

Advanced modelling of Cross Laminated Timber (CLT) panels in bending

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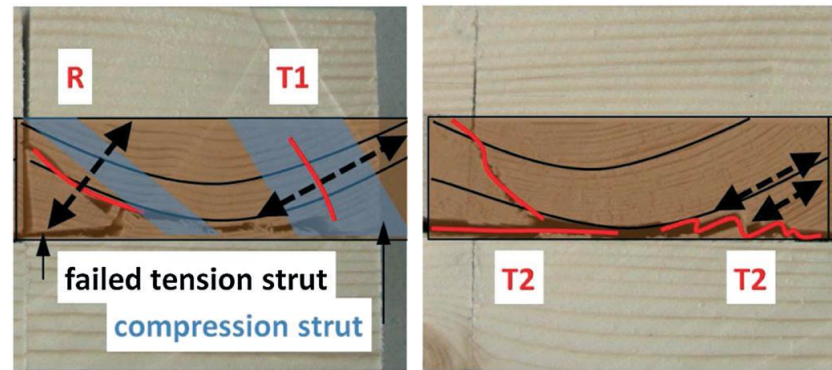
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Why an advanced modelling of CLT panels ?

- Better knowledge of bending behaviour, quantify CLT advantages and limits

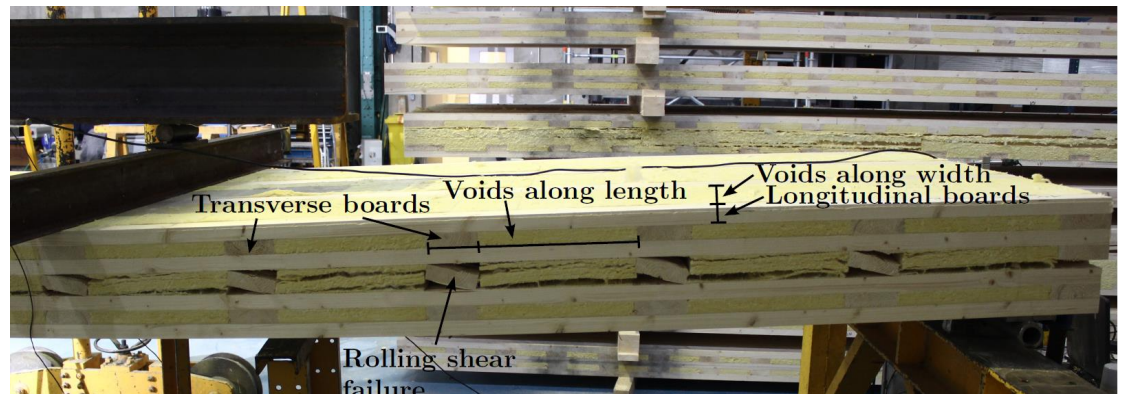


(Hochreiner et al. 2013)

- Explore innovative configurations



(Chen, 2011)

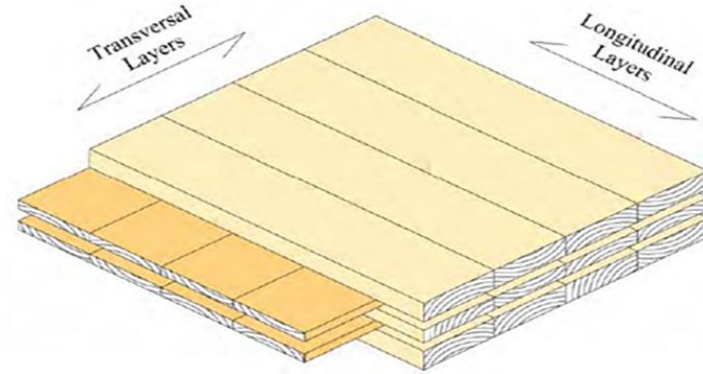


- CLT panels in bending: reference test and modelling
- Comparison with the reference behaviour
- Investigation on CLT properties
- Innovative CLT panels: extension to higher heterogeneities

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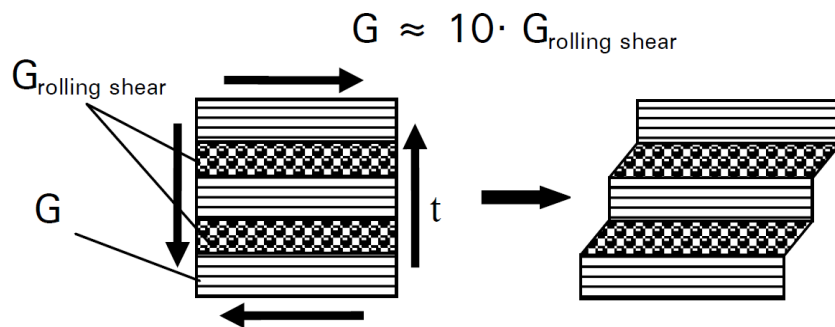
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Cross Laminated Timber (CLT) panels



□ Crosswise lay-up:

- Dimensional stability, possibility of prefabrication
- High stiffness and strength along the two directions
- Transverse shear weakness: rolling shear failure

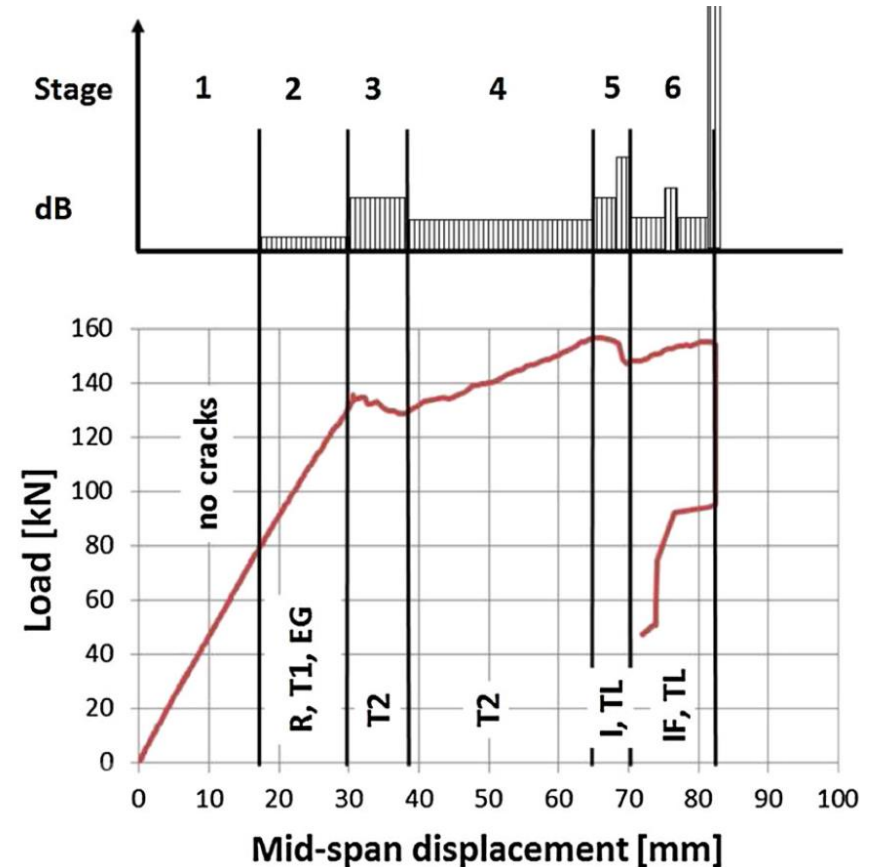


(Mestek et al. 2008)

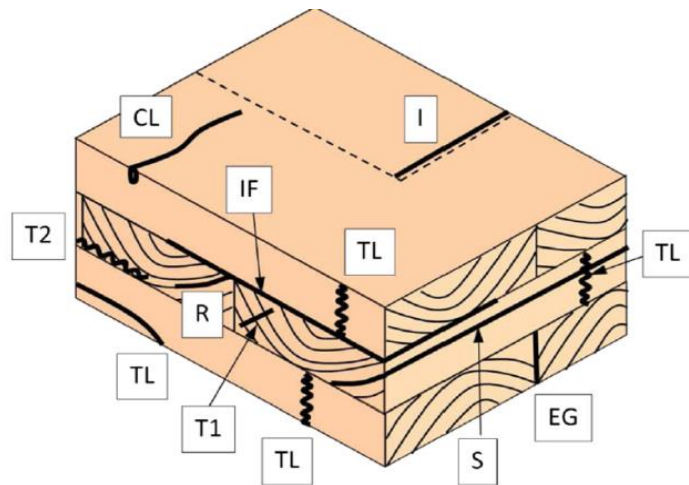


(Zhou, 2013)

Reference experimental test (Hochreiner et al. 2013)



- Progressive failure modes
- Edge-gluing and rolling shear failure as first modes



CLT panels in bending: heterogeneities

Material scale

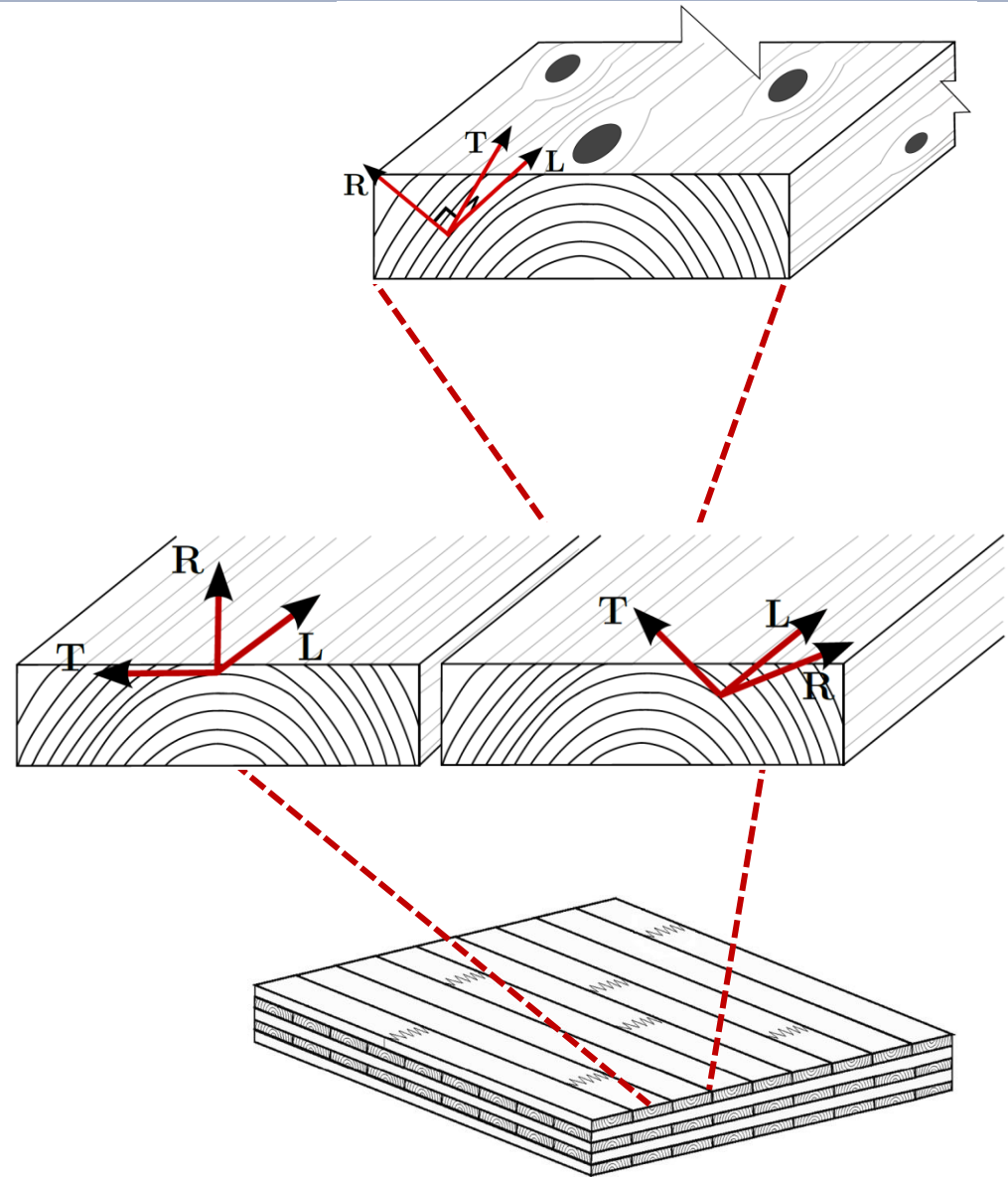
- Orthotropic behaviour of wood
- Natural variability

Layer scale

- Variation of wood's coordinate system
- Lateral boards glued or not

Structure scale

- Multi-layer and shear-compliant plates



CLT panels in bending: modelling

Material scale

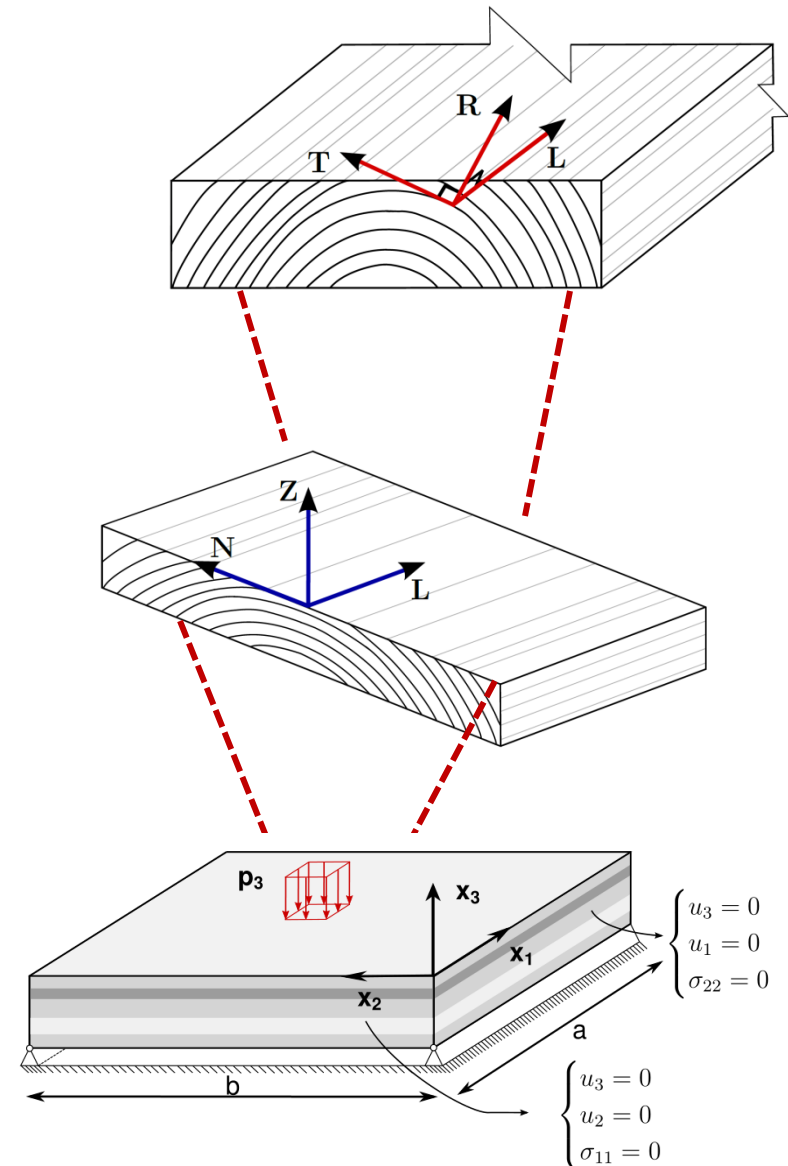
- Norway spruce: Homogeneous, elasto-brittle, orthotropic (Keuneke, 2008 and Dhal, 2009)
- Failure criterion for wood (van der Put, 1982)

Layer scale

- Equivalent layer-based mechanical model

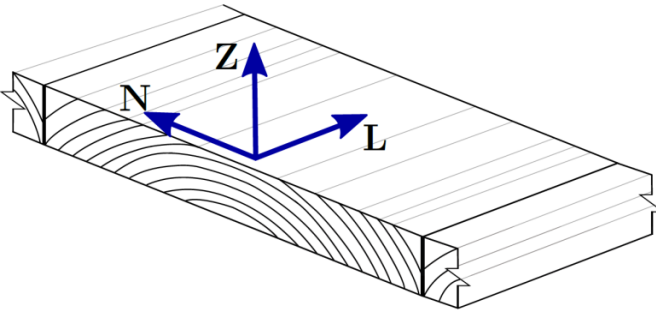
Structure scale

- 3D exact solution for layered plates in bending (Pagano, 1969-1970)



Layer scale : the equivalent-layer model

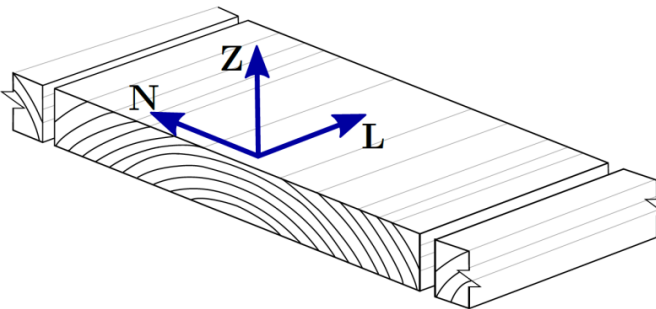
- **Continuous** : no distinction between Directions N and Z → transverse isotropy



Elasticity	E_L	E_N	E_Z	G_{LZ}	G_{LN}	G_{ZN}	ν_{LZ}	ν_{LN}	ν_{ZN}
	12800	511	511	602	602	53	0.41	0.41	0.48
Failure	$f_{L,t}$	$f_{L,c}$	$f_{N,t}$	$f_{N,c}$	$f_{Z,t}$	$f_{Z,c}$	f_{LZ}	f_{LN}	f_{ZN}
	63.4	28.9	2.8	3.6	2.8	3.6	4.8	4.8	2.0

[MPa]

- **Discontinuous** : no stress transmission and rupture along Direction N
→ “damaged” model



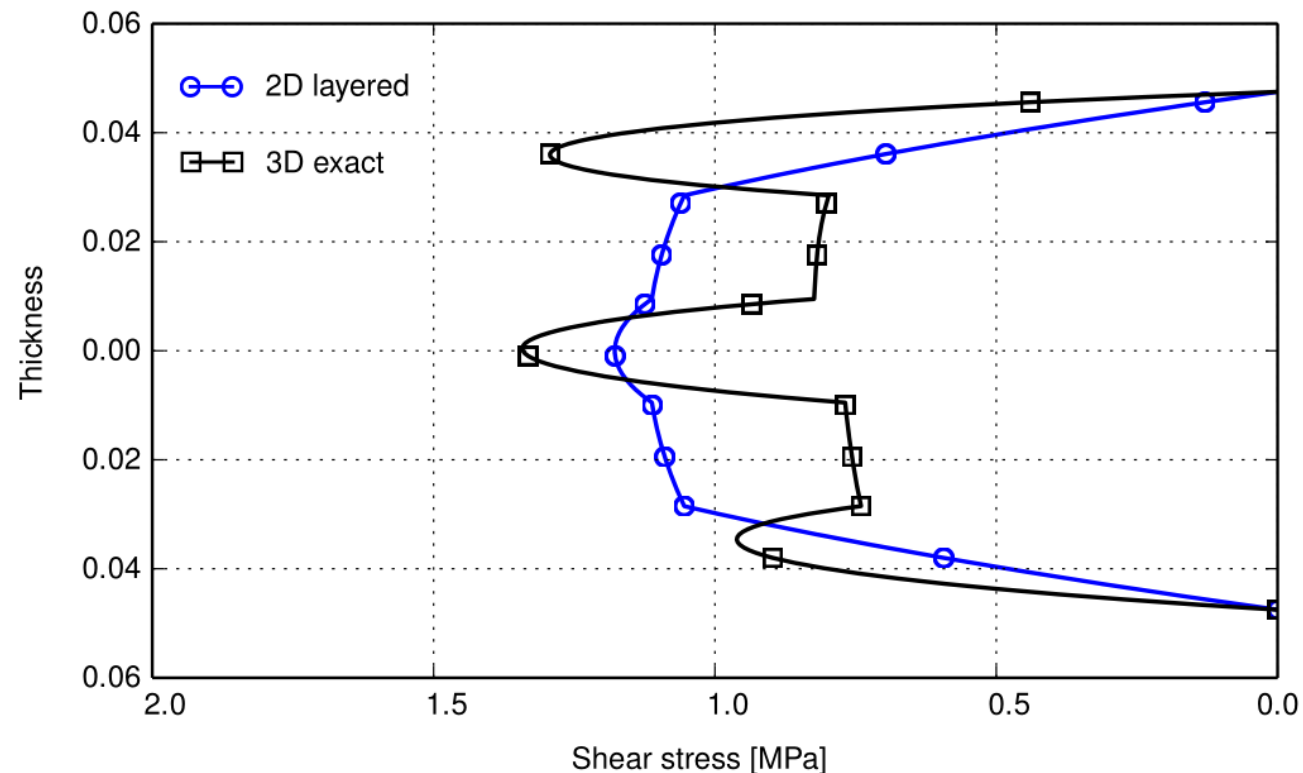
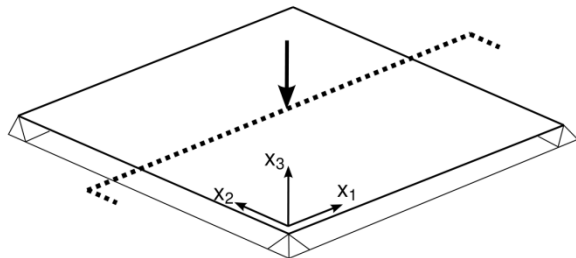
Elasticity	E_L	E_N	E_Z	G_{LZ}	G_{LN}	G_{ZN}	ν_{LZ}	ν_{LN}	ν_{ZN}
	12800	0.0	511	602	602	53	0.41	0.0	0.0
Failure	$f_{L,t}$	$f_{L,c}$	$f_{N,t}$	$f_{N,c}$	$f_{Z,t}$	$f_{Z,c}$	f_{LZ}	f_{LN}	f_{ZN}
	63.4	28.9	-	-	2.8	3.6	4.8	4.8	2.0

[MPa]

Structure scale : Pagano's 3D exact solution

- Better estimation of stress field than reduced 2D or 1D approaches, especially dealing with transverse shear

e.g. transverse shear distribution of 3D solution and plate theory for layered plates (Lebée and Sab, 2010) under the concentrated load. 5-ply CLT, slenderness 20



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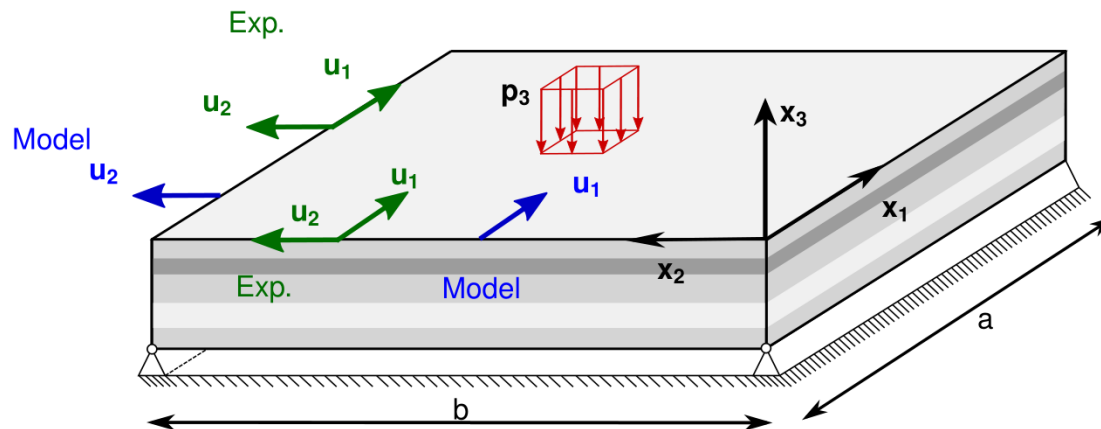
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Plate's global stiffness comparison

- Distinction between glued and non-glued plate's narrow boards (non-damaged and damaged model)

Continuous panel (0 - 50 kN)	Global Stiffness [$\frac{kN}{mm}$]	measuring error
Experimental reference	4.60	$\pm 5.0\%$
Predicted	5.03 (+9.3%)	-
Discontinuous panel (80 - 120 kN)	Global Stiffness [$\frac{kN}{mm}$]	measuring error
Experimental reference	4.14	$\pm 5.0\%$
Predicted	4.60 (+11.1%)	-

- Discrepancy between modelled and actual boundary conditions



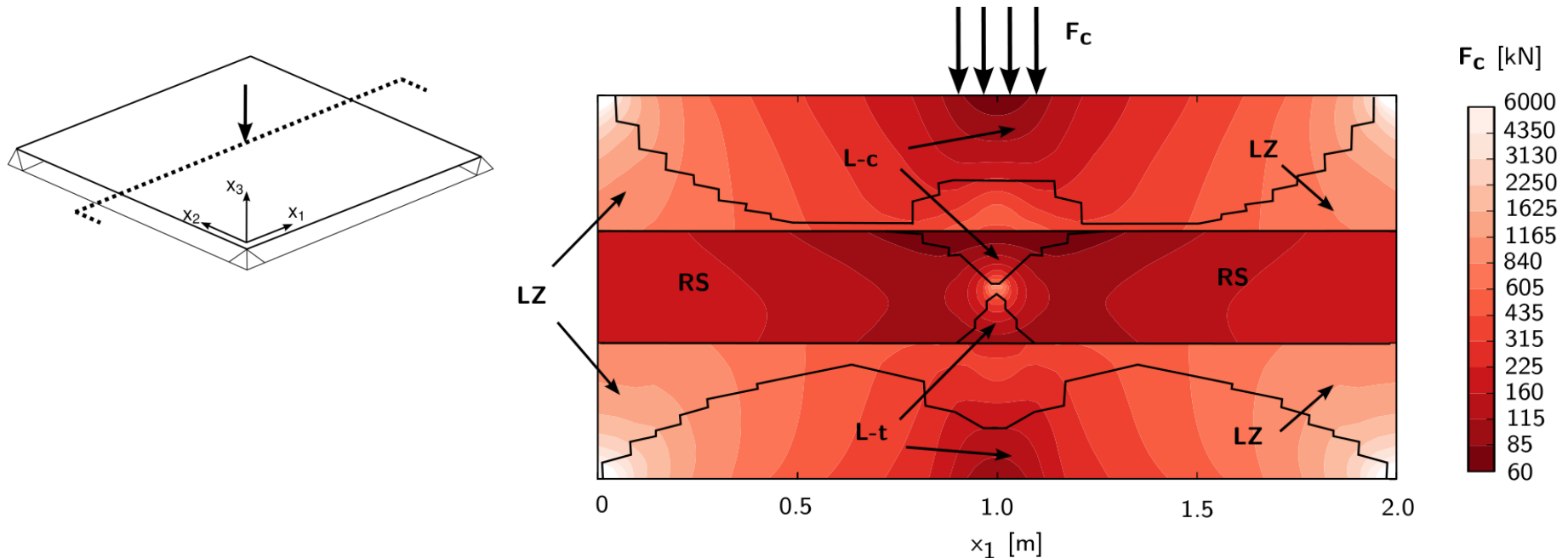
Failure stages comparison

- Pointwisely dominant

$$\text{failure mode} = \max\left(\frac{\sigma_l}{f_l}, \dots, \frac{\tau_{zn}}{f_{zn}}\right)$$

Failure mode	Abbreviation
Tensile Longitudinal	L-t
Compressive Longitudinal	L-c
Tensile Direction-N	N-t
Compressive Direction-N	N-c
Rolling Shear	RS
Transverse shear LZ	LZ

- Propagation of the failure criterion within CLT cross section at panel mid-span



Failure stages comparison

Load level [kN]	Failure modes		
	Reference test	Continuous	Discontinuous
50	-	N-c	-
60	-	N-c	L-c
70	-	N-t	L-c
80	RS/EG	N-t	RS
90	RS/EG	RS	RS
100	RS/EG	L-t	RS
120	L-t	L-t	L-t

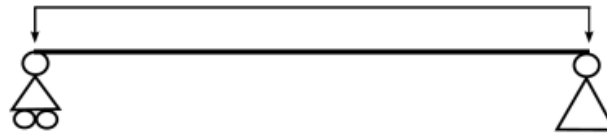
- Continuous model more in accordance at low load levels
- Discontinuous model predicts better CLT global load-carrying capacity

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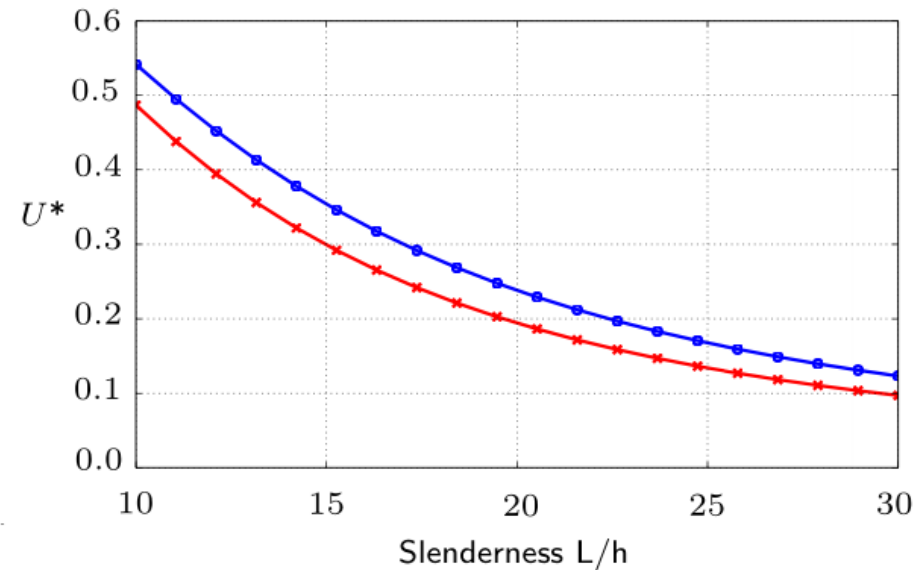
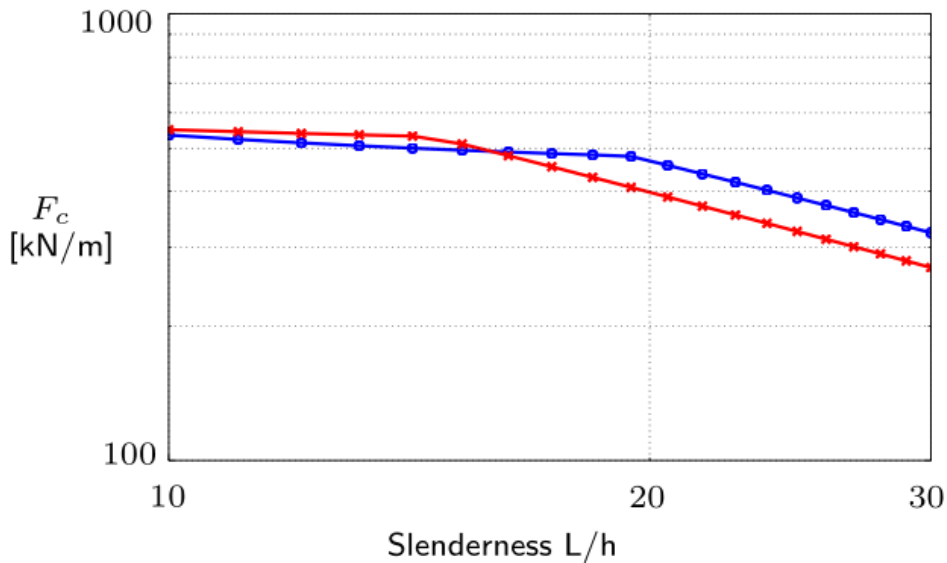
Influence of (rolling) shear effects

- Failure load (left) and shear contribution to deflection (right)



— CLT - 5ply

— CLT - 3ply



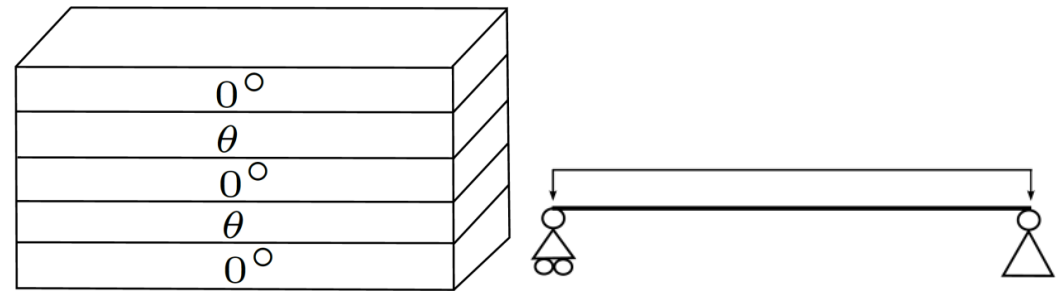
U^* = normalized deflection difference using the presented model and thin-plates theory

New orientation for transverse layers

- Influence on bending behaviour of varying transverse layers' orientation

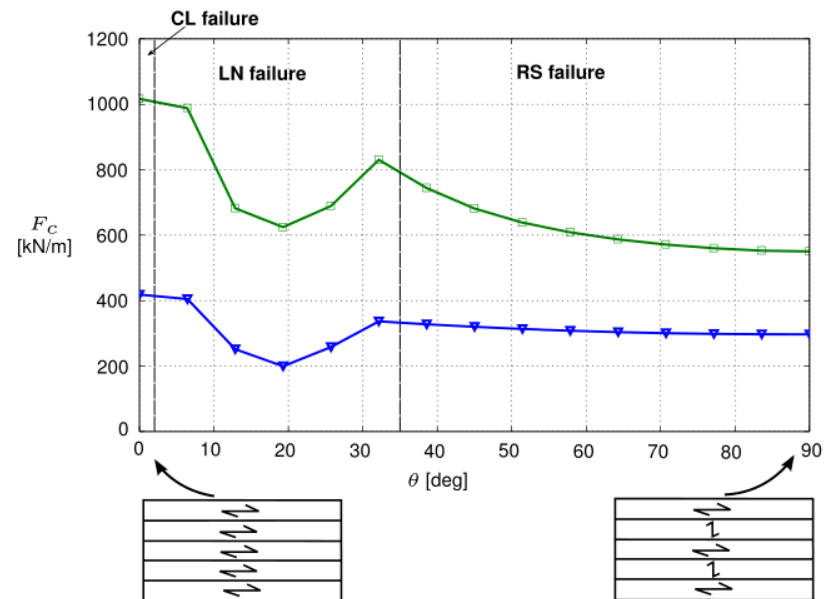
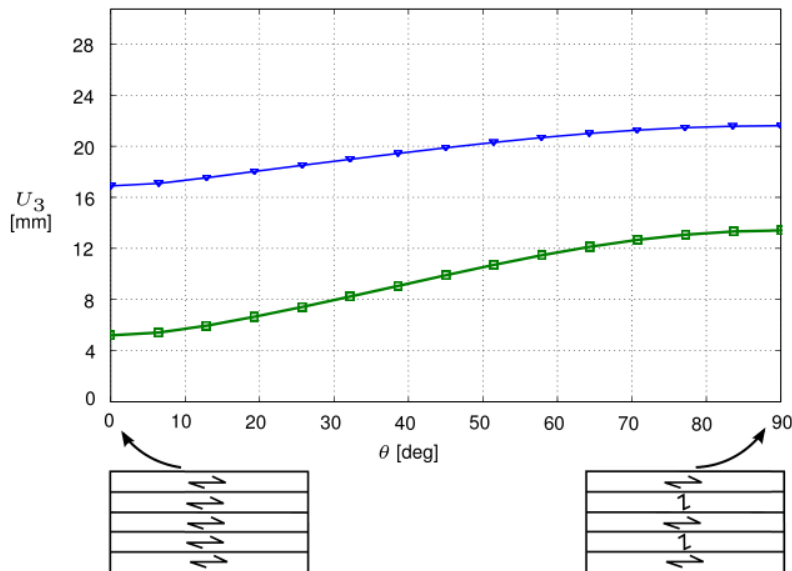


(Chen, 2011)



□ Slenderness 10

▽ Slenderness 25



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Technological challenge

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



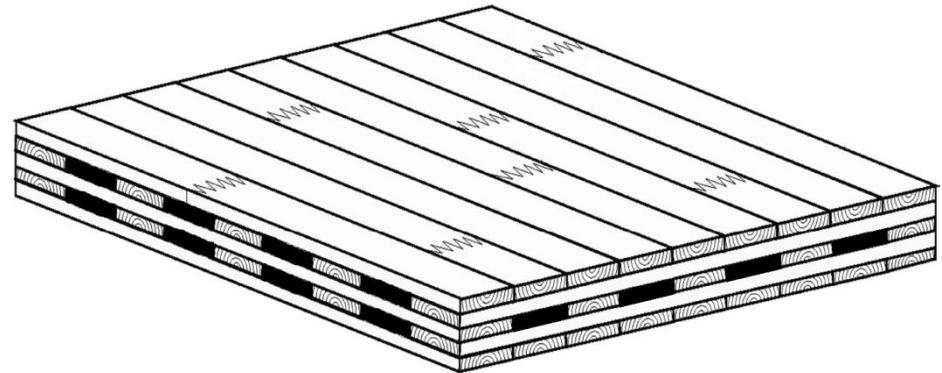
- Higher heterogeneities : periodic voids within the panel



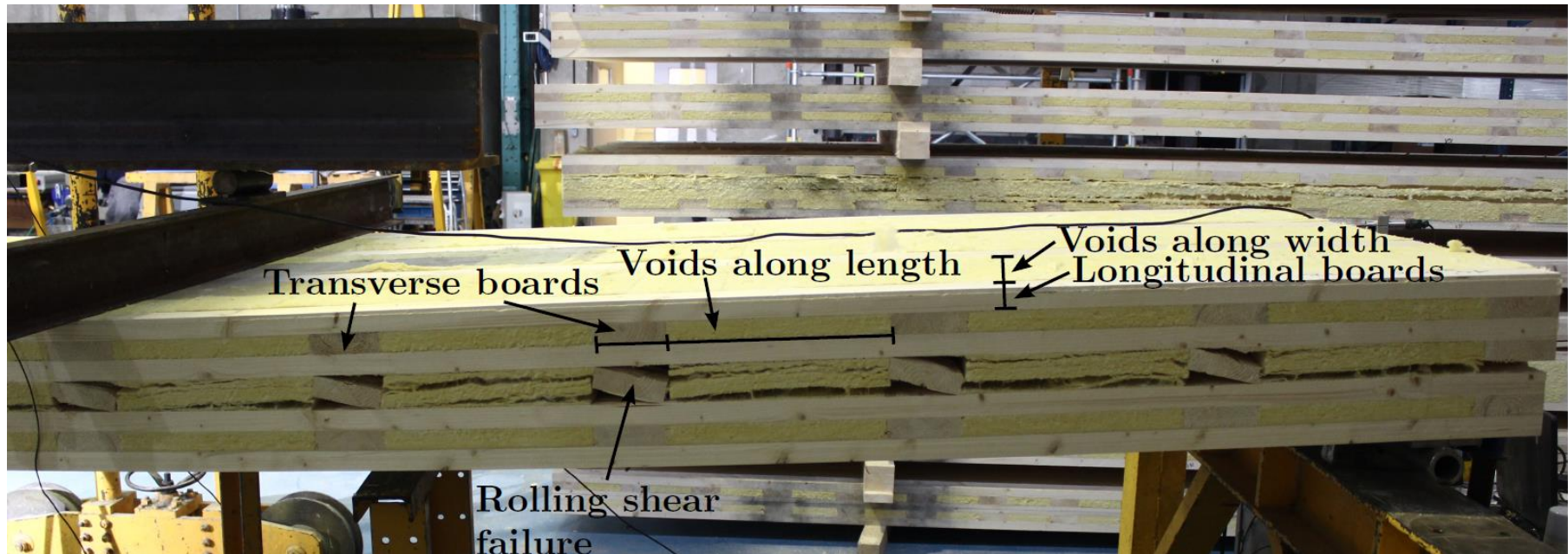
(<http://www.techniwood.fr/>)

➤ Influence of high heterogeneities on floor's bending performance ?

➤ Transverse shear effects ?



Experimental campaign – 4 points bending



	CLT	Panobloc®
Slenderness ratio	46.5	28
Wood volume fraction	1.0	0.25
Failure load (predicted) [kN]	75 (79)	33 (48)
Failure mode (predicted)	CL (CL)	RS (RS)
Shear contribution to deflection (predicted) [%]	3.6 (3.4)	25 (9.6)

Conclusion

- Mechanical properties of *clear* wood → CLT “System effect”
- Continuous or discontinuous equivalent layer
- Quantification of shear influence
- New orientations of transverse layers not convenient

Outlooks

- More accurate modelling for higher heterogeneities case: extension of Reissner-Mindlin plate theory to heterogeneous panels
- Simplified tool for design-helping of classic and innovative CLT panels

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