Bending behaviour of massive and aerated timber floors

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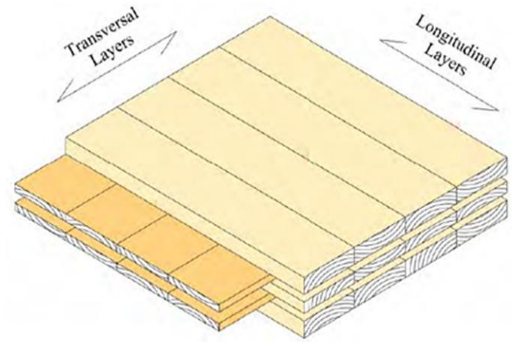
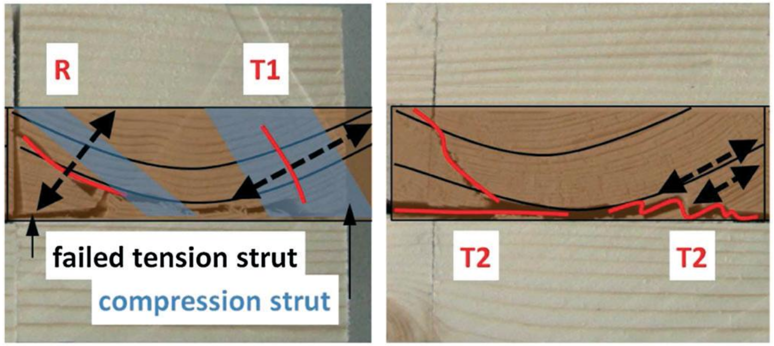
Cross Laminated Timber (CLT) floors



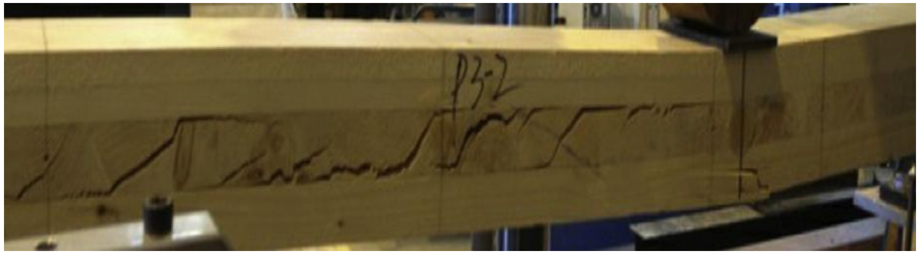
- ❑ Uniform mechanical and hygroscopic behaviour
- ❑ Low self-weight (timber: 450 , RC: 2500 , steel: 8000 [Kg/m^3])
- ❑ Possibility of prefabrication, reduction of building time
- ❑ Good seismic behaviour

CLT floors heterogeneities

- "Low" heterogeneities



(Hochreiner et al. 2013)



(Zhou, 2013)

- Stronger heterogeneities: floors with regularly spaced boards

(http://www.techniwood.fr/)

Contents

- Low heterogeneities
  - Modelling, validation and parameter study
- Stronger heterogeneities
  - Experimental campaign
    - Bending tests – structure scale
    - Material characterization – small scale
  - Simplified and advanced modelling

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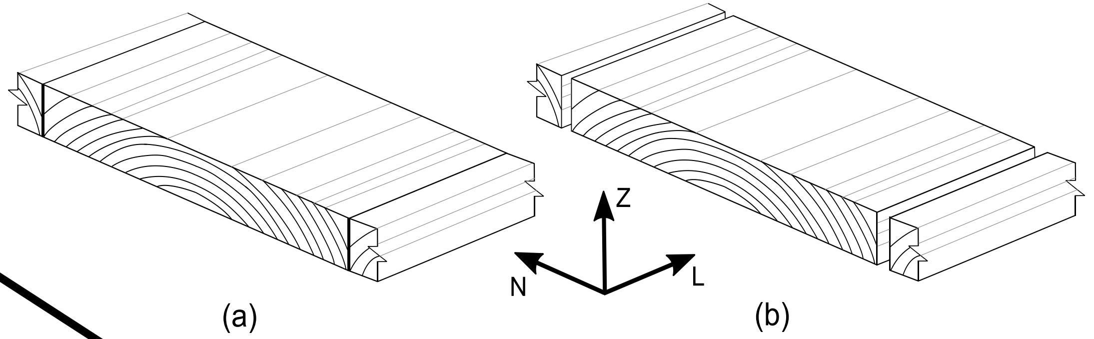
Low heterogeneities: modelling



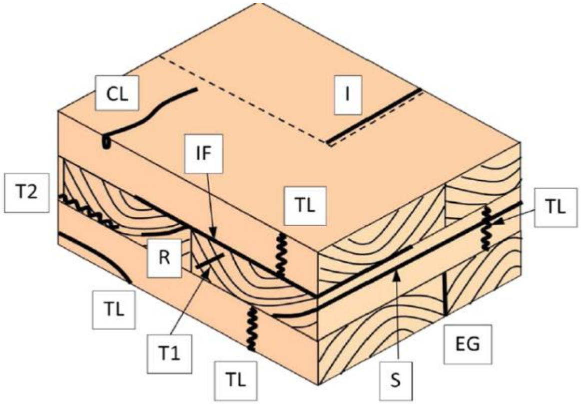
- Equivalent layer model, continuous or discontinuous
  - Exact 3D analytical solution for composites in bending (Pagano, 1969)

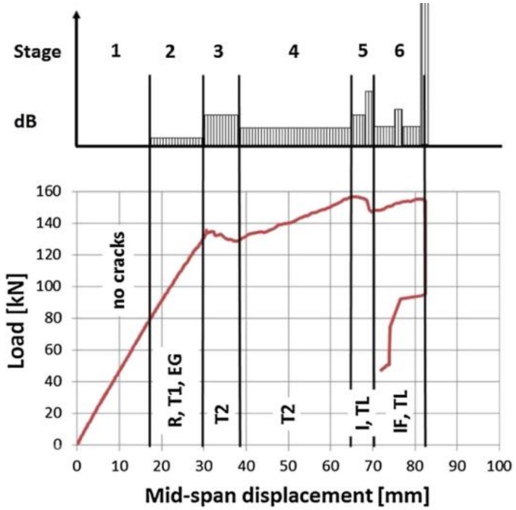
→ Elastic displacements and **stresses**

- Failure criterion for wood (van Der Put, 1982)
- Point - wise dominant failure mode = $\max(\frac{\sigma_l}{f_l}, ..., \frac{\tau_{zn}}{f_{zn}})$

→ Panel's failure load and failure mode

Low heterogeneities: validation





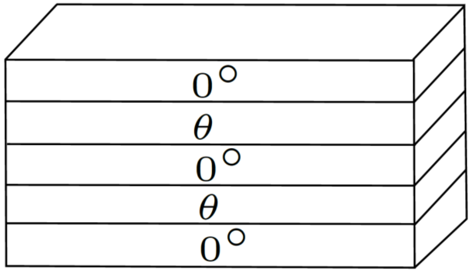
(Hochreiner et al. 2013)

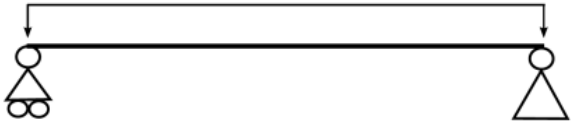
- Good agreement between the predicted and actual panel's global stiffness and variation of failure modes (Franzoni et al, 2015)
- Each layer model is consistent with the corresponding edge-gluing regime
- Gluing the lateral boards slightly increases panel's stiffness (about 8%) but introduces also an additional failure mode
- The discontinuous model gives a better prediction of global load carrying capacity

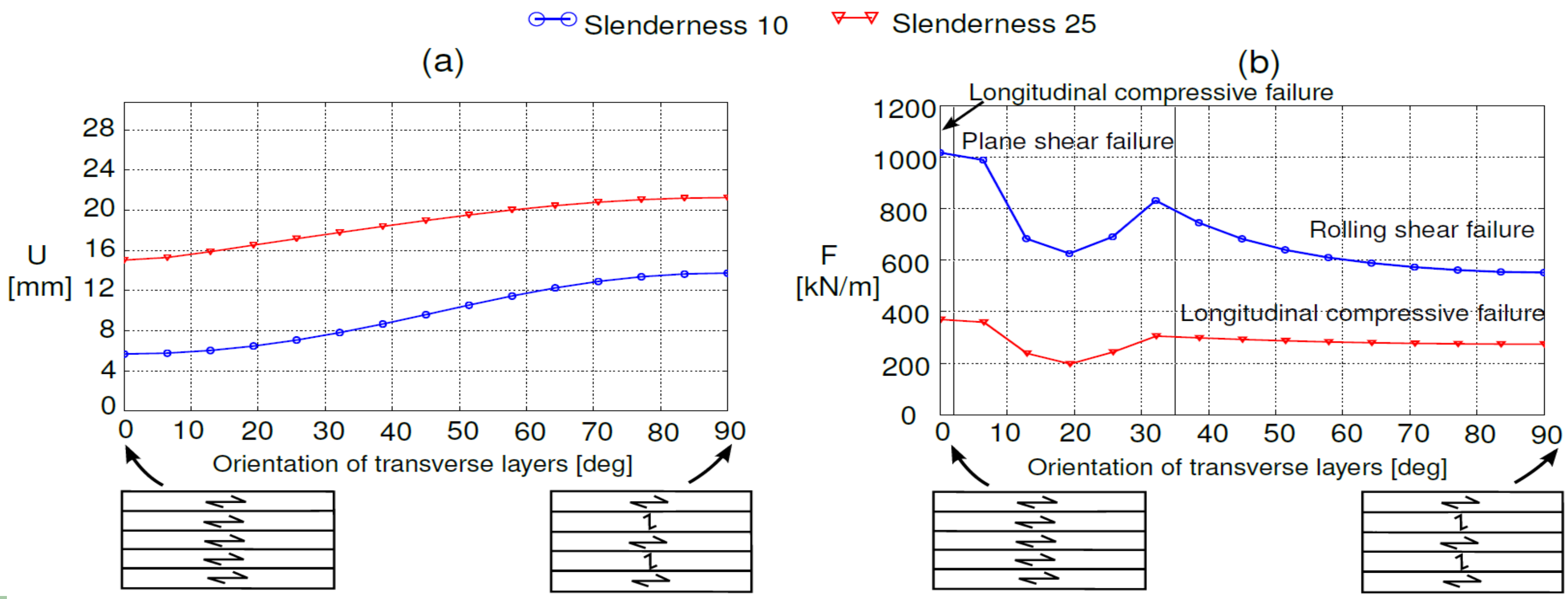
New orientation for transverse layers

- Influence on bending behaviour of varying transverse layers' orientation

(Chen, 2011)







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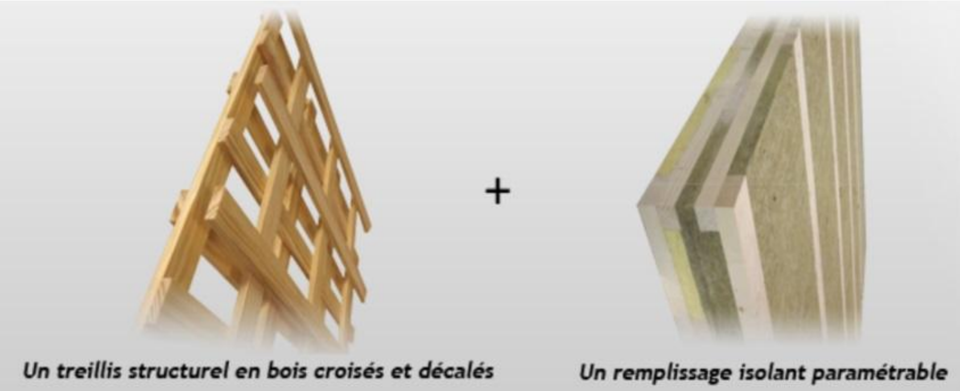
Stronger heterogeneities

Lighter (high-rise buildings) and more acoustically efficient CLT floors

→ Stronger heterogeneities : periodic voids within the panel

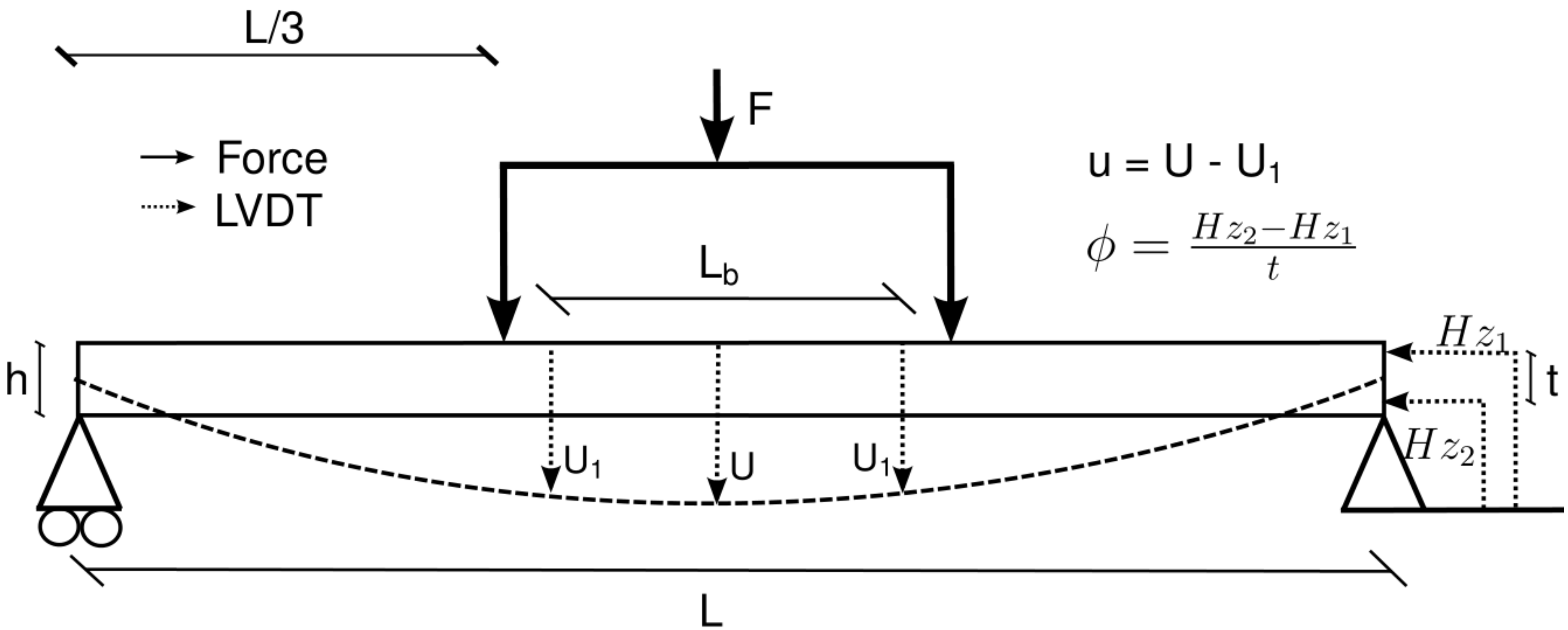


(http://www.techniwood.fr/)

Influence on CLT floor's bending behaviour ?

Stronger heterogeneities – 4 points bending tests

- Measuring system: vertical and horizontal LVDTs
- Bending deflection (*u*) and absolute rotation at supports (ϕ)



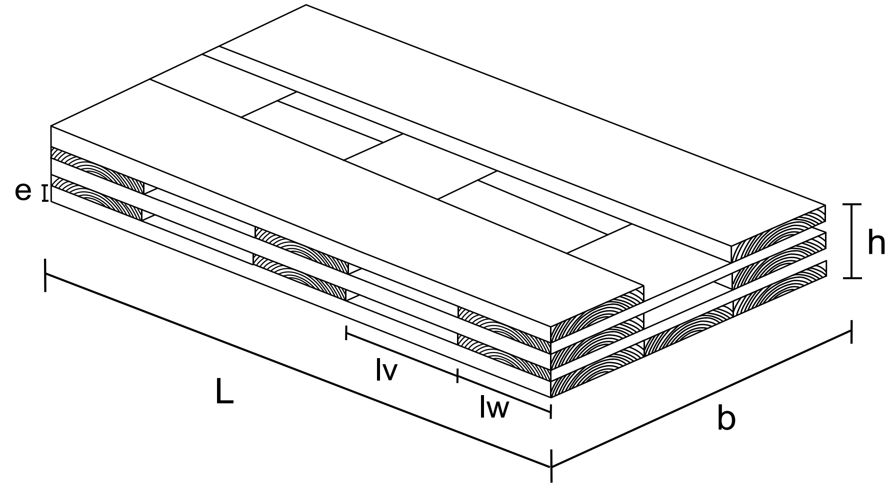
Effective bending stiffness EI

→ Shear stiffness GA

Ratio shear deflection / bending deflection

Stronger heterogeneities – 4 points bending tests

- Classical (massive) CLT panels and regularly spaced ones
- Two ratios wood/void: 2/3 and 1/3



	CLT	Panobloc®	Panobloc®
Slenderness ratio L/h	46.5	28	28
Wood/void ratio	-	2/3	1/3
Total wood volume fraction	1.0	0.4	0.25
Failure load [kN]	75	68	34
Bending Stiffness [kNm^2]	890	3400	1950
Shear/Bending deflection [$\%$]	3.0	17	27

Stronger heterogeneities – 4 points bending tests

- Failure modes :

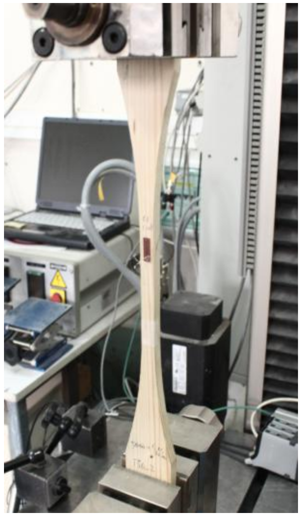
Massive CLT panel: ductile longitudinal compressive cracks before tensile failure

Panobloc® 2/3, less spaced: tensile failure of bottom boards

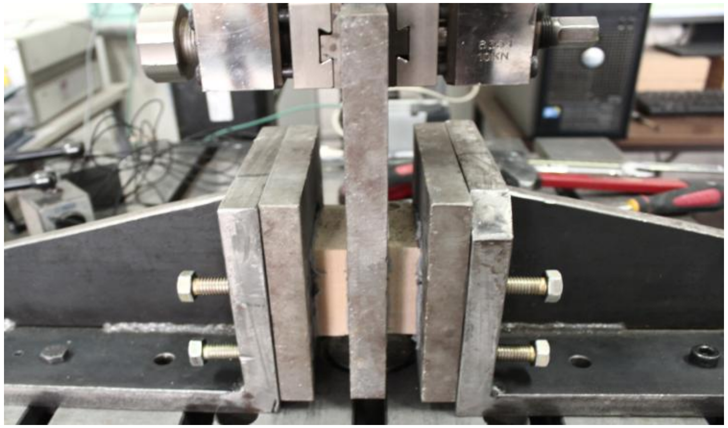
Panobloc® 1/3, more spaced: rolling shear failure of transverse boards

Stronger heterogeneities – material characterization

- Axial – parallel to grain and rolling shear tests



Axial Tests	**n**	**Mean** [Mpa]	**COV** [%]
$E_{L\,(t+c)}$	21	12700	17.2
$f_{L,t}$	10	85	17.3
$f_{L,c}$	8	51	6.4



Shear Tests	**n**	**Mean** [Mpa]	**COV** [%]
G_{ZN}	7	110	25
f_{ZN}	9	1.7	17

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Stronger heterogeneities – simplified and advanced modelling

- Classical CLT floor comparison:

- Equivalent-layer model for low heterogeneities (discontinuous)
- Two design methods: shear analogy (Kreuzinger, 1999) and gamma method (EN, 2004)

Massive CLT	Gamma method	Shear analogy	Equivalent layer - discontinuous
Failure load	**-**	**-**	**+5%**
Bending stiffness	**-7%**	**-7.5%**	**-5.5%**
Shear deflection	**-8%**	**+7%**	**+5.5%**

Stronger heterogeneities – simplified and advanced modelling

➢ Aerated timber floors: simplified and advanced approaches

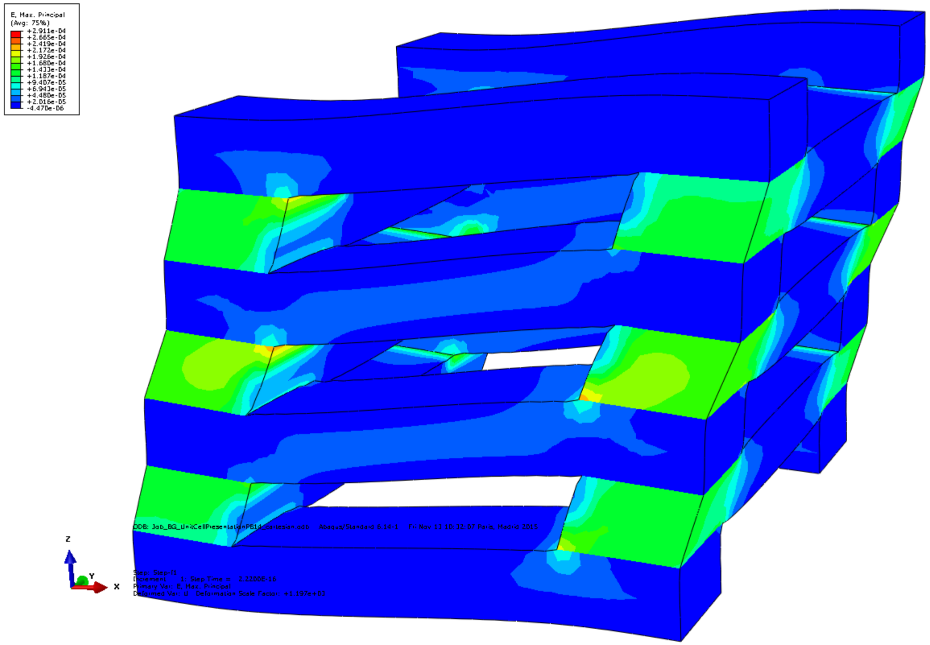
- **Simplified**: reducing the mechanical properties by the wood volume fractions

- **Advanced**: periodic homogenization scheme handled by a high-order plate theory (Lebée and Sab, 2012)

Ex. Wood volume fraction of Panobloc 2/3 → **0.4**

→ Modulus $E_L^* = E_L \cdot \mathbf{0.4}$ …

→ Strength $f_{L,t}^* = f_{L,t} \cdot \mathbf{0.4}$ …



Stronger heterogeneities – simplified and advanced modelling

Panobloc® 2/3	Shear analogy*	Equivalent layer – discontinuous*	Periodic homogenization
Failure load	**-**	**+40%**	**In progress**
Bending stiffness	**+7.5%**	**+7%**	**+6%**
Shear deflection	**-73%**	**-60%**	**+8.5%**

Panobloc® 1/3	Shear analogy*	Equivalent layer – discontinuous*	Periodic homogenization
Failure load	**-**	**+34%**	**In progress**
Bending stiffness	**+8%**	**+9%**	**+7.5%**
Shear deflection	**-84%**	**-76%**	**+6%**

*** = mechanical properties reduced by the wood volume fraction**

Conclusion – Low heterogeneities

- Reliable modelling: 3D solution + equivalent layer + failure criterion

- Low influence on global behaviour of edge-glued layers

- Low favourable impact of changing transverse layers' orientation

Conclusion – Strong heterogeneities

	CLT	Panobloc®	Panobloc®
Slenderness ratio L/h	28	28	28
Total wood volume fraction	1.0	0.4	0.25
Weight $[kg]$	550	-60%	-75%
Failure load $[kN]$	200	-65%	-83%
Bending Stiffness $[kNm^2]$	8500	-60%	-75%
Shear/Bending deflection $[\%]$	10	+70%	+170%

- Need of an advanced modelling to predict the shear effects

On going work → Modelling of strength and failure modes, parameter studies

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