Bern University of Applied Sciences
Architecture, Wood and Civil Engineering

Glulam Reborn:
A flexible Adhesive Interface to increase the Bending Resistance of Glulam

COST E55 – Modelling the Performance of Timber Structures
3rd Workshop, Espoo Finland, March 2008

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With contributions by Marc Donzé

1. Introduction

Since invention 100 years ago glulam has been manufactured with stiff adhesives.

Author challenges this established rule and investigates use of flexible adhesives:

- **Can an elastic adhesive interface elevate the bending strength of glulam?**
- **Which load-bearing behaviour of adhesive interface in tensile shear tests?**

Challenges:

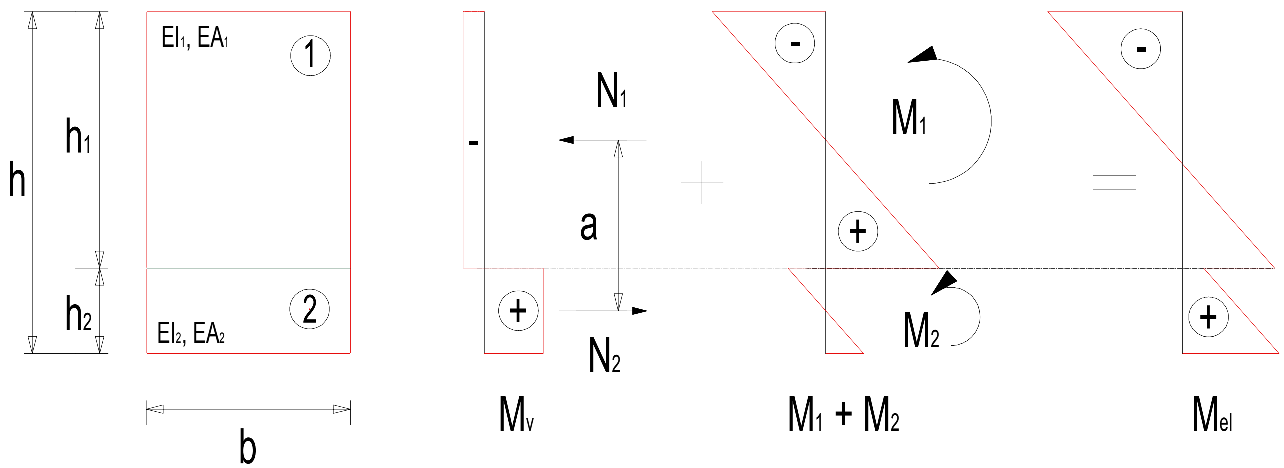
- **Modelling**
- **Can industrial partner develop adhesive interfaces which meet requirements?**
- **Will real beams behave according to the calculation models?**

Relevance for COST E55:

- **After evaluation of structural performance: practical improvement measures**
- **New technique to obtain higher grade timbers**

2. Theoretical Considerations of Beam Behaviour

2.1 Equations of Gamma Method for bipartite beam



$$EI_{ef} = EI_1 + EI_2 + \gamma \cdot S \quad \text{mit} \quad S = \frac{EA_1 \cdot EA_2 \cdot a^2}{EA_1 + EA_2} = \frac{Ebh^3}{4} \cdot \left(1 - \left[\frac{h_2}{h}\right]\right) \cdot \left(\frac{h_2}{h}\right)$$

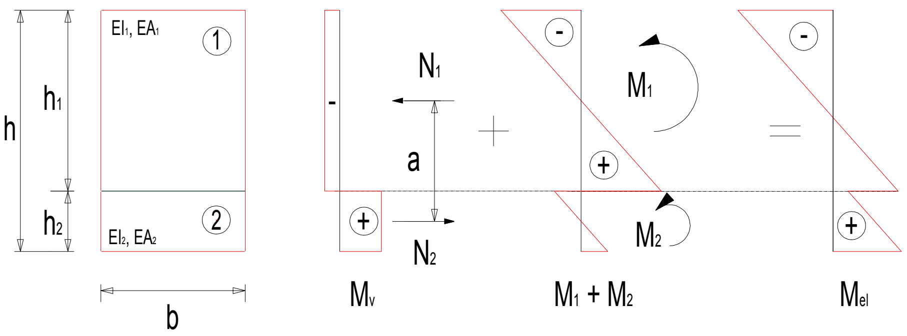
$$\sigma_{i,M}(x) = \pm M(x) \cdot \frac{E_i}{EI_{ef}} \cdot \frac{h_i}{2}$$

$$\sigma_{i,N}(x) = \pm M(x) \cdot \frac{\gamma \cdot S}{a \cdot EI_{ef}} \cdot \frac{1}{A_i}$$

$$\left|\sigma_i(x)\right| = \frac{M(x)}{EI_{ef}} \cdot \left(E \cdot \frac{h_i}{2} \pm \frac{\gamma \cdot S}{a} \cdot \frac{1}{A_i}\right)$$

2. Theoretical Considerations of Beam Behaviour

2.2 Optimization of bending resistance of bipartite beam

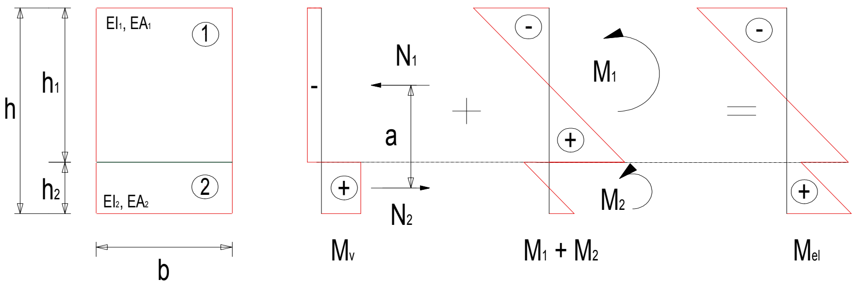


- The stresses in both members are related to each other
- Assuming simultaneous tensile failure in both members leads to two equations
- Once σ_{N1}, σ_{M1}, σ_{N2} and σ_{M2} have been determined, the corresponding moments can be calculated
- The total bending resistance is the sum of the partial moments:

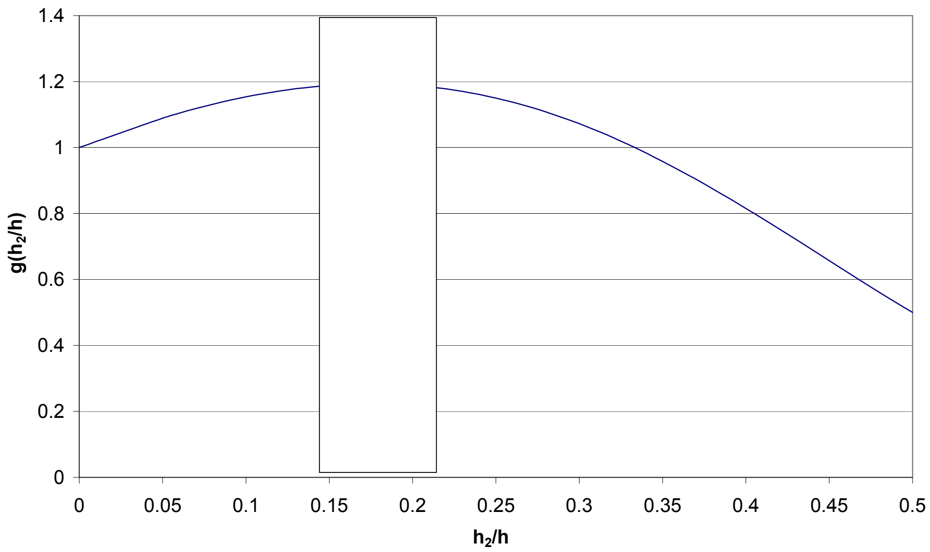
$$M_u = M_V + M_1 + M_2 = \frac{f_{m,u} \cdot b \cdot h^2}{6} \cdot \frac{\left[1 - 6 \cdot \left(\frac{h_2}{h}\right)^2 + 6 \cdot \left(\frac{h_2}{h}\right)^3\right]}{\left[1 - 2 \cdot \left(\frac{h_2}{h}\right) + 2 \cdot \left(\frac{h_2}{h}\right)^2\right]} \qquad \left\{0 \leq \frac{h_2}{h} \leq 0.5\right\}$$

2. Theoretical Considerations of Beam Behaviour

2.2 Optimization of bending resistance of bipartite beam



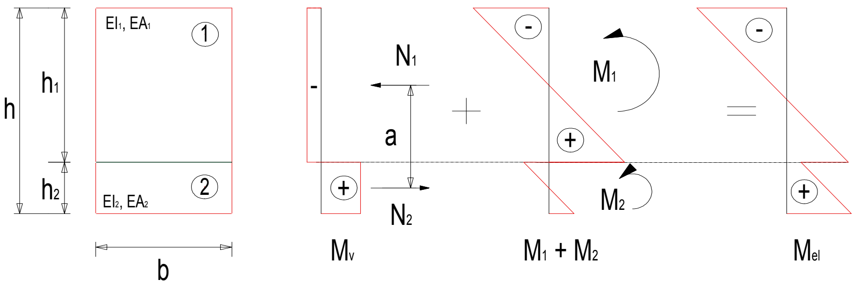
The relationship can be differentiated to obtain the maximum value for g(h_2/h):



$$M_u = \frac{f_{m,u} \cdot b \cdot h^2}{6} \cdot g\left(\frac{h_2}{h}\right)$$

2. Theoretical Considerations of Beam Behaviour

2.3 Corresponding reduction of bending stiffness of bipartite beam

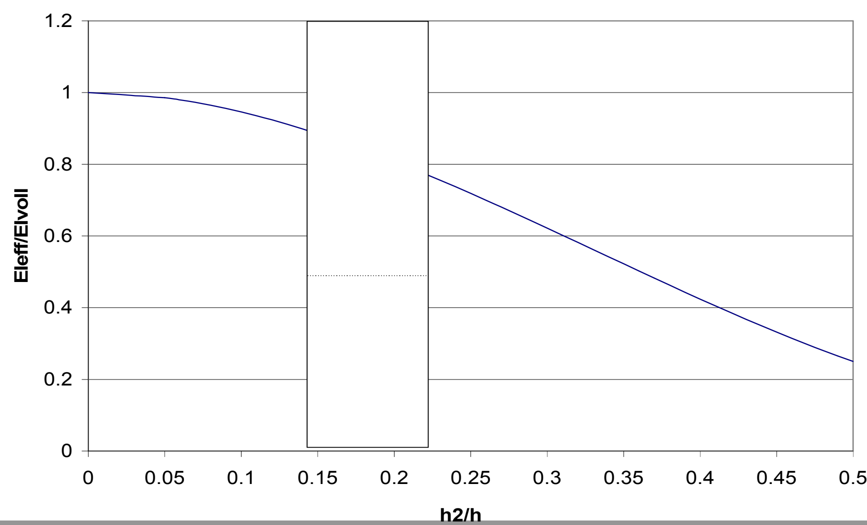


The Gamma-Factor can be optimized: $$\frac{M_2}{M_V} = \frac{EI_2}{\gamma \cdot S} \Rightarrow \gamma = \frac{EI_2}{S} \cdot \frac{M_V}{M_2} \Rightarrow \gamma_{idéal} = 1 - 2 \cdot \left(\frac{h_2}{h}\right)$$

The bending stiffness falls:

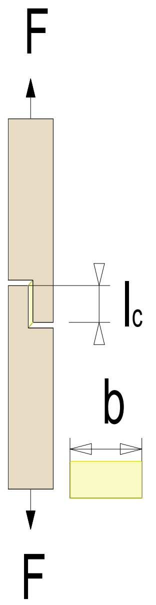
$$EI_{ef} = EI_{ef} = EI_1 + EI_2 + \gamma \cdot S$$

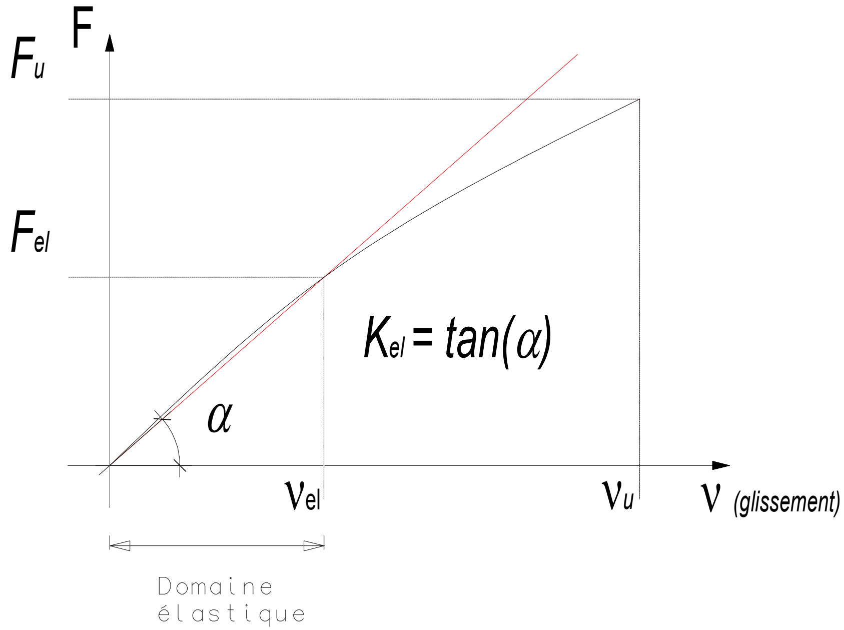
$$EI_{ef} = \frac{Ebh^3}{12} \cdot \left[1 - 6 \cdot \left(\frac{h_2}{h}\right)^2 + 6 \cdot \left(\frac{h_2}{h}\right)^3\right]$$



3. Adhesive interface; requisite force-deformation slope

Classical tensile-shear test for adhesive interfaces:





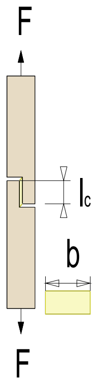
$$K_{el} = \frac{F_{el}}{\nu_{el}} \rightarrow \frac{N}{mm}$$

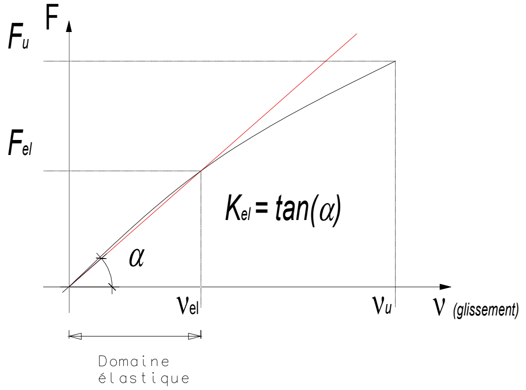
The Gamma-method works with the following adaptation (A_C=adhesive area):

$$k_{el} = \frac{K_{el}}{A_c} \cdot b$$

3. Adhesive interface; requisite force-deformation slope

Classical tensile-shear test for adhesive interfaces:





The following relationships of the Gamma-method:

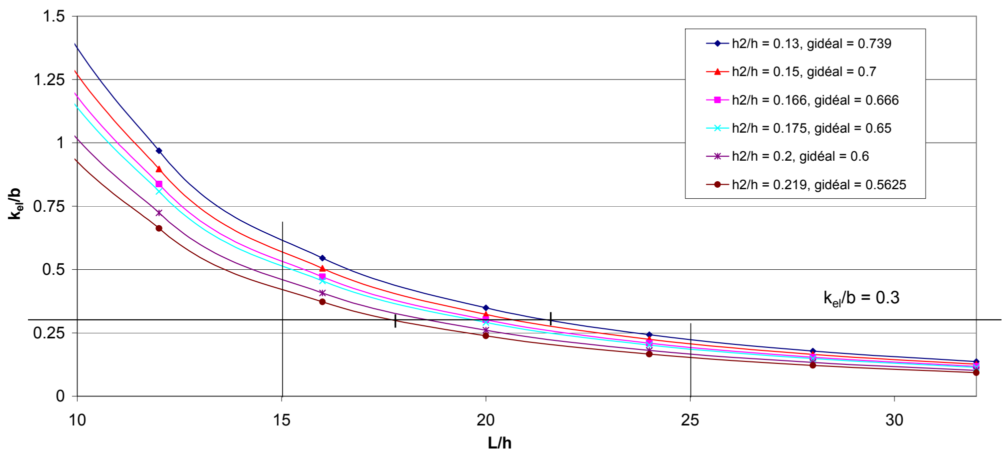
$$\gamma = \left(1 + \frac{\pi^2 \cdot S}{k_{el} \cdot L^2 \cdot a^2}\right)^{-1} \qquad \gamma_{idéal} = 1 - 2 \cdot \left(\frac{h_2}{h}\right)$$

Lead to the solution:

$$\frac{k_{el}}{b} = \frac{\pi^2 \cdot S}{\left(\frac{1}{\gamma_{idéal}} - 1\right) \cdot L^2 \cdot a^2 \cdot b} = \frac{2 \cdot \pi^2 \cdot E \cdot h \cdot \left(\frac{h_2}{h}\right)^2 \cdot \left[1 + \left(\frac{h_2}{h}\right)\right]}{L^2 \cdot \left[1 - 2 \cdot \left(\frac{h_2}{h}\right)\right]}$$

3. Adhesive interface; requisite force-deformation slope

The requisite stiffness of the adhesive interface as a function of L/h for h_2/h=0.15-0.25 (E=11'000 N/mm2)

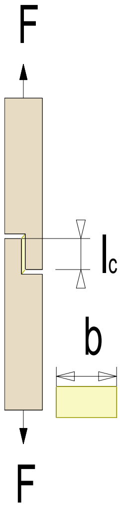


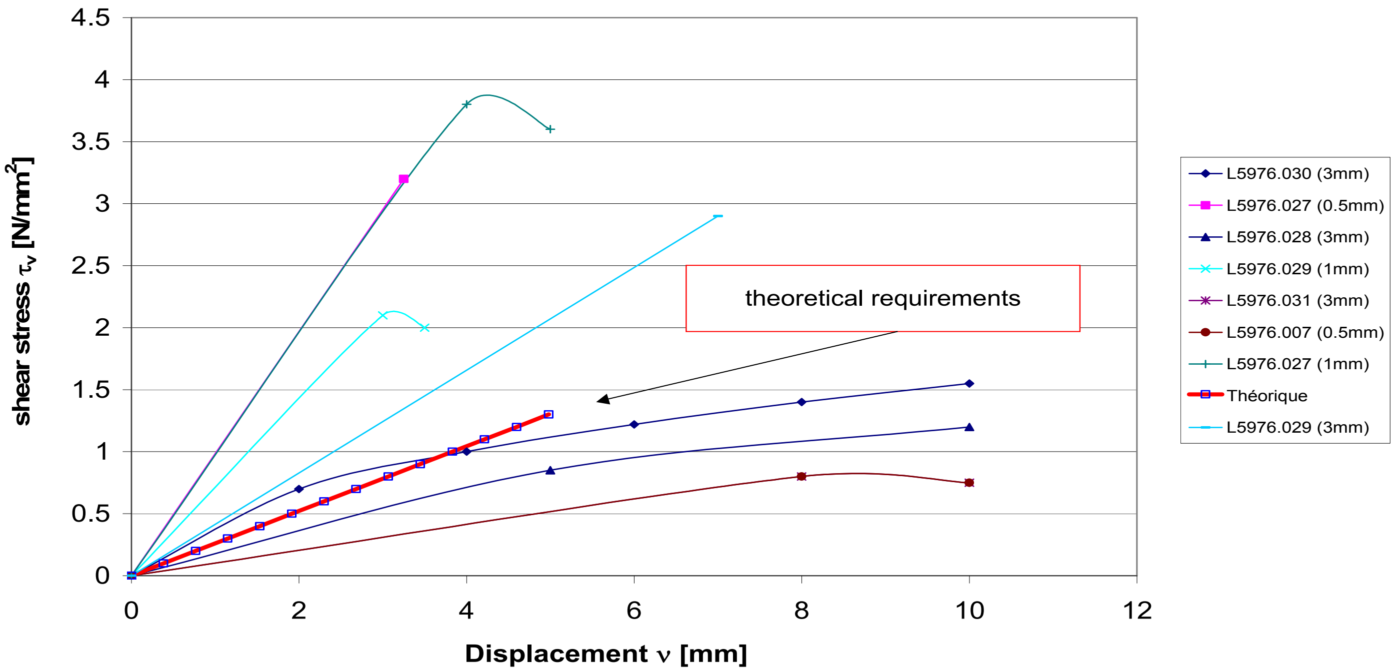
For L/h≈20 the following final result is obtained for the requisite slope of the force-displacement diagramme in the classical tensile shear test:

$$K_{el} = \frac{k_{el}}{b} \cdot A_c = 0.3 \cdot 200 = 60 \frac{N}{mm^2}$$

3. Adhesive interface; requisite force-deformation slope

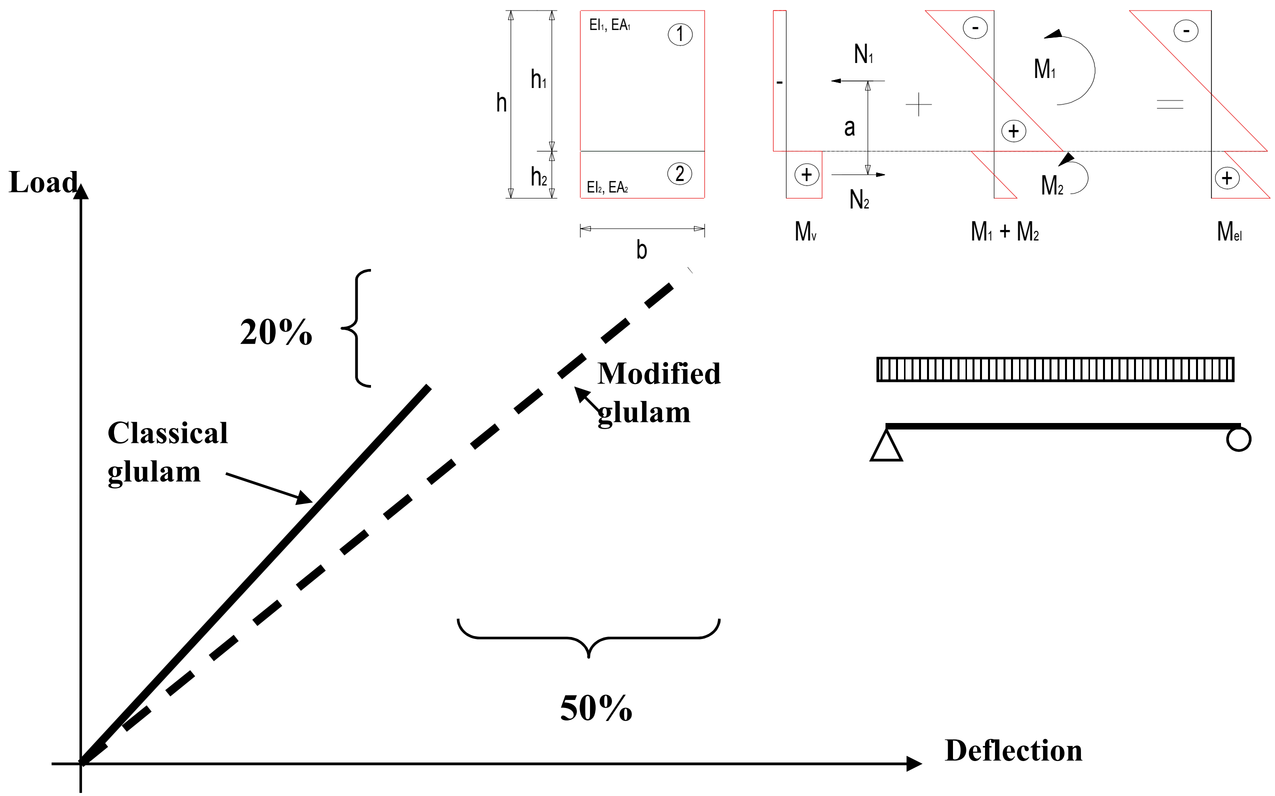
The adhesive manufacturer manages to produce the required adhesives on polyurethane basis!





4. Conclusions and Outlook

Bipartite glulam beam with elastic adhesive interface has higher bending resistance and greater deformability than conventional glulam.



The adhesive manufacturer has achieved the requisite adhesive interfaces.
Bending tests with structural sized beams will be carried out to verify the theoretical models.

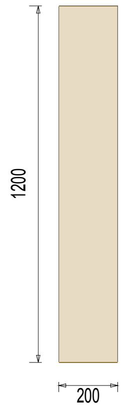
4. Conclusions and Outlook

Examples of possible practical uses:

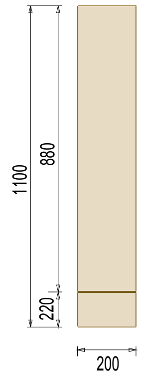
a) Long span structures generally, particularly in earthquake zones

Example: shed, Switzerland

conventional



Future?



b) Load redistribution in continuous glulam beams may be feasible: