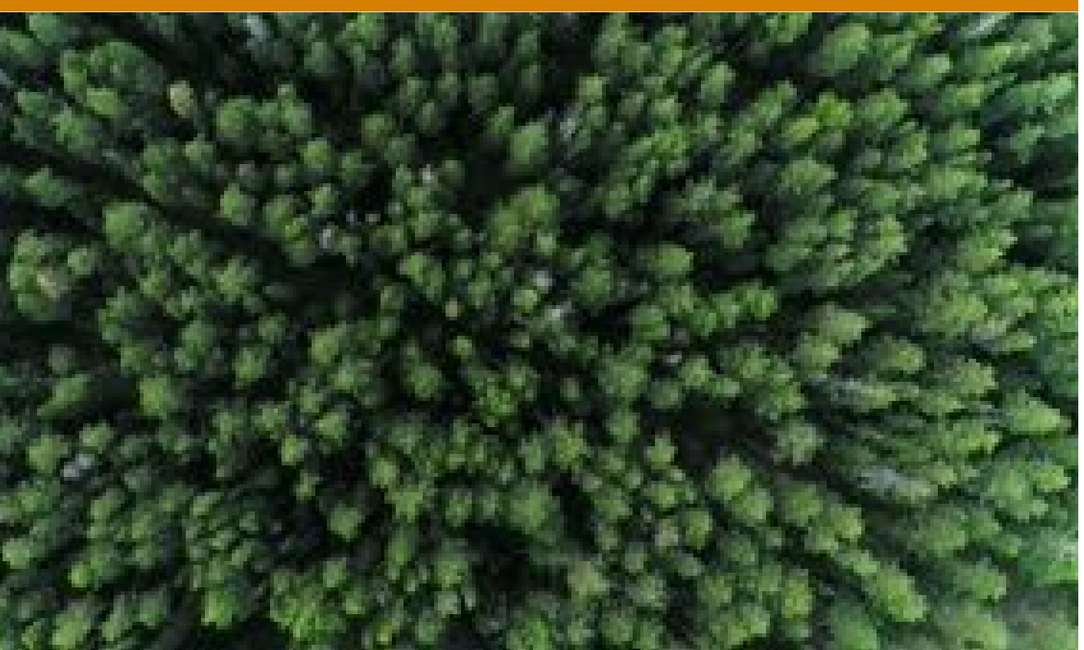


Off-site construction could contribute to sustainability goals by reducing materials waste, noise, and air dust as well as enabling circular building systems

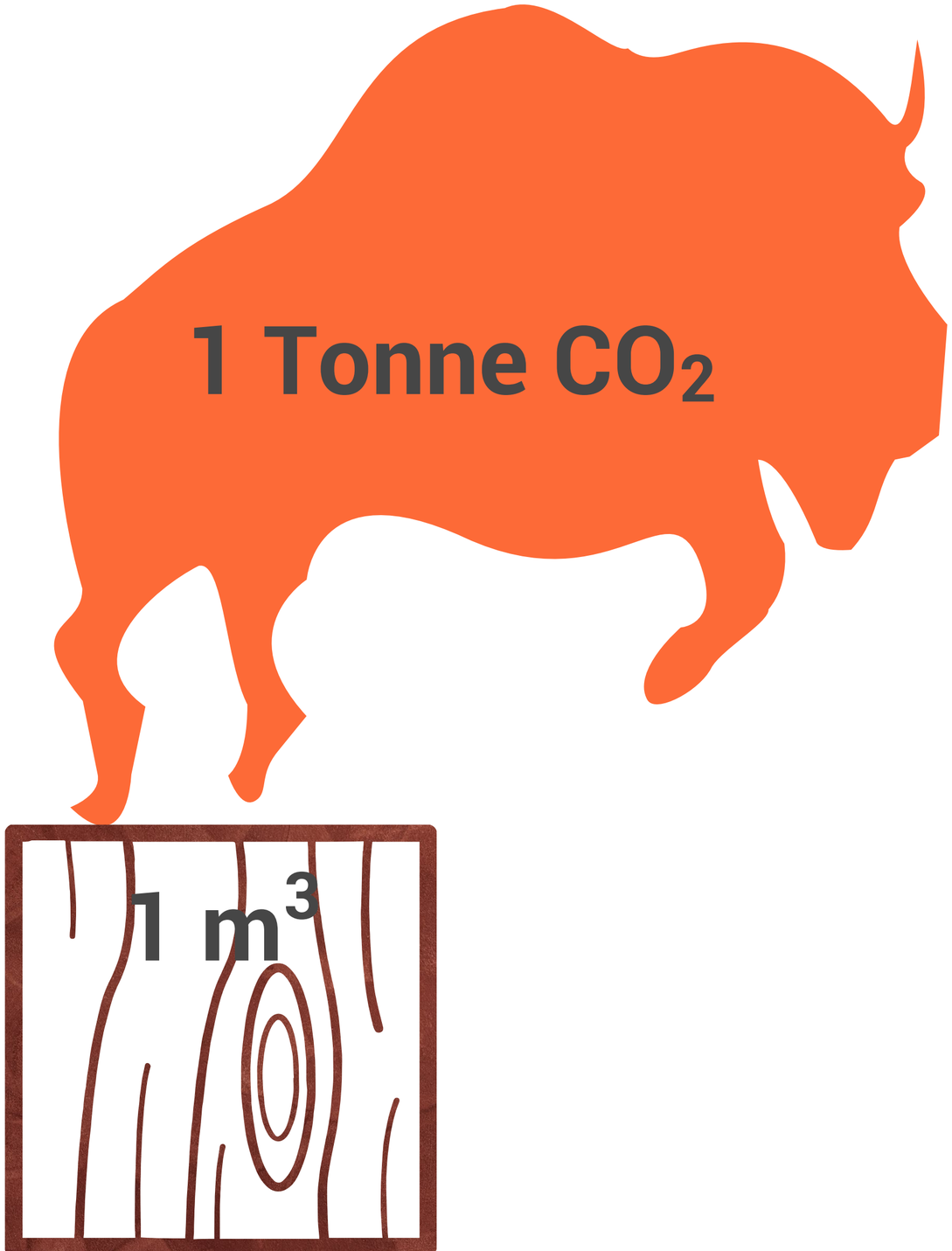

[www.abc.net.au]

Reduce concrete

Carbon sequestration



The sink of carbon sequestration in wood products helps to offset sources of carbon dioxide to the atmosphere.



Test result

Timber

22 March 2020

negative

QR will be updated in 05:46

Cradle to Gate Embodied Carbon A1 - A3

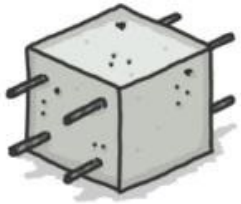
Rammed Earth
48 kgCO_2e/m³
Ranges from 40 to 170 kgCO_2e/m³

Softwood Timber
110 kgCO_2e/m³
Ranges from 1 to 480 kgCO_2e/m³

Cross Laminated Timber
219 kgCO_2e/m³
Ranges from 160 to 320 kgCO_2e/m³

Stone Generally
237 kgCO_2e/m³
Ranges from 60 to 2,100 kgCO_2e/m³

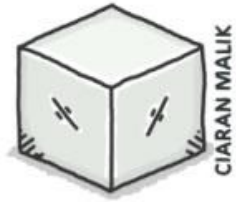
Clay Brick Wall*
345 kgCO_2e/m³
Ranges from 260 to 1,100 kgCO_2e/m³



Reinforced Concrete**
635 kgCO_2e/m³
Ranges from 120 to 1,370 kgCO_2e/m³

Glass Generally
3,600 kgCO_2e/m³
Ranges from 2,300 to 5,100 kgCO_2e/m³

Steel Section
12,090 kgCO_2e/m³
Ranges from 7,600 to 28,000 kgCO_2e/m³

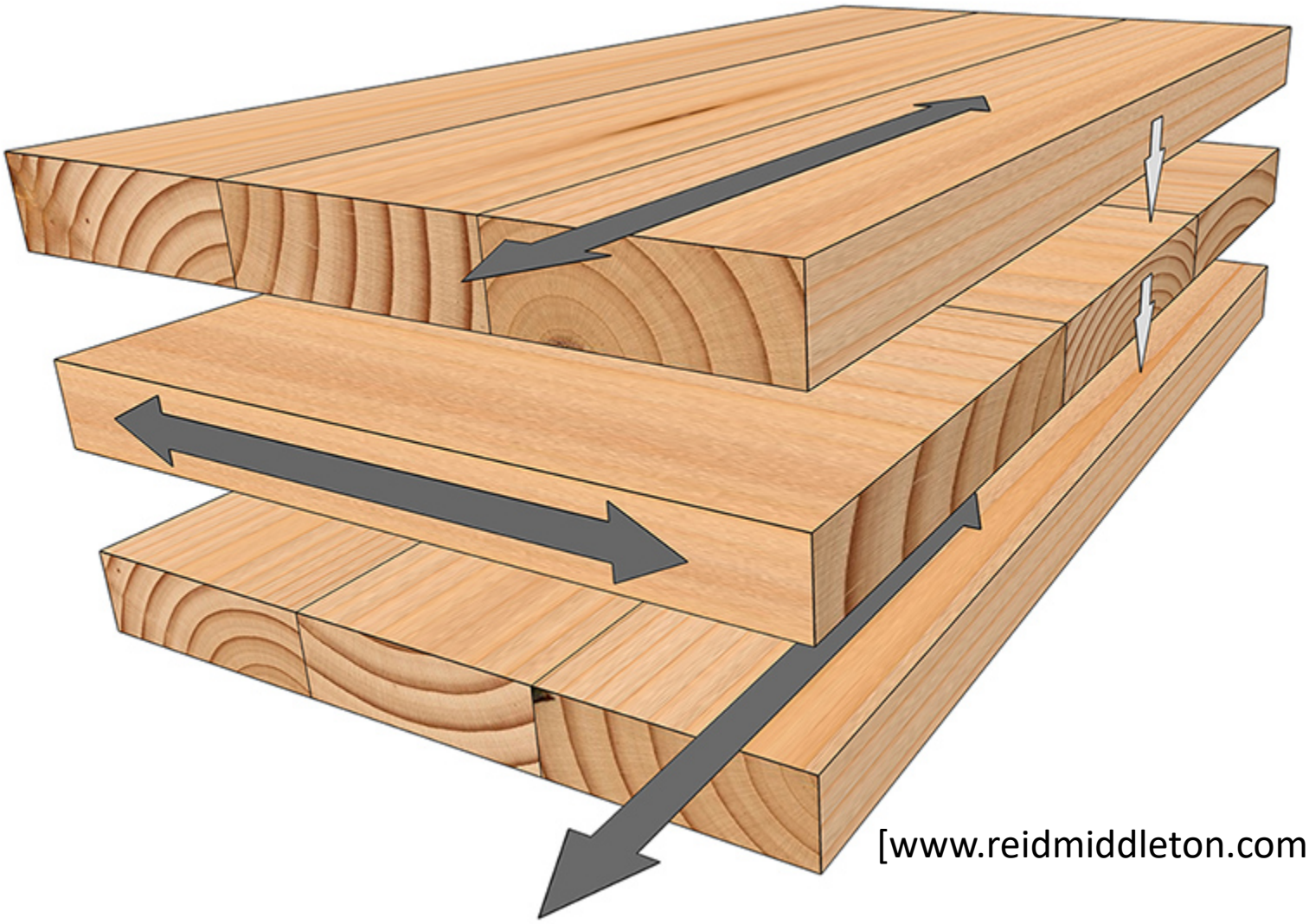


Aluminium Generally
18,009 kgCO_2e/m³
Ranges from 2,400 to 58,000 kgCO_2e/m³

Source: http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html
Using database summary values for product stage, does not include construction, use, end of life or benefits stages.
Ranges are presented to show how values can vary, and require interpretation based on source and analysis method.
*Based on values for brick walls, which use 1,500 bricks for 1m³ of mortar
**Based on C32/40 concrete with 2% reinforcement, maximum based on 4% reinforcement

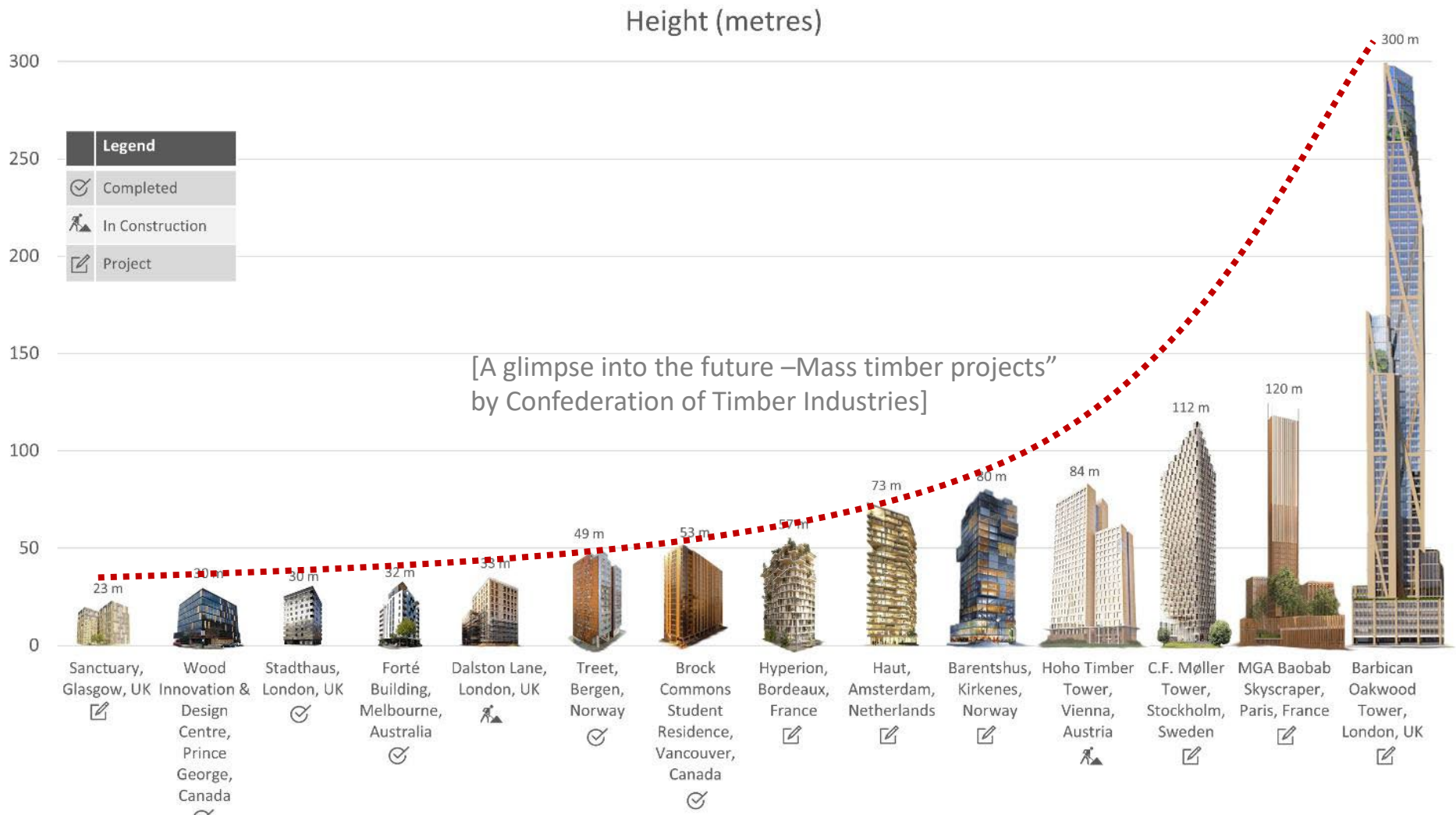
CLT

Reduce concrete in building



[www.reidmiddleton.com]

Reduce concrete in building



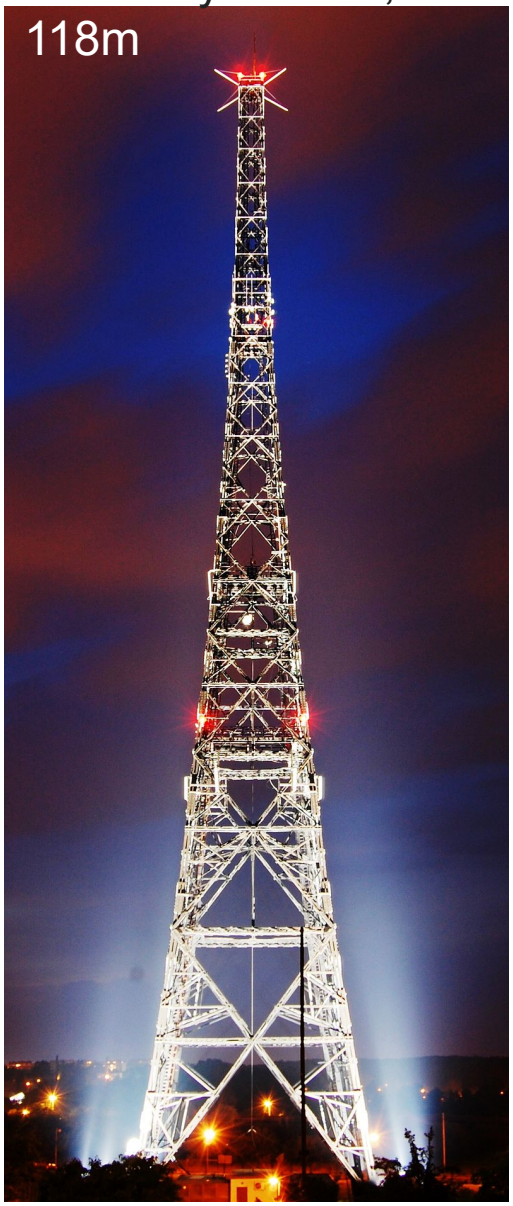
Mjøsa Tower
Norway, 2019
85 m

[www.globalconstructionreview.com]

Sanctuary of Truth
Thailand, 1981-
105 m

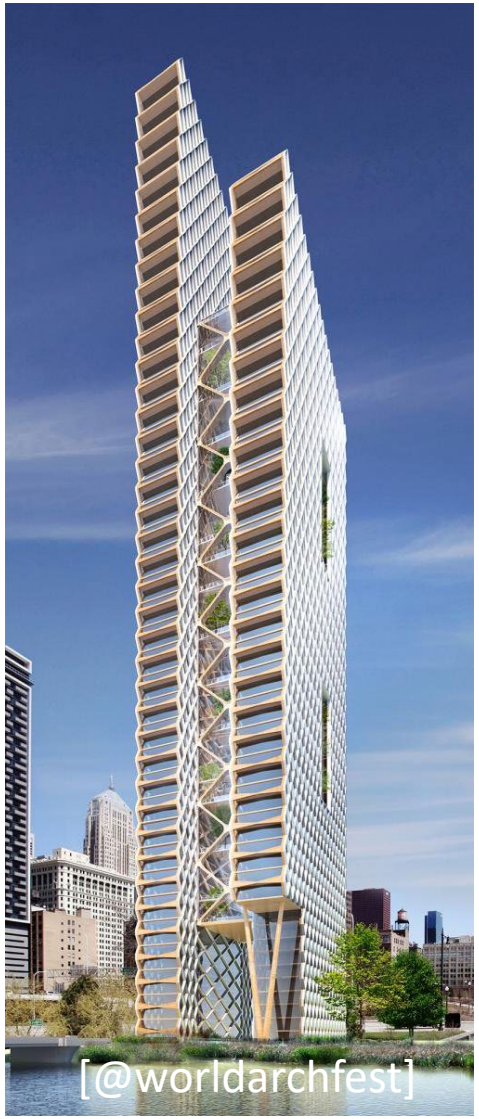
[www.trell.co]

Gliwice Radio Tower
Germany/Poland, 1935
118m



www.wikipedia.com

River Beech Tower
Chicago USA, 228m

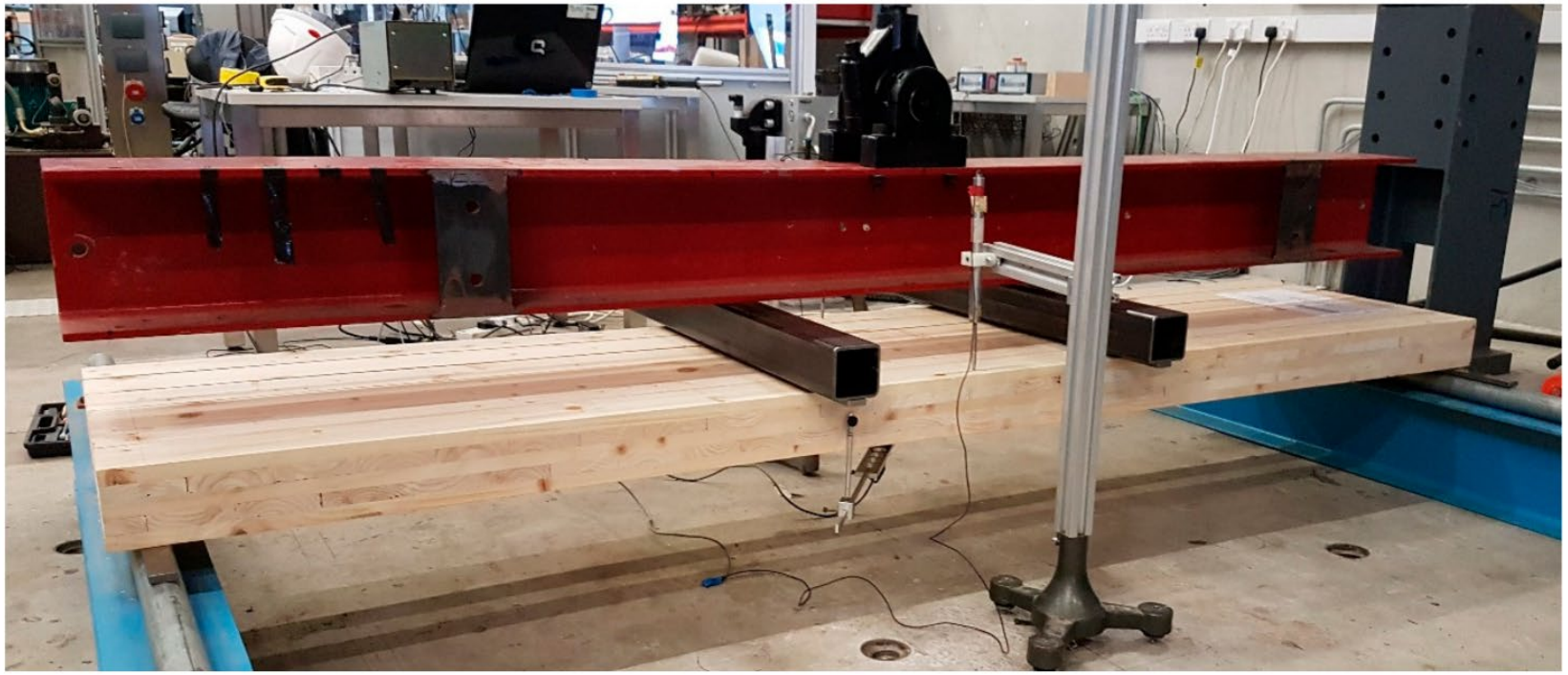


Oakwood Tower
London UK, 305m

W350 Project
Tokyo Japan, 350m

CLT Testing

Reduce concrete in building



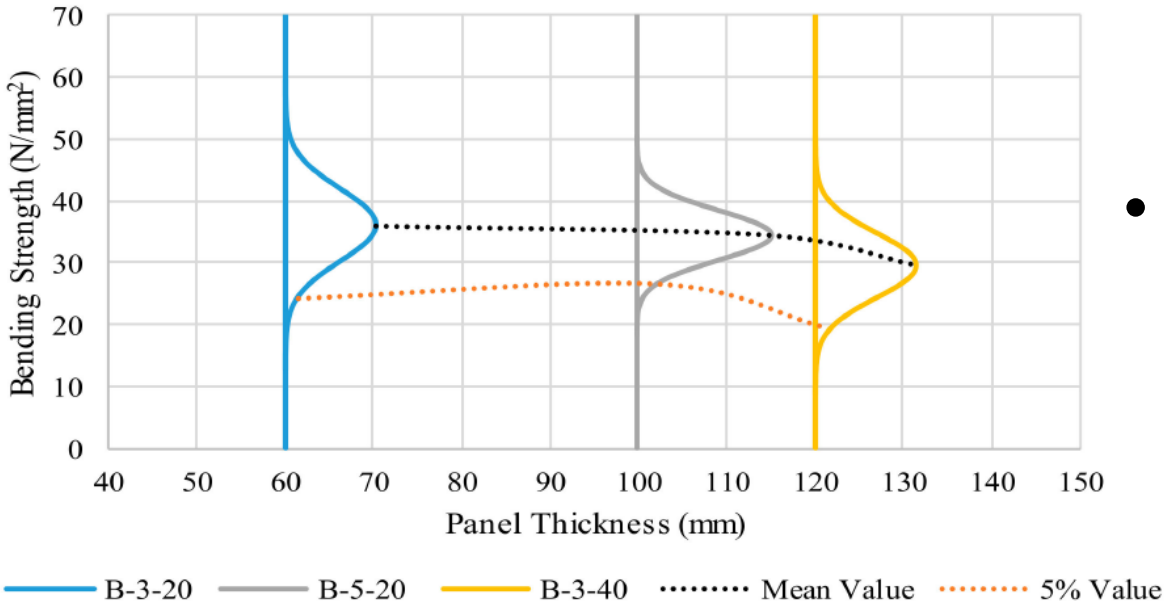
(a)

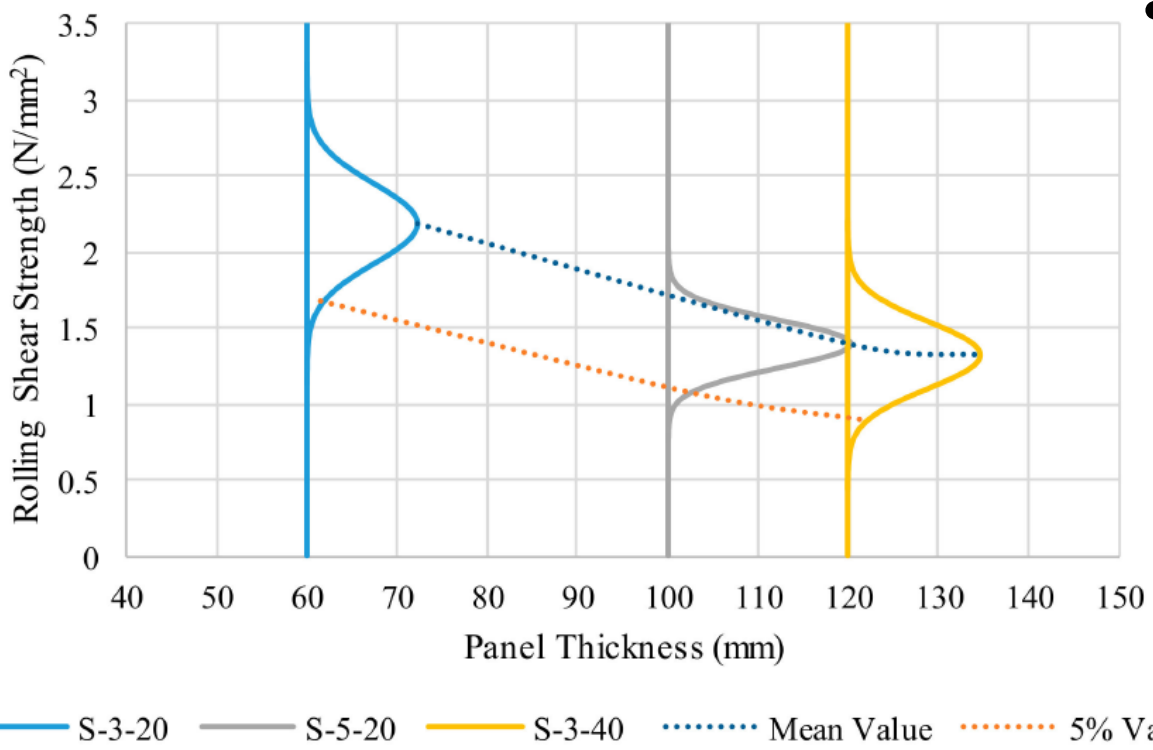
(b)

[Sikora et al., 2016]

Proper quality control. Manufacturing defects result in delamination failure

Reduce concrete in building



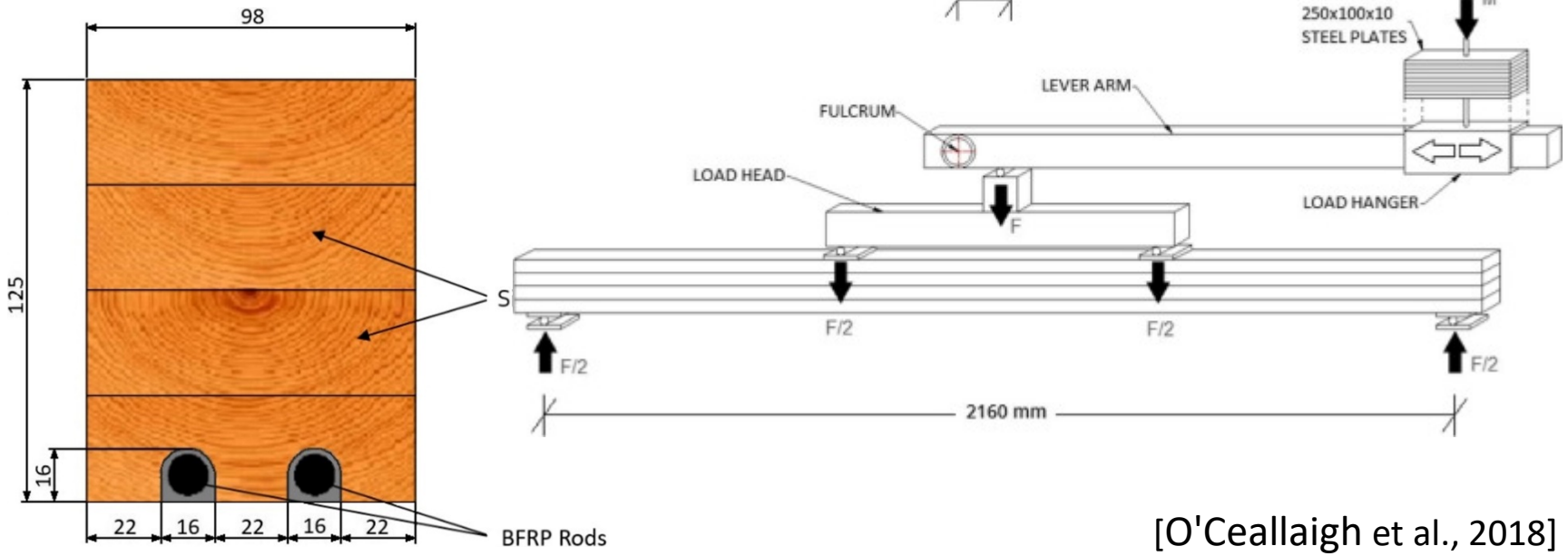


- Bending strength influenced by the number of layers - The homogenising or laminating effect
- Bending and rolling shear strength decrease with increasing panel thickness, irrespective of the number of layers

[O'Ceallaigh et al., 2018]

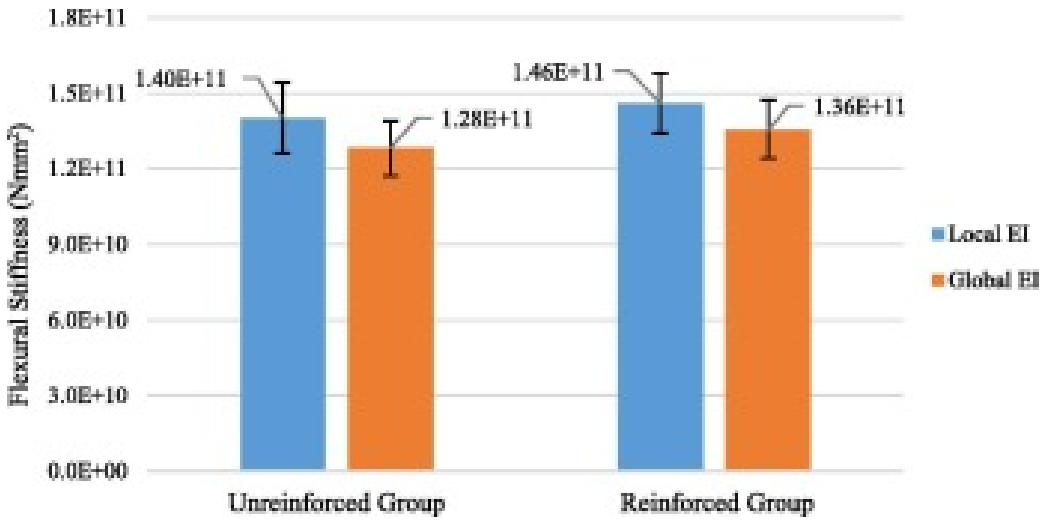
Reduce concrete in building

Basalt reinforced timber elements

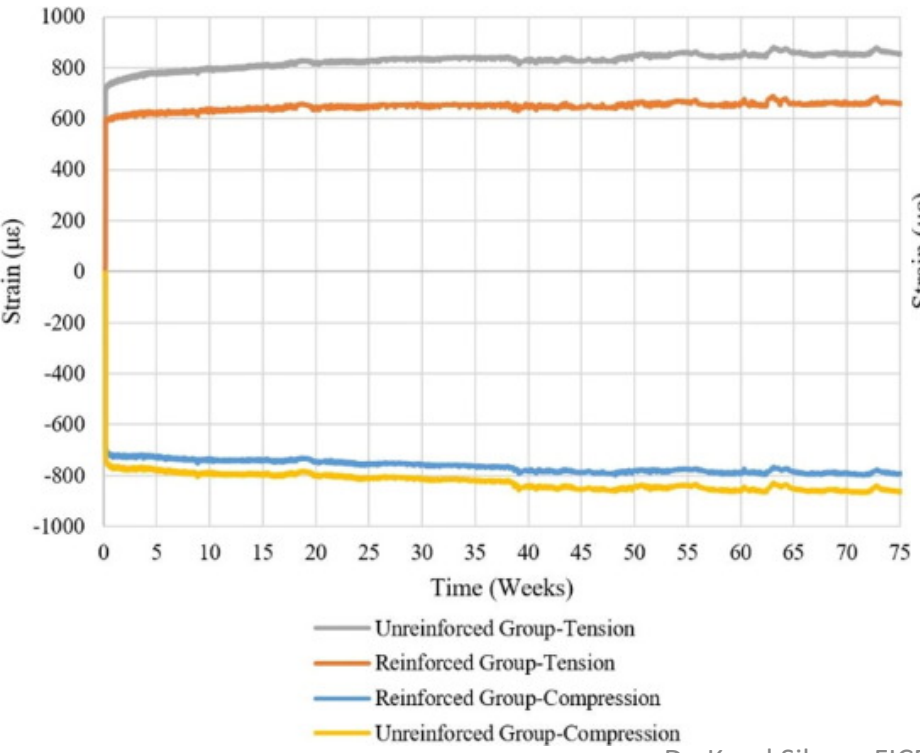


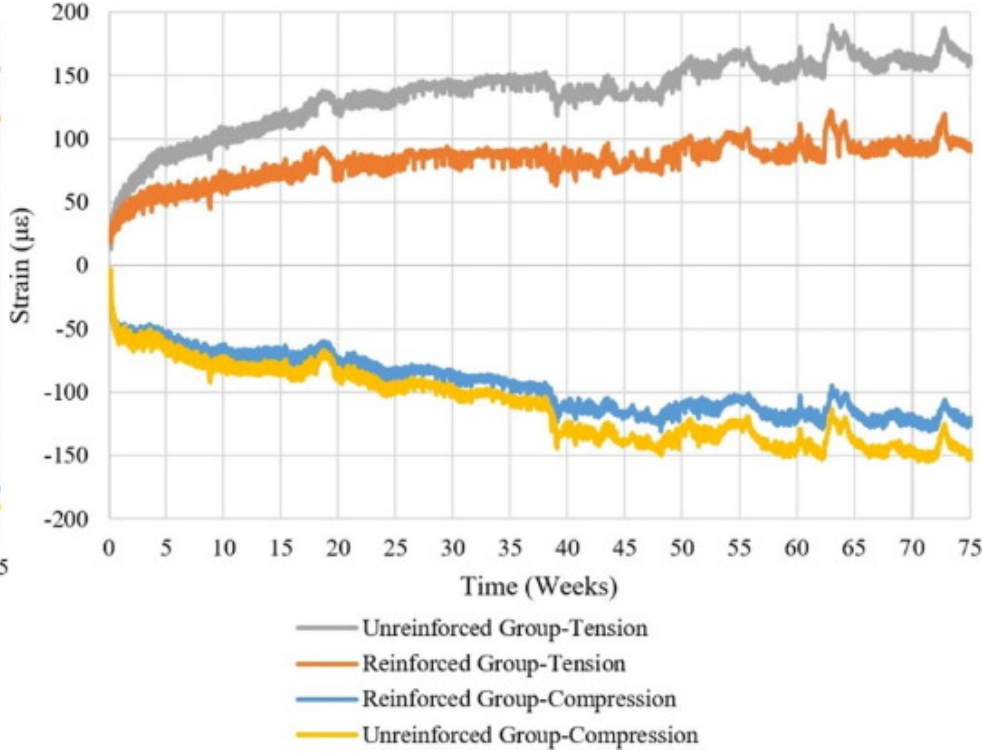
[O'Ceallaigh et al., 2018]

Reduce concrete in building



- Stiffness increase by basalt reinforcement
- No significant effect on creep

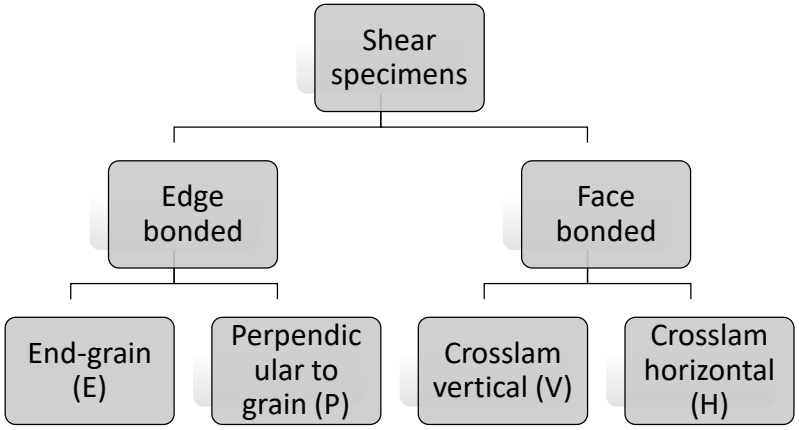


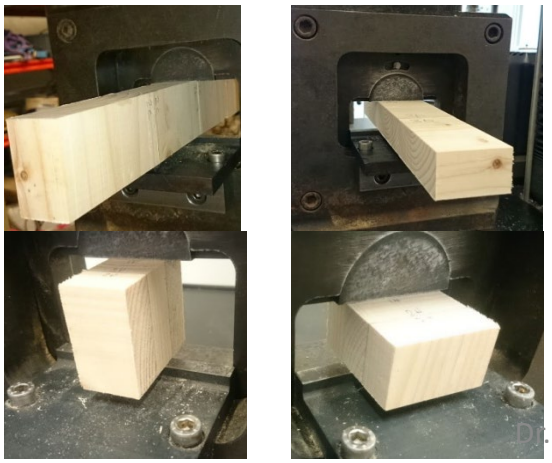


Connections

Reduce concrete in building

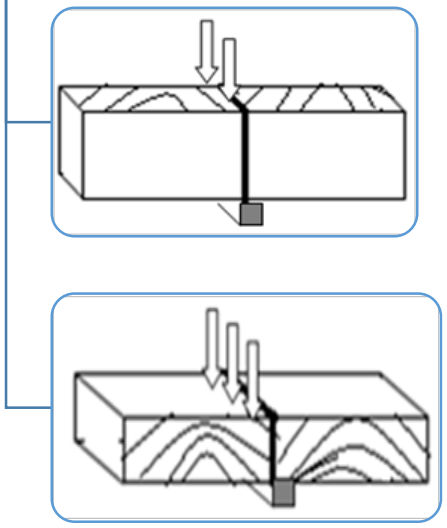
Adhesive bonds in CLT





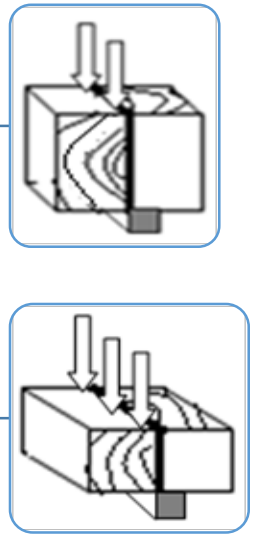
Blocks of edge bonded boards:

0.4; 0.6; 0.8; 1.0 N/mm^2



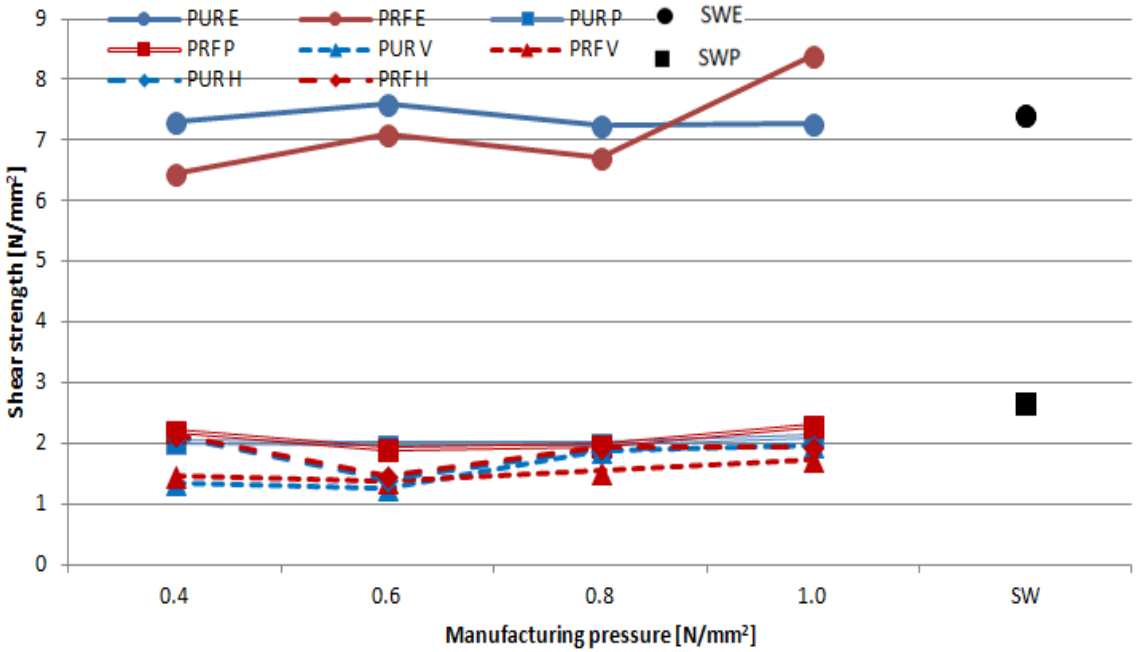
Surface bonded 3-layer CLT panels:

0.4; 0.6; 0.8; 1.0 N/mm^2

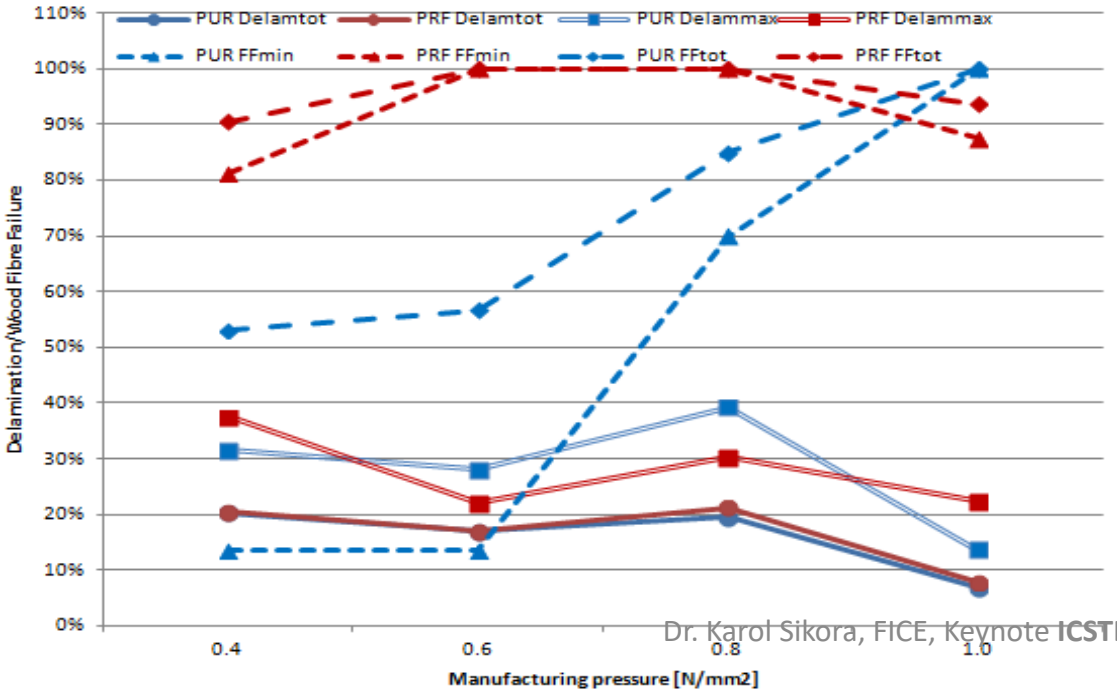


[Sikora et al., 2016]

Reduce concrete in building



- Manufacturing pressure of 0.4 N/mm^2 is sufficient for PUR & PRF



- PRF specimens superior durability. Delamination unsatisfactory for PUR specimens manufactured with pressures below 0.8 N/mm^2

[Sikora et al., 2016]

Reduce concrete in building

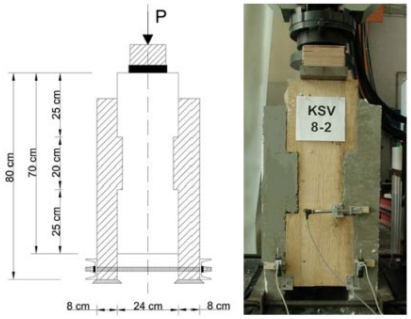
Timber concrete composites (TCC)

- replacing the lower part of a reinforced concrete section (ineffective) with timber:
  - rapid erection of the timber part, with a function of permanent formwork for the concrete topping
  - reduced load imposed on the foundation
  - increased seismic resistance
  - the possibility of using the timber as a decorative ceiling lining
  - low embodied energy

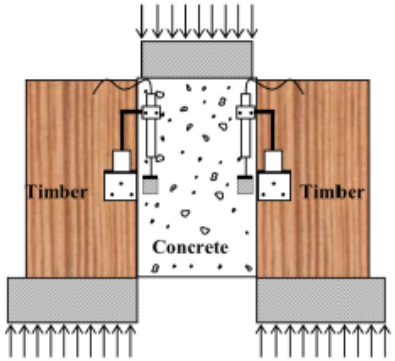
[structurecraft.com]

Reduce concrete in building

TCC connection testing methodologies: push out test

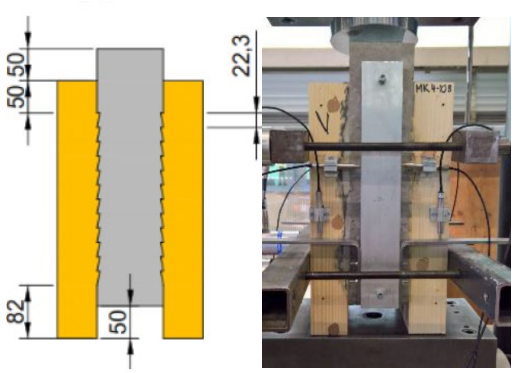


[Kuhlmann and Michelfelder, 2004]

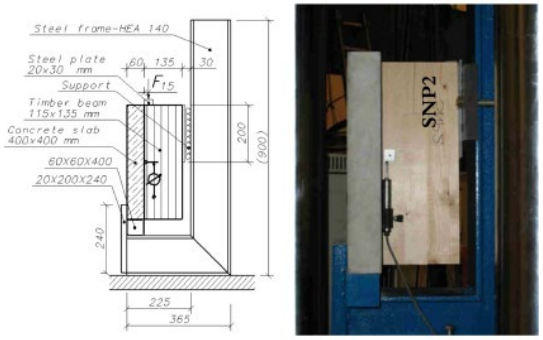


[Dias, 2005]

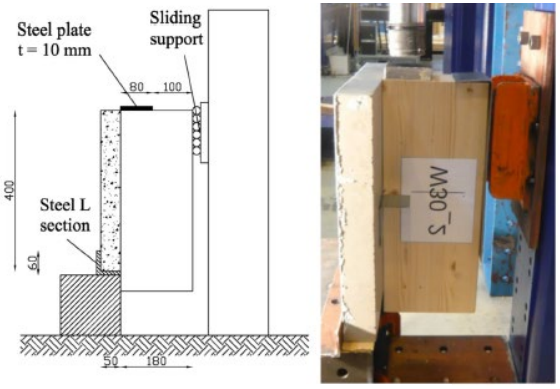
[Döhrer and Rautenstrauch, 2006]



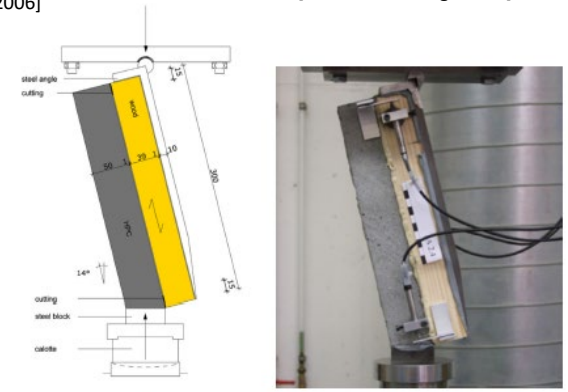
[Müller and Frangi, 2017]



[Łukaszewska, 2009]



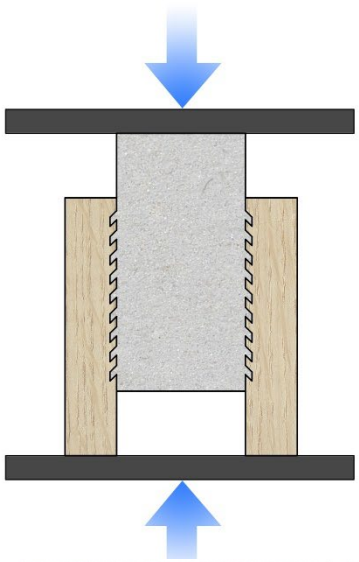
[Crocetti, Sartori, and Tomasi 2014]

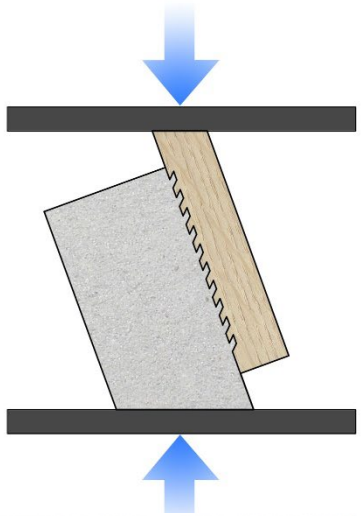


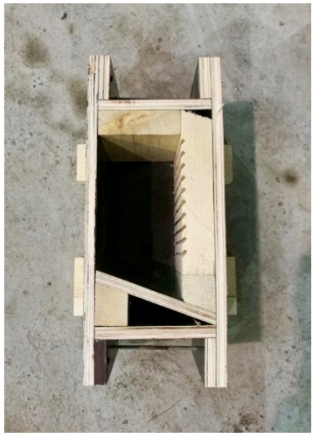
[Eisenhut, Seim, and Kühlborn, 2016]

Reduce concrete in building

Push-out vs. asymmetrical shear

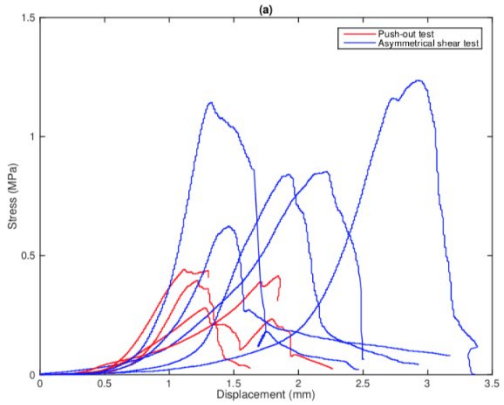


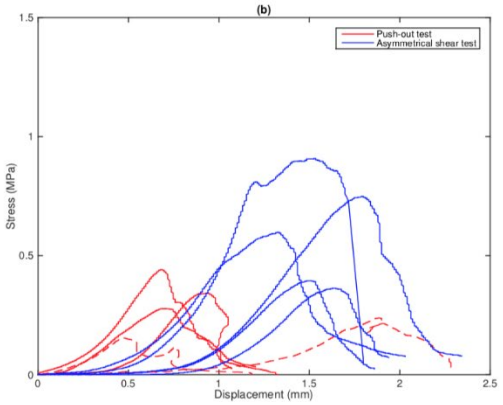


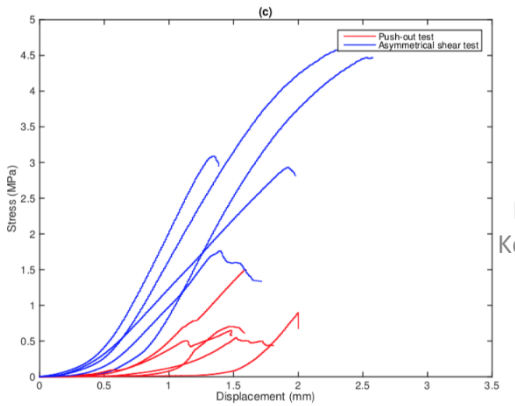


- Push-out tests remain a much more relevant
- Push-out tests focus entirely on the shear strength
- Asymmetrical shear test add tensile stresses

[Richard et al., 2019]



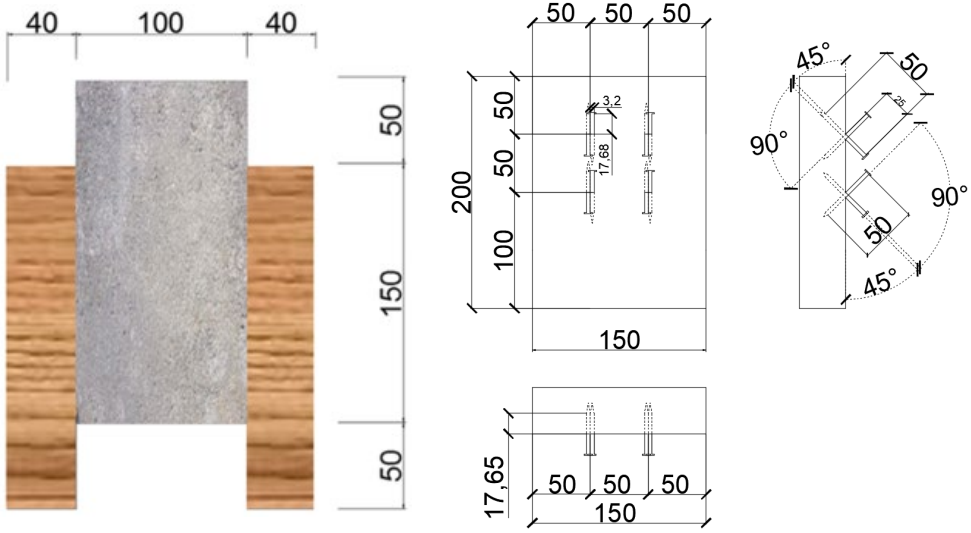


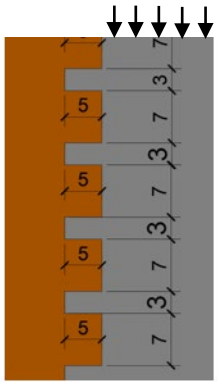


Dr. Karol Sikora, FICE, Keynote **ICSTEESD-2020**

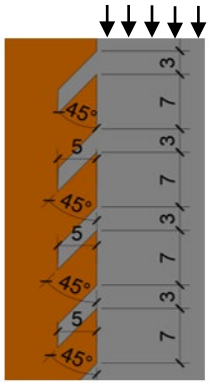
Novel connections: Micro-notched vs. adhesive vs. nails

Reduce concrete in building

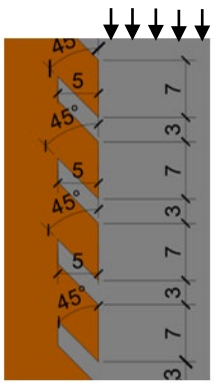




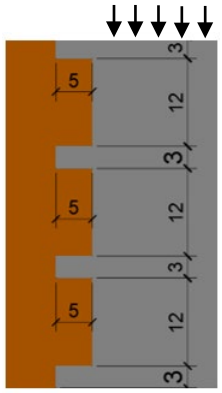
- Rectangular
- Spacing: 10mm
- MR10



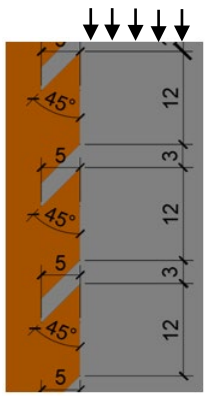
- Slope up
- Spacing: 10mm
- MSU10



- Slope down
- Spacing: 10mm
- MSD10



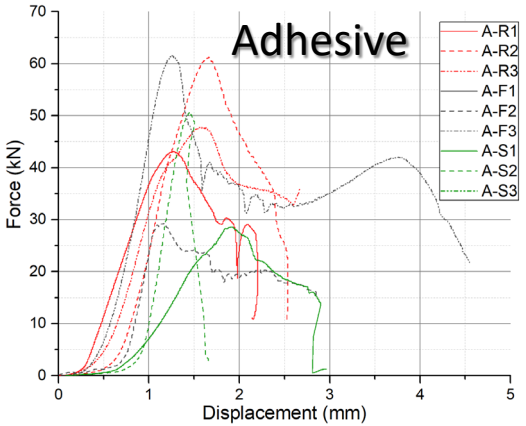
- Rectangular
- Spacing: 15mm
- MR15

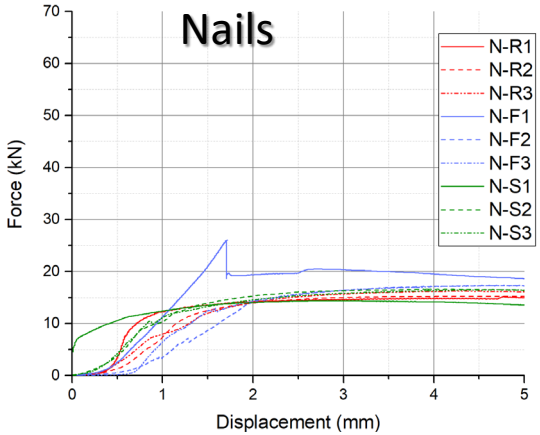


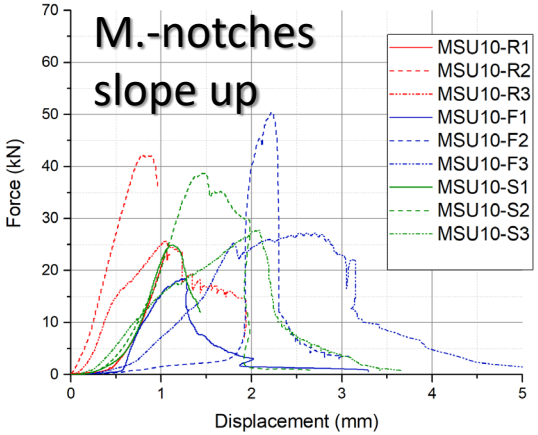
- Slope up
- Spacing: 15mm
- MSU15

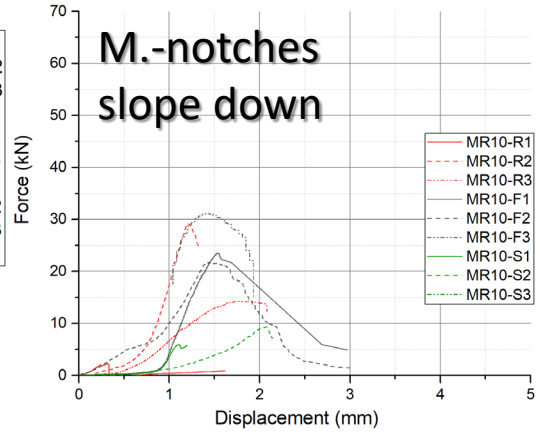
[Sikora & Liu, 2018]

Reduce concrete in building

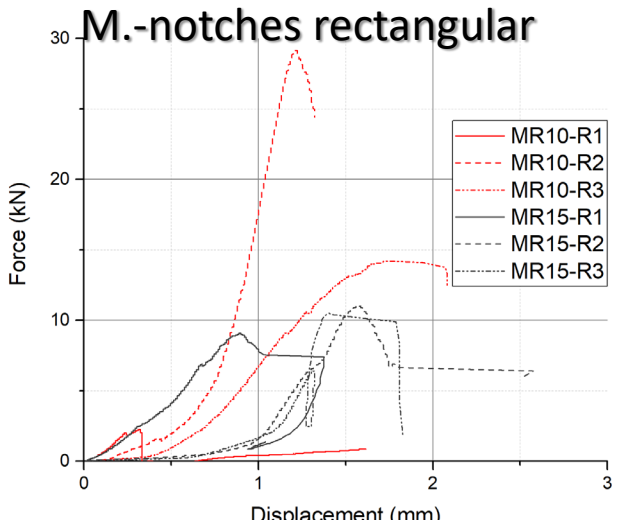


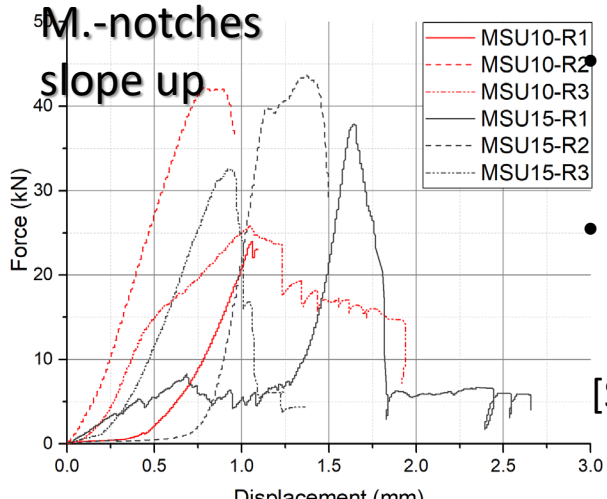






- Concrete workability influence connection. Positive effect of micro-noted connection, negative on wet-adhesive.
- Shear strength of rectangular micro-notch connection low. Inclined micro-notch high shear strength.
- For adhesive connection increasing the strength of concrete can increase the shear strength of connection.



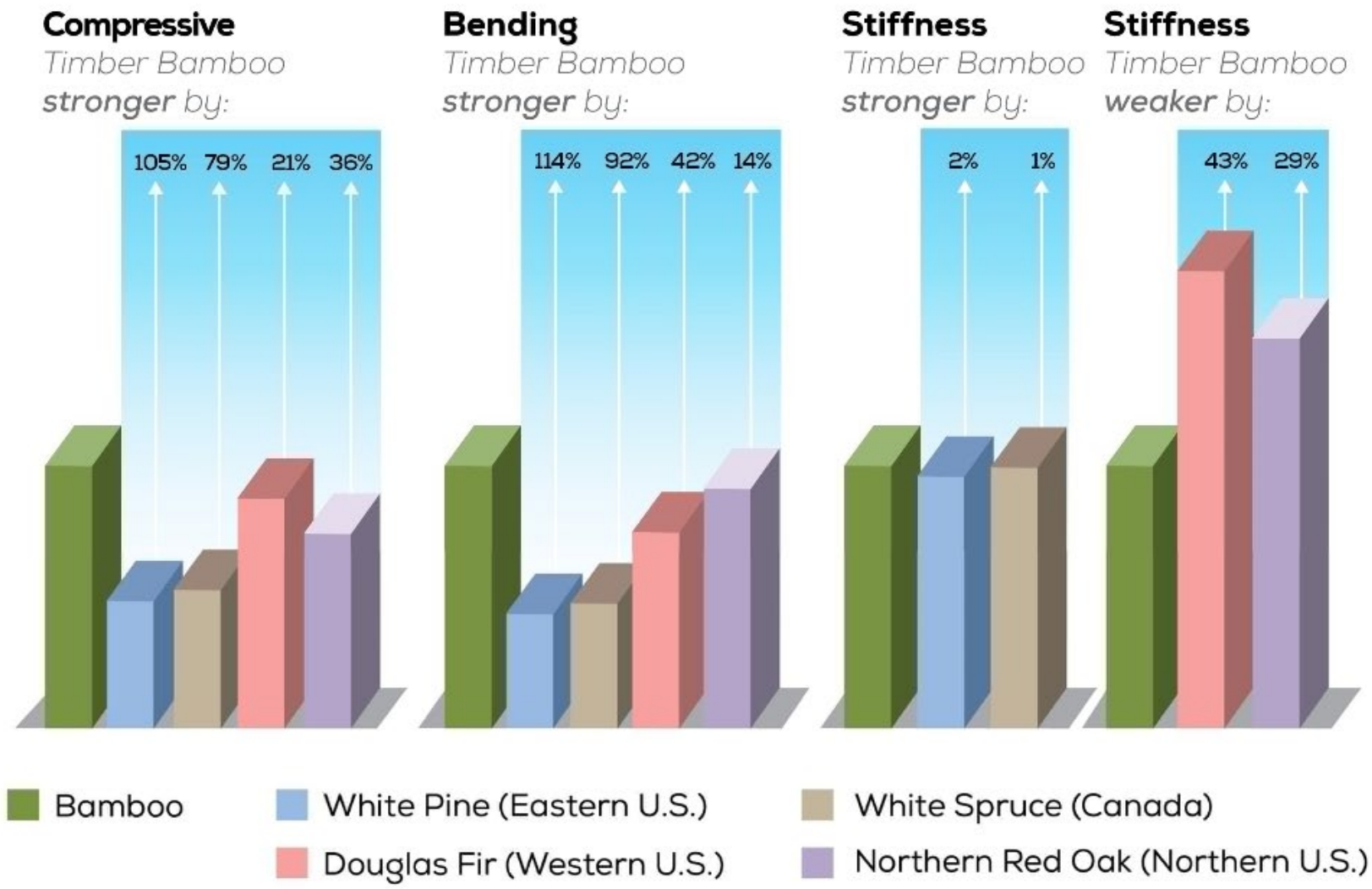


- For rectangular micro-notches spacing - significant influence - shorter gaps higher strength
- For the inclined micro-notch connection only slight differences

[Sikora & Liu, 2018]

Pics credit to:
可汗之风
KHANWIND

North American Softwood Compared To Timber Bamboo (Moso)



Source: Data Charted from Dixon, 2014

Reduce concrete in building

“Bamboo Eye” Pavilion
Beijing China, 9m height, 54mx40m

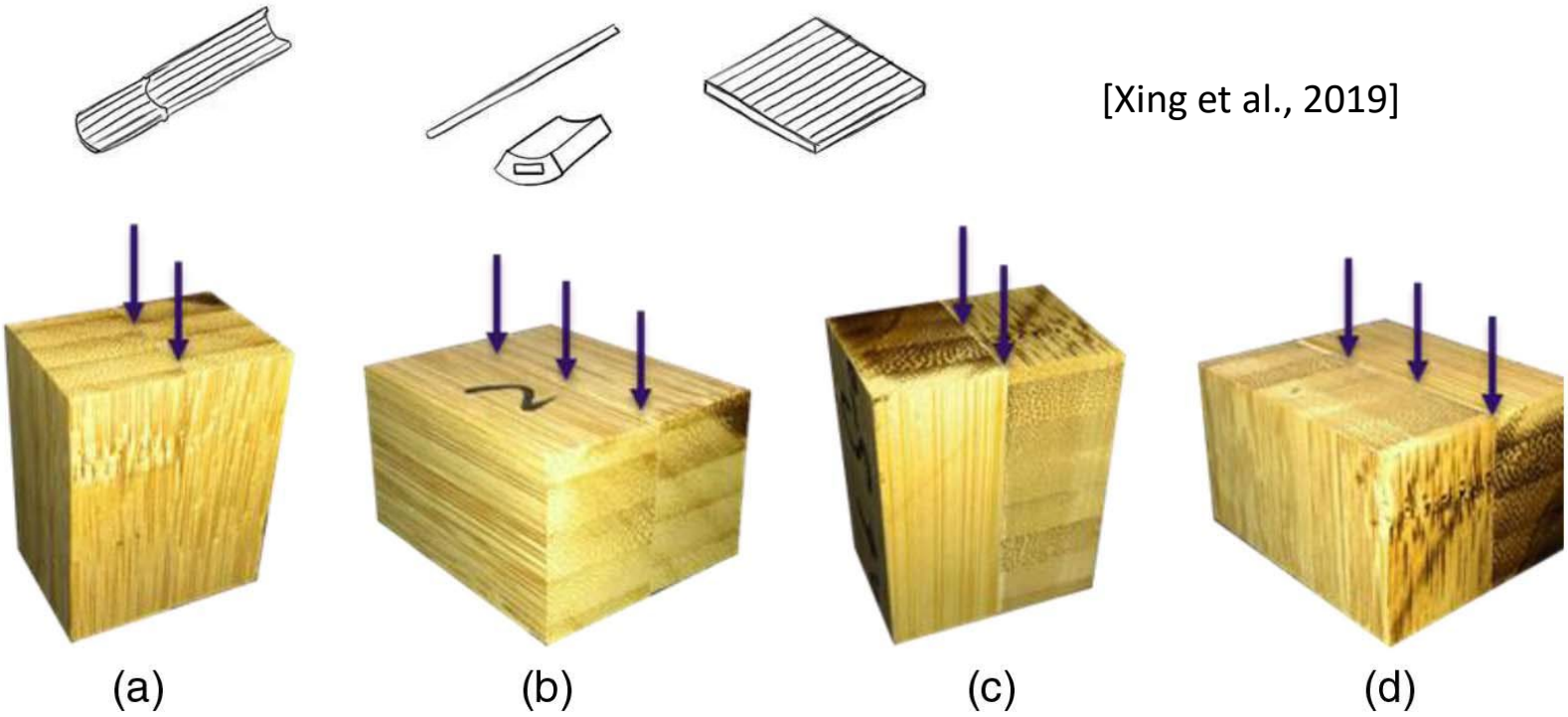
[www.inbar.int]

Sculpture of St Vincent Ferrer
Bayambang, Philippines, 50m

[www.guinnessworldrecords.com]

Reduce concrete in building

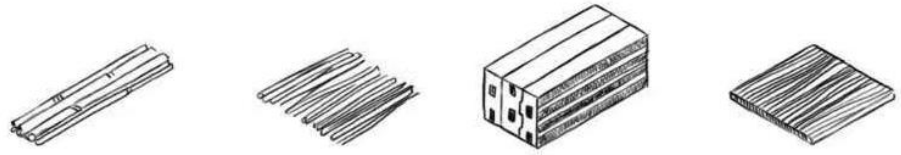
Cross-laminated bamboo adhesive bonds: glued natural bamboo panel

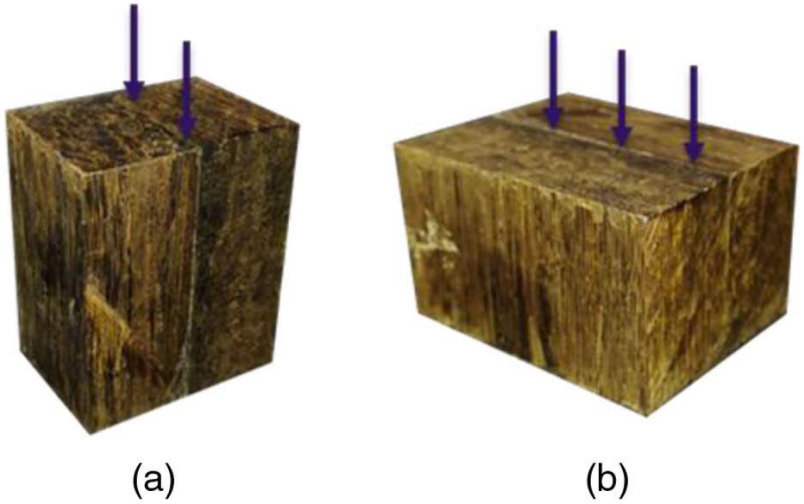


[Xing et al., 2019]

Reduce concrete in building

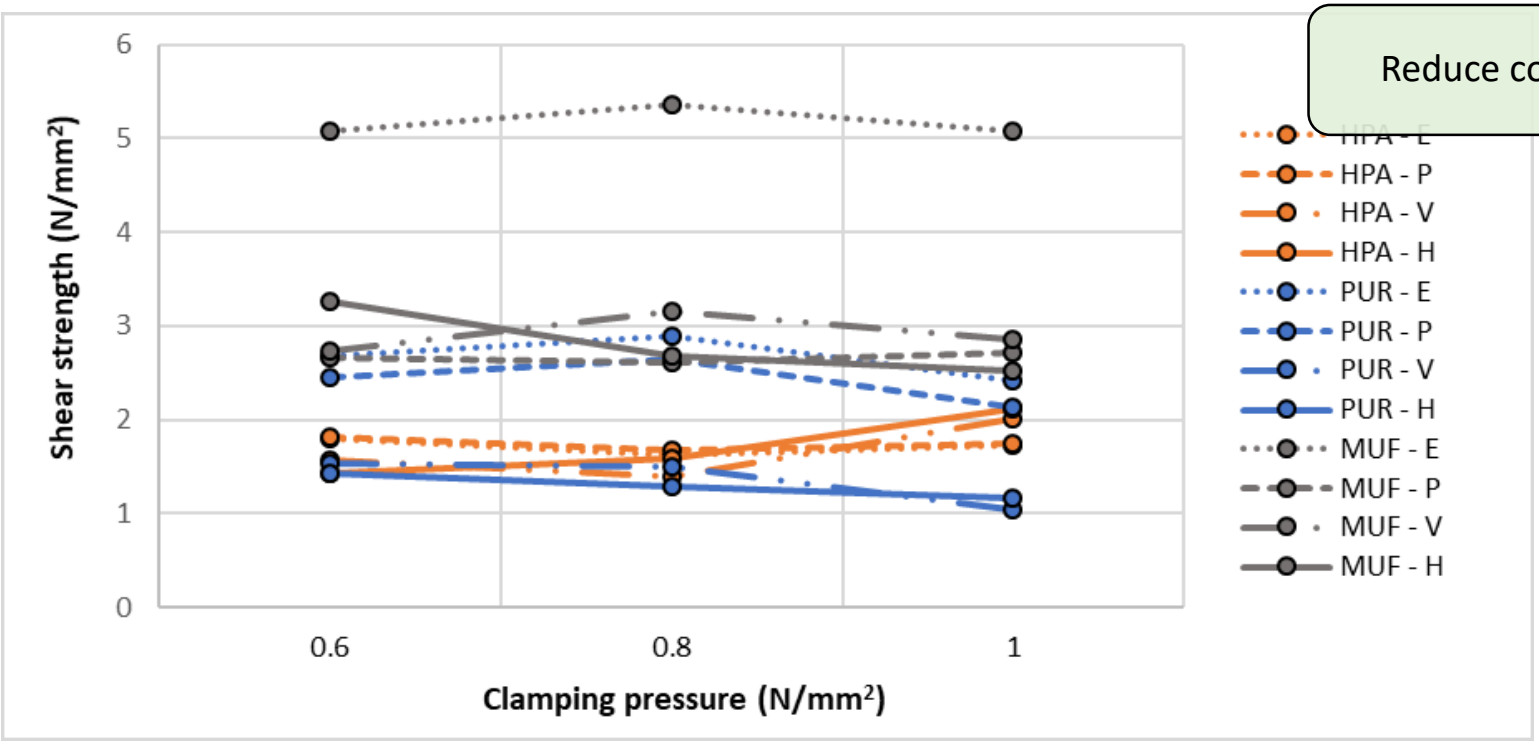
Cross-laminated bamboo adhesive bonds: bamboo scrimber





[Xing et al., 2019]

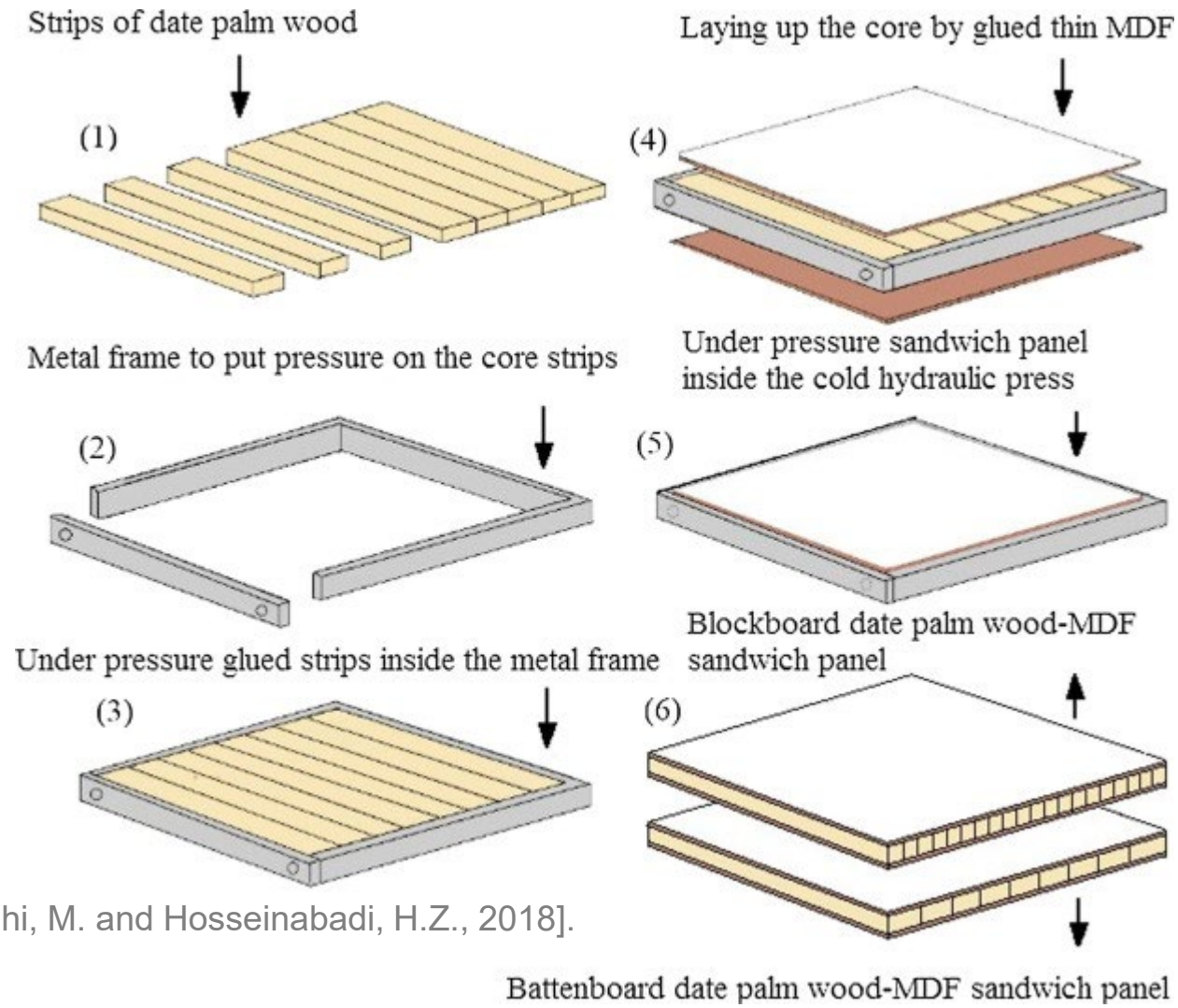
Reduce concrete in building



- The clamping pressure of 0.6 MPa sufficient, although lower than of timber
- 1. PVA 2. MUF 3. PUR 4. HPA
- EPI not appropriate

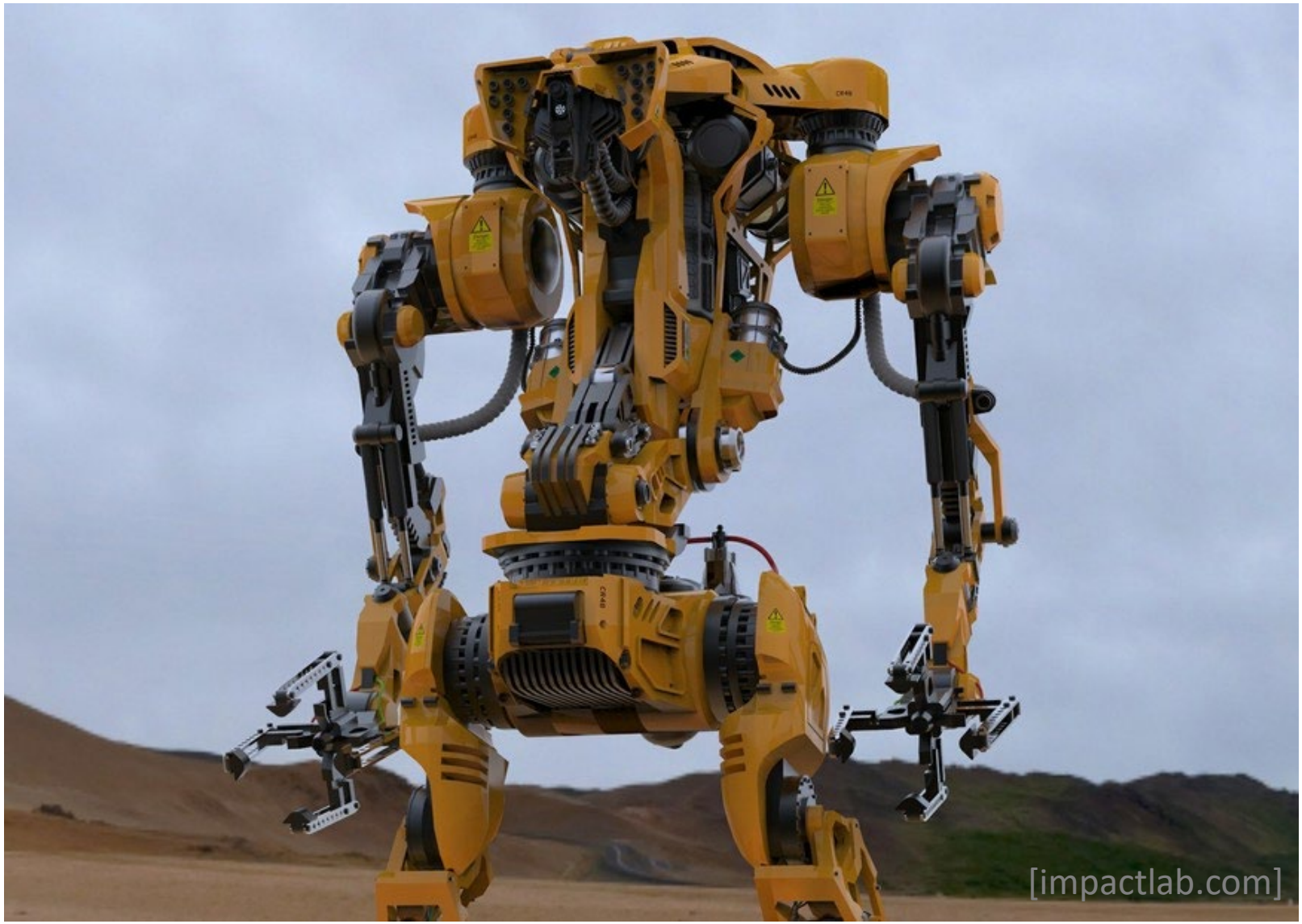
[Xing et al., 2019]

Reduce concrete in building



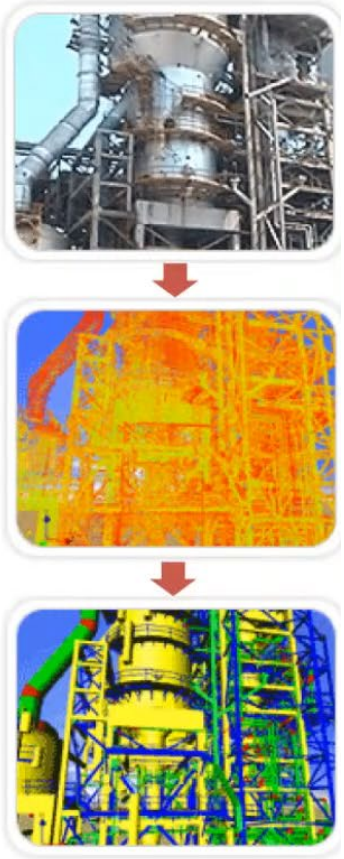
[Haseli, M., Layeghi, M. and Hosseinabadi, H.Z., 2018].

Automation Robotics AI

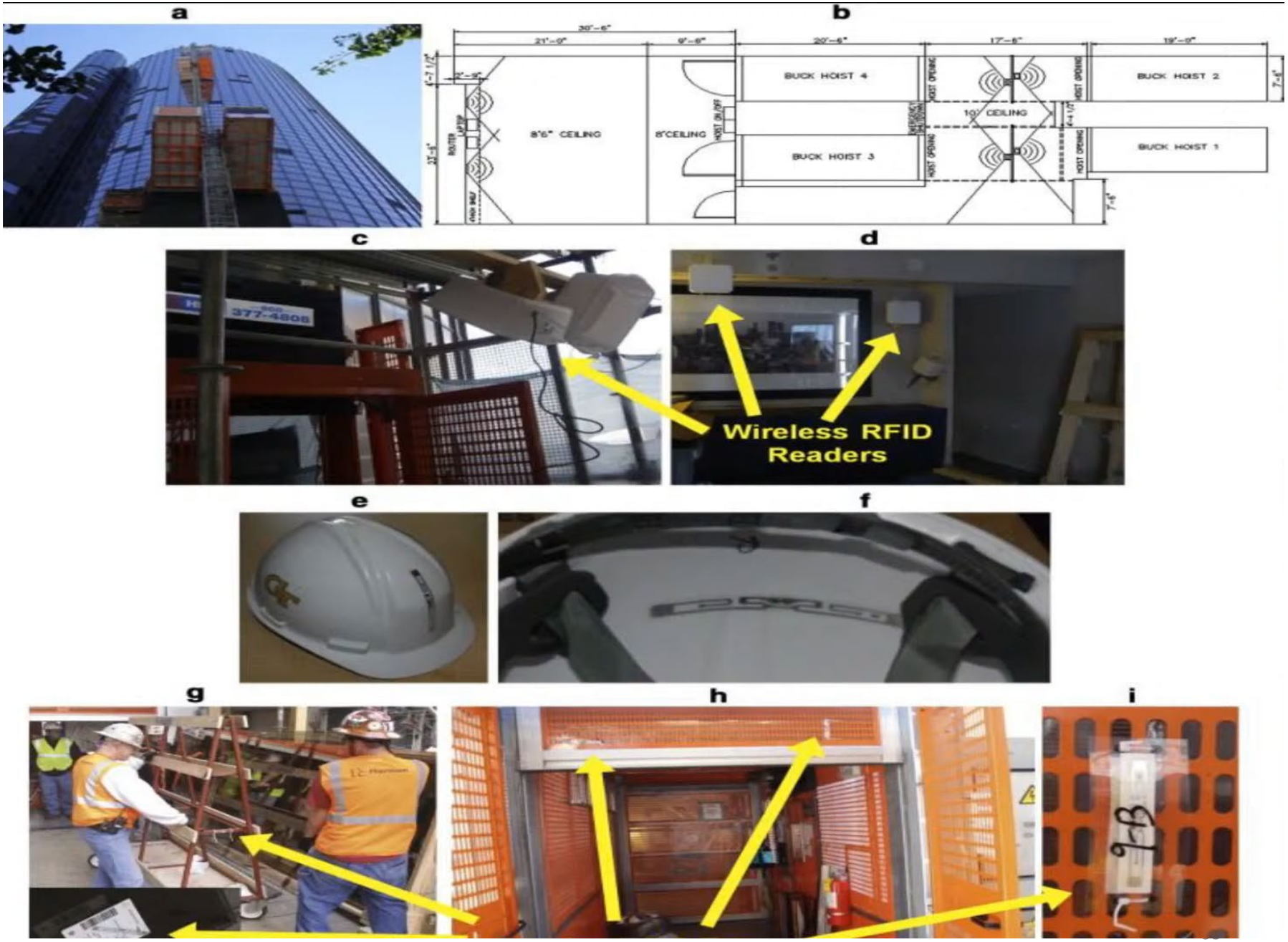


Challenge for IT and Automation

- Restoring and Improving Urban Infrastructure
  - Lack of viable methods to map/label existing infrastructure
    - 2/3 of effort needed to model simple infrastructure spent on manually converting surface data to a geometric model
      - Result: As-built models not produced for most new and retrofit construction
      - Leads to rework and design changes
        - » Cost up to 10% of installed costs
        - » Lead to reduced sustainability (significant material waste)



[courtesy M. Skibniewski]



[courtesy M. Skibniewski]

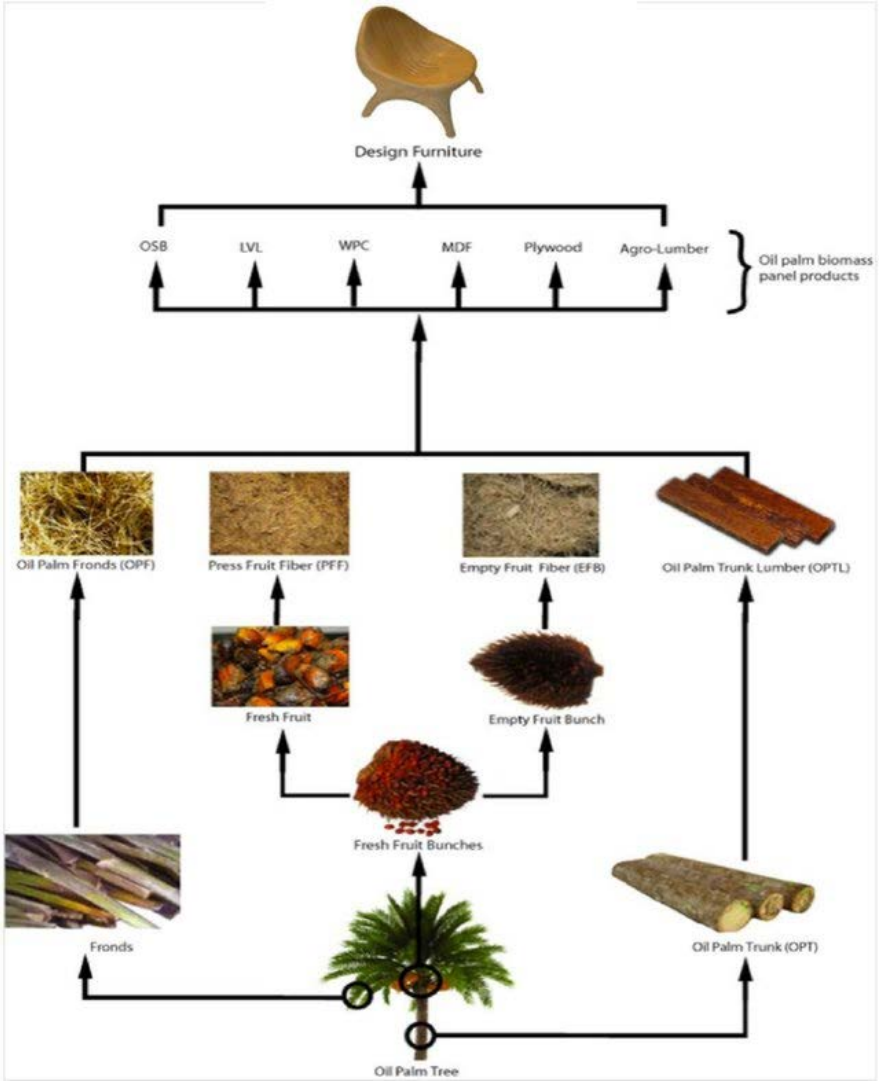
Pre COVID-19 plan to have 25 % of all new construction made with 3D printers by 2030 in UAE

2-story 6,900 square-foot government office

[parametrichouse.com]

[www.re-thinkingthefuture.com]

Palm

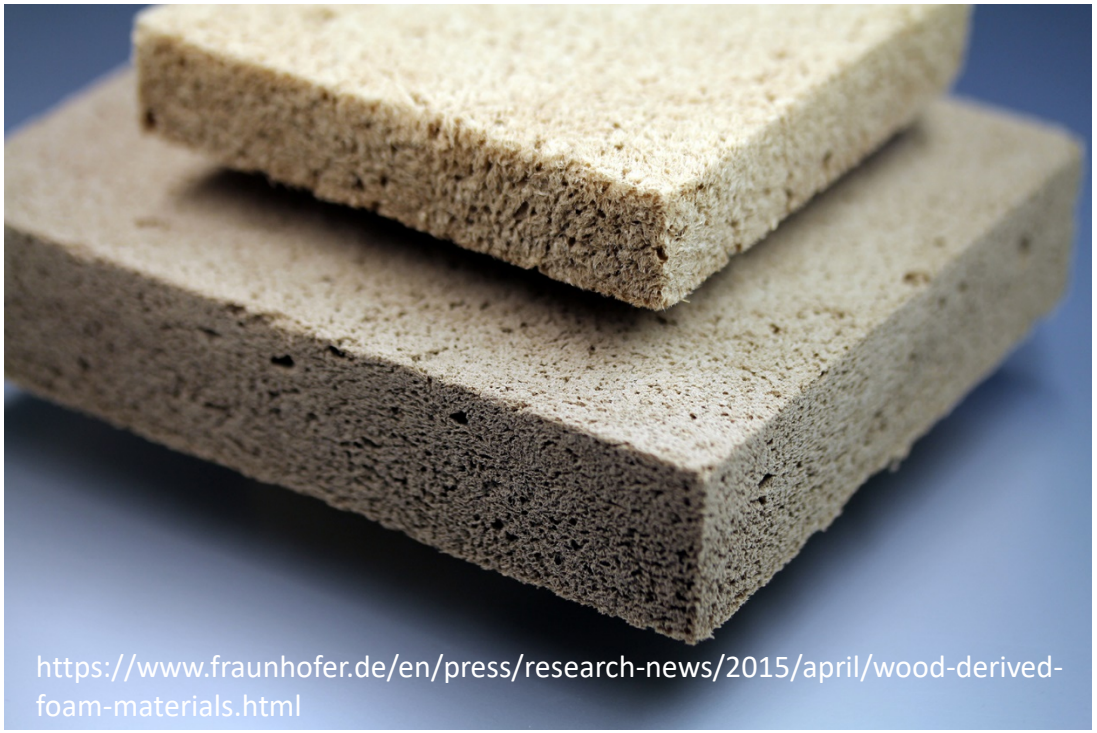


S. S. Suhaily, M. Jawaid, H. P. S. Abdul Khalil, A. R. Mohamed, and F. Ibrahim

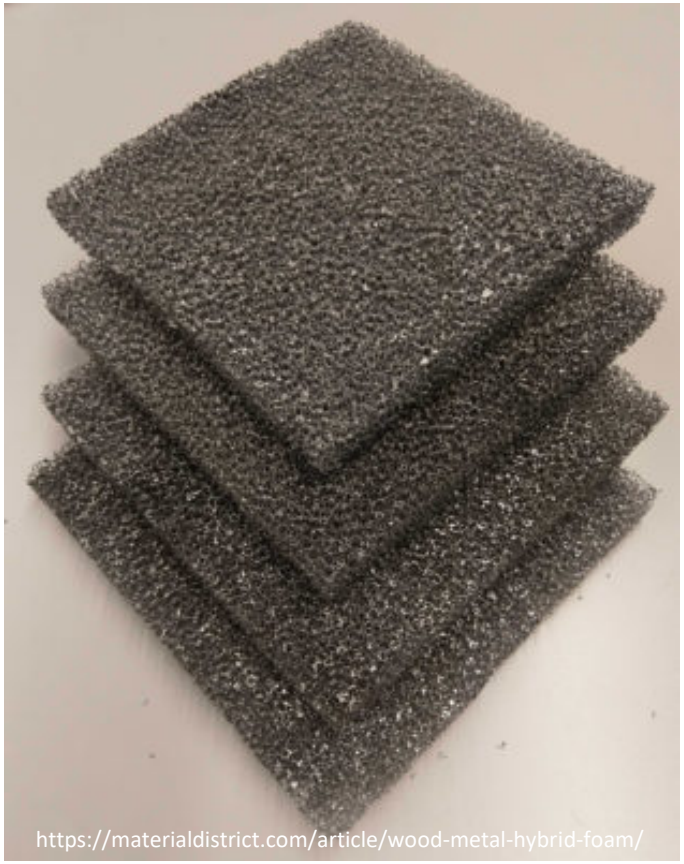
Straw composite

http://www.renewmaterial.com

Wood & wood metal-hybrid foam

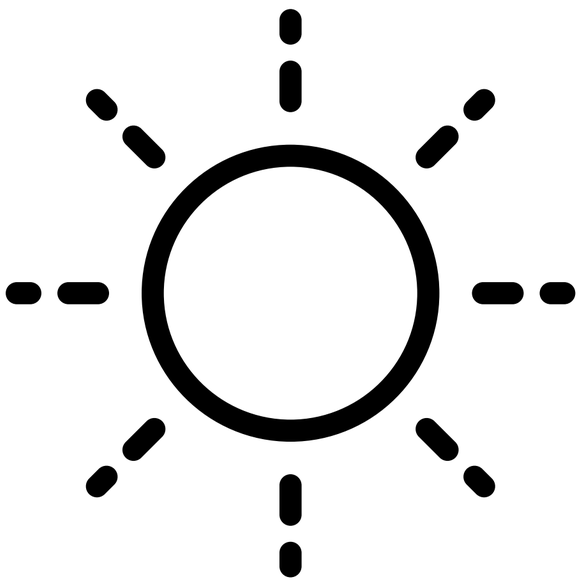


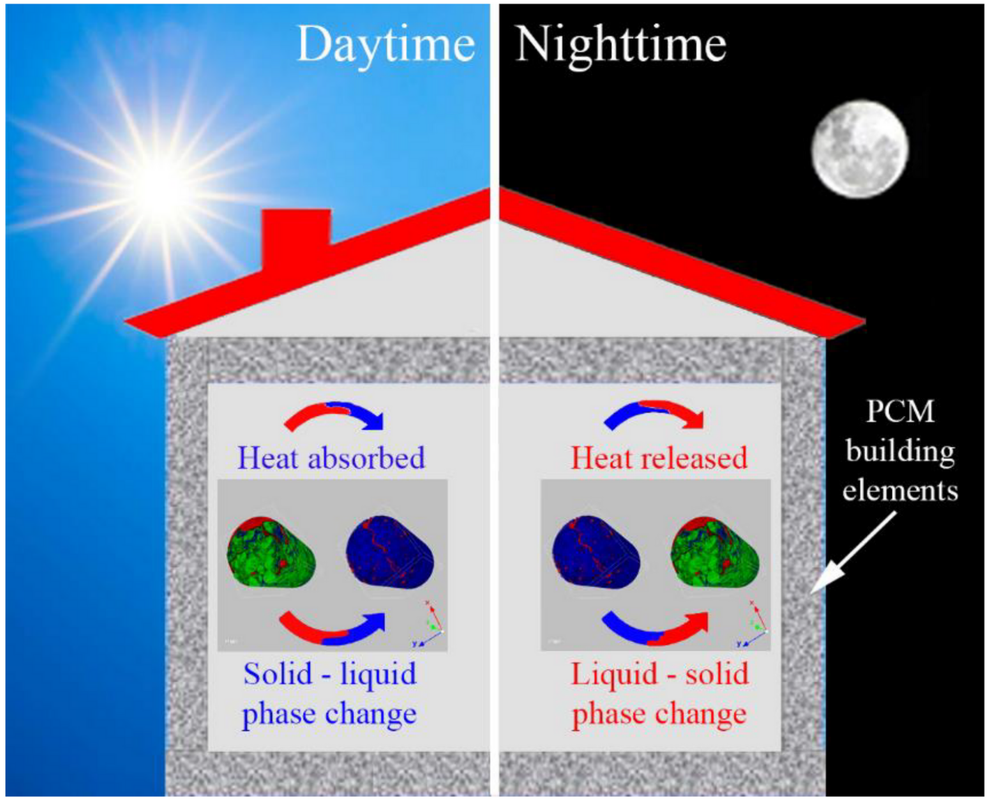
https://www.fraunhofer.de/en/press/research-news/2015/april/wood-derived-foam-materials.html



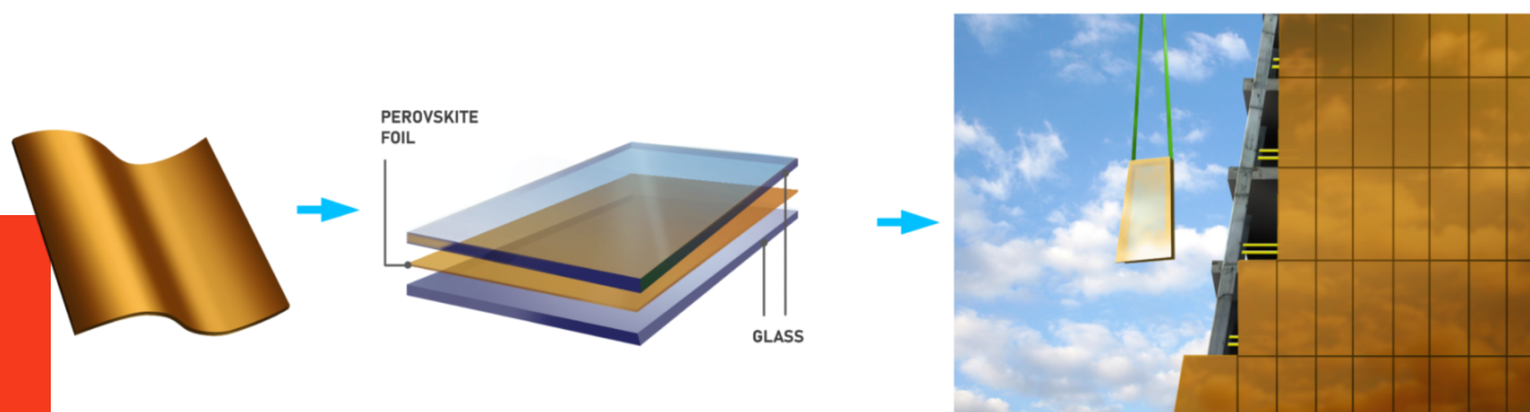
https://materialdistrict.com/article/wood-metal-hybrid-foam/

Energy in building fabric





Source: Podara et al., 2021



Source: sauletech.com

Thermal energy storage as a part of building fabric can be used to increase the energy efficiency of a building by reducing the mismatch between supply and demand of heat or cold.


धन्यवाद
Thank you
谢谢
សូមអរគុណ
شکرا
Dziękuję
Рахмат
karol@karolsikora.info
www.karolsikora.info