# European Hardwoods

## WP 2 / 3 / 4 / 5

**MPA STUTTGART**
**Otto-Graf-Institut**
**Materials Testing Institute University of Stuttgart**

Maren Hirsch, Simon Aicher

# Structure of presentation

| Work package | Theme |
|---|---|
| **WP 2** | Basic hardwood strength data and grading tools |
| **WP 3** | Adhesives for structural hardwood bonding |
| **WP 4** | Glulam made of hardwoods or hardwoods and softwoods |
| **WP 5** | Cross laminated hybrid timber |

# Basic hardwood strength data and grading tools

## WP 2

MPA STUTTGART
Otto-Graf-Institut
Materials Testing Institute University of Stuttgart

Maren Hirsch, Simon Aicher

# Current status of WP 2

| Task | Current status |
|------|----------------|
| Contribution of all hardwood data from tests at the MPA | finished (04/2015) |

**data** → **FCBA + project partners**

**discussion**
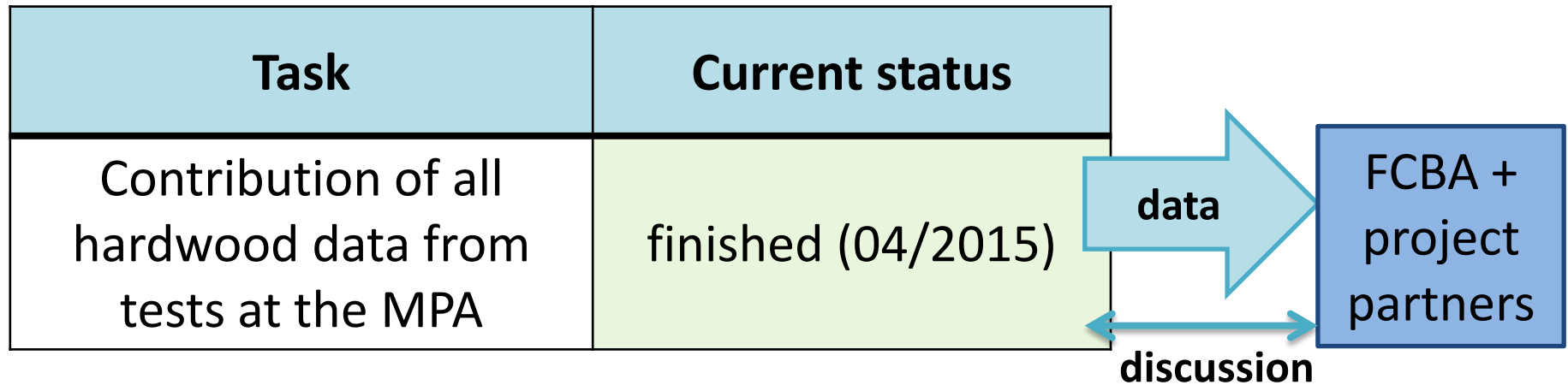
# Datasets of tested components

| Species (trade name) | European oak | | American white oak | American white oak + European oak | Sweet chestnut | Dark red meranti |
|---|---|---|---|---|---|---|
| Species (botanical name) | Quercus robur / petraea | | Quercus alba | Quercus alba / robur / petraea | Castanea sativa | Shorea pauciflora |
| Producer | 1 | 2 | 1 | 3 | 4 | 6 |
| Origin | Czech Republic, South Germany | France | USA (mainly Indiana) | USA + Germany | North Spain | Indonesia |
| Grading class | LS13 acc. DIN 4074-5, additional demand: max. diameter of knots = 7 mm | LS10/LS13 acc. DIN 4074-5 | LS13 acc. DIN 4074-5, additional demand: max. diameter of knots = 7 mm | LS13 acc. DIN 4074-5 | LS10/LS13 acc. DIN 4074-5 | LS13 acc. DIN 4074-5 |
| Structure of cross section | Standard: homogenous structure / Premium: marginal lamellas without finger joints | combined structure with LS13 marginal lamellas (> 1/6 h) and LS10 middle lamellas (< 2/3 h) | Standard: homogenous structure / Premium: marginal lamellas without finger joints | Additional demand: 2 marginal lamellas without finger joints | - | - |
| Density | 600 kg/m³ to 750 kg/m³ | c. 730 kg/m³ | c. 810 kg/m³ | c. 800 kg/m³ | c. 570 kg/m³ | 400 kg/m³ to 650 kg/m³ |
| Lamella thickness | 19 mm to 23 mm | 20 mm | 19 mm to 23 mm | 20 mm | 20 mm to 30 mm | 20 mm to 30 mm |
| Section width | 50 mm to 70 mm | 50 mm to 160 mm | 30 mm und 60 mm | 60 mm | 50 mm to 200 mm | 50 mm to 200 mm |
| Section height | 80 mm to 280 mm | 80 mm to 400 mm | 100 mm to 360 mm | 140 mm | 80 mm to 900 mm | 80 mm to 900 mm |
| Element length | to 12000 mm, Premium to 4000 mm | to 12000 mm | c. 3000 mm | 2700 mm | to 13500 mm | to 13500 mm |
| Distance between finger joints | min. 300 mm | 300 mm to 1200 mm | c. 380 mm to 1200 mm | c. 380 mm to 1200 mm | | min. 150 mm |
| Adhesive for finger joints | MUF-adhesive system Casco 0475 + hardener 0367 (CascoGrip™ ProDesigne) | | MUF-adhesive system Casco 1247 + hardener 2526 | MUF-adhesive system Casco 0475 + hardener 0367 (CascoGrip™ ProDesigne) | MUF-adhesive system Casco 1247 + hardener 2526 | MUF-adhesive system Casco 1247 + hardener 2526 |
| Adhesive for surface gluing | | | MUF-adhesive system Casco 0475 + hardener 0367 | | | |

- 6 datasets for glulam made of hardwood
- bending tests of 287 glulam beams

# Datatests of tested boards

| Species (trade name) | European oak | | American white oak | | American white oak + European oak | Sweet chestnut | European birch | Dark red meranti | European beech |
|---|---|---|---|---|---|---|---|---|---|
| Species (botanical name) | Quercus robur / petraea | | Quercus alba | | Quercus alba + Quercus robur / petraea | Castanea sativa | Betula spp. | Shorea pauciflora | Fagus sylvatica |
| Producer | 1 | 2 | 1 | | 3 | 4 | 5 | 6 | 7 |
| Specification | - | - | Adhesive A | Adhesive B | - | - | - | - | - |
| Origin | Czech Republic, South Germany | France | USA (mainly Indiana) | | USA + Germany | North Spain | not specified | Indonesia | Germany |
| Grading class | LS13 acc. DIN 4074-5[1] | LS10 and LS13 acc. DIN 4074-5 | LS13 acc. DIN 4074-51 | | LS13 acc. DIN 4074-5 | LS10 und LS13 acc. DIN 4074-5 - "furniture quality" | LS10 und LS13 acc. DIN 4074-5 | LS13 acc. DIN 4074-5 | LS13 acc. DIN 4074-5 |
| Density | 600 kg/m³ to 750 kg/m³ | c. 730 kg/m³ | c. 810 kg/m³ | | c. 800 kg/m³ | c. 550 kg/m³ | c. 650 kg/m³ | 400 kg/m³ to 650 kg/m³ | 640 kg/m³ to 770 kg/m³ |
| Lamella thickness | 19 mm to 23 mm | 20 mm | 19 mm to 23 mm | | 20 mm | 20 mm to 30 mm | 21 mm | 18 mm to 23 mm | 42 mm |
| Adhesive for finger joints | MUF-adhesive system Casco 0475 + hardener 0367 (CascoGrip™ ProDesigne) | | MUF-adhesive system Casco 0475 + hardener 0367 (CascoGrip™ ProDesigne) | MUF-adhesive system Casco 1247 + hardener 2526 | MUF-adhesive system Casco 0475 + hardener 0367 (CascoGrip™ ProDesigne) | MUF-adhesive system Casco 1247 + hardener 2526 | 1-K-PUR-adhesive Purbond HB S109 | MUF-adhesive system Cascomin Syntheko 1242 + hardener 2542 | MUF-adhesive system |

[1] additional demand: max. diameter of knots = 7 mm

- 9 datasets for boards with and without fingerjoints
- species: **european oak**, **sweet chestnut**, birch, beech, american white oak , dark red meranti
- tensile tests of 806 boards without fingerjoints
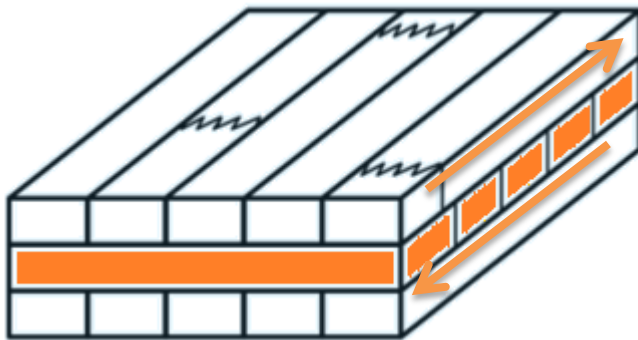- bending tests of 738 boards with fingerjoints

# Cross-laminated hybrid timber

WP 5

Maren Hirsch, Simon Aicher

# Cross laminated hybrid timber

**Var. A**

low grade beech
in the middle layer

Tasks:

1. Characterisation of the „low grade" beech wood by visual grading

2. Testing and modelling of the rolling shear properties

3. Testing and modelling of the CLT-element properties

# Raw material for the middle layer

21 boards

(b = 135 mm, t = 38 mm,

l = 4,0 m)

„First impressions":

- shrinkage cracks with large gaps

- redheart

- low knotiness (unexpected!)

- mainly flat-sawn

- mainly cut from the log-center

# Visual grading

grading criteria acc. to DIN 4074-5 for the visual grading of boards and planks

(primarily edgewise bent boards and planks should be graded as beams)

| Grading criteria | Grading classes | | |
|---|---|---|---|
| | LS7 | LS10 | LS13 |
| 1.   knots | | | |
| –   single knot | up to 1/2 | up to 1/3 | up to 1/5 |
| –   accumulation of knots | up to 2/3 | up to 1/2 | up to 1/3 |
| –   narrow side knot [a] | – | up to 2/3 | up to 1/3 |
| 2.   slope of grain [b] | up to 16 % | up to 12 % | up to 7 % |
| 3.   pith | not permitted [c] | not permitted | not permitted |
| 4.   annual ring width | – | – | – |
| 5.   cracks | | | |
| –   shrinkage cracks | permitted | permitted | permitted |
| –   lightning cracks, frost cracks, ring shakes | not permitted | not permitted | not permitted |
| 6.   wane | up to 1/3 | up to 1/4 | up to 1/8 |
| 7.   curvature [d] | | | |
| –   longitudinal curvature | up to 12 mm | up to 8 mm | up to 8 mm |
| –   torsion | 2 mm / 25 mm width | 1 mm / 25 mm widht | 1 mm / 25 mm width |
| –   tangential curvature | up to 1/20 | up to 1/30 | up to 1/50 |
| 8.   discoloration, decay | | | |
| –   nailable brown and red stripes | up to 3/5 | up to 2/5 | up to 1/5 |
| –   decay | not permitted | not permitted | not permitted |
| 9.   damage from greenwood insects | not permitted | not permitted | not permitted |
| 10. other characteristics | shall be taken into consideration analogously to the other grading criterias | | |

[a]   Does not apply for boards for glulam.

[b]   This grading criteria should not be considered for beech.

[c]   For oak permitted.

[d]   These grading criterias should not be considered for not dry-sorted wood.

# Visual grading of the test boards

Visual grading acc. to DIN 4074-5:

$\quad$ 15 x $\quad$ < LS7

$\quad\quad$ 5 x $\quad\quad$ LS7

$\quad\quad$ 1 x $\quad\quad$ LS10

$\quad\quad$ 0 x $\quad\quad$ LS13

Decisive grading criteria:

$\quad$ 10 x $\quad\quad$ pith

$\quad$ 7 x $\quad\quad$ longitudinal curvature

$\quad$ 3 x $\quad\quad$ wane

$\quad$ 1 x $\quad\quad$ knots

| Grading criteria | | Grading classes | | |
|---|---|---|---|---|
| | | LS7 | LS10 | LS13 |
| 1. | knots | | | |
| – | single knot | up to 1/2 | up to 1/3 | up to 1/5 |
| – | accumulation of knots | up to 2/3 | up to 1/2 | up to 1/3 |
| – | narrow side knot [a] | – | up to 2/3 | up to 1/3 |
| 2. | slope of grain [b] | up to 16 % | up to 12 % | up to 7 % |
| 3. | pith | not permitted [c] | not permitted | not permitted |
| 4. | annual ring width | – | – | – |
| 5. | cracks | | | |
| – | shrinkage cracks | permitted | permitted | permitted |
| – | lightning cracks, frost cracks, ring shakes | not permitted | not permitted | not permitted |
| 6. | wane | up to 1/3 | up to 1/4 | up to 1/8 |
| 7. | curvature [d] | | | |
| – | longitudinal curvature | up to 12 mm | up to 8 mm | up to 8 mm |
| – | torsion | 2 mm / 25 mm width | 1 mm / 25 mm widht | 1 mm / 25 mm width |
| – | tangential curvature | up to 1/20 | up to 1/30 | up to 1/50 |
| 8. | discoloration, decay | | | |
| – | nailable brown and red stripes | up to 3/5 | up to 2/5 | up to 1/5 |
| – | decay | not permitted | not permitted | not permitted |
| 9. | damage from greenwood insects | not permitted | not permitted | not permitted |
| 10. | other characteristics | shall be taken into consideration analogously to the other grading criterias | | |

[a] Does not apply for boards for glulam.

[b] This grading criteria should not be considered for beech.

[c] For oak permitted.

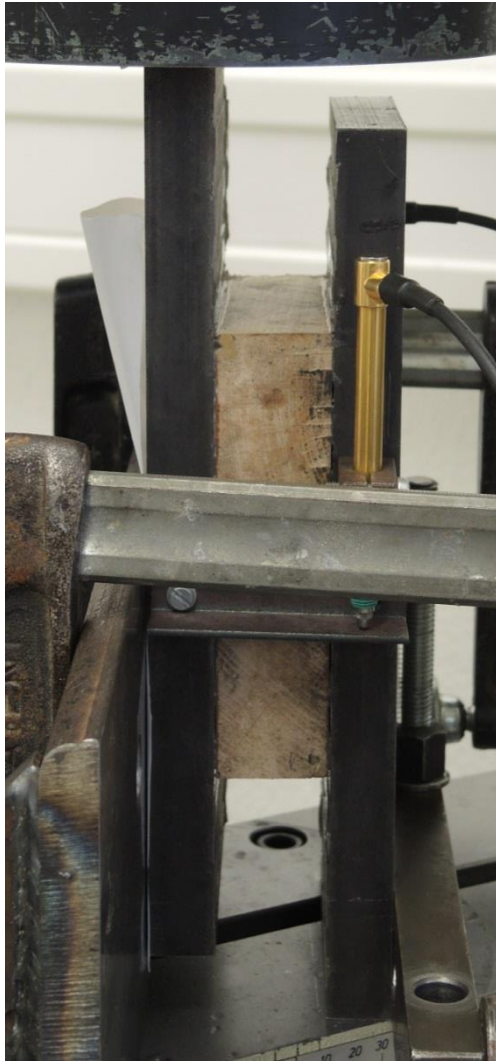[d] These grading criterias should not be considered for not dry-sorted wood.

# Testing of rolling shear

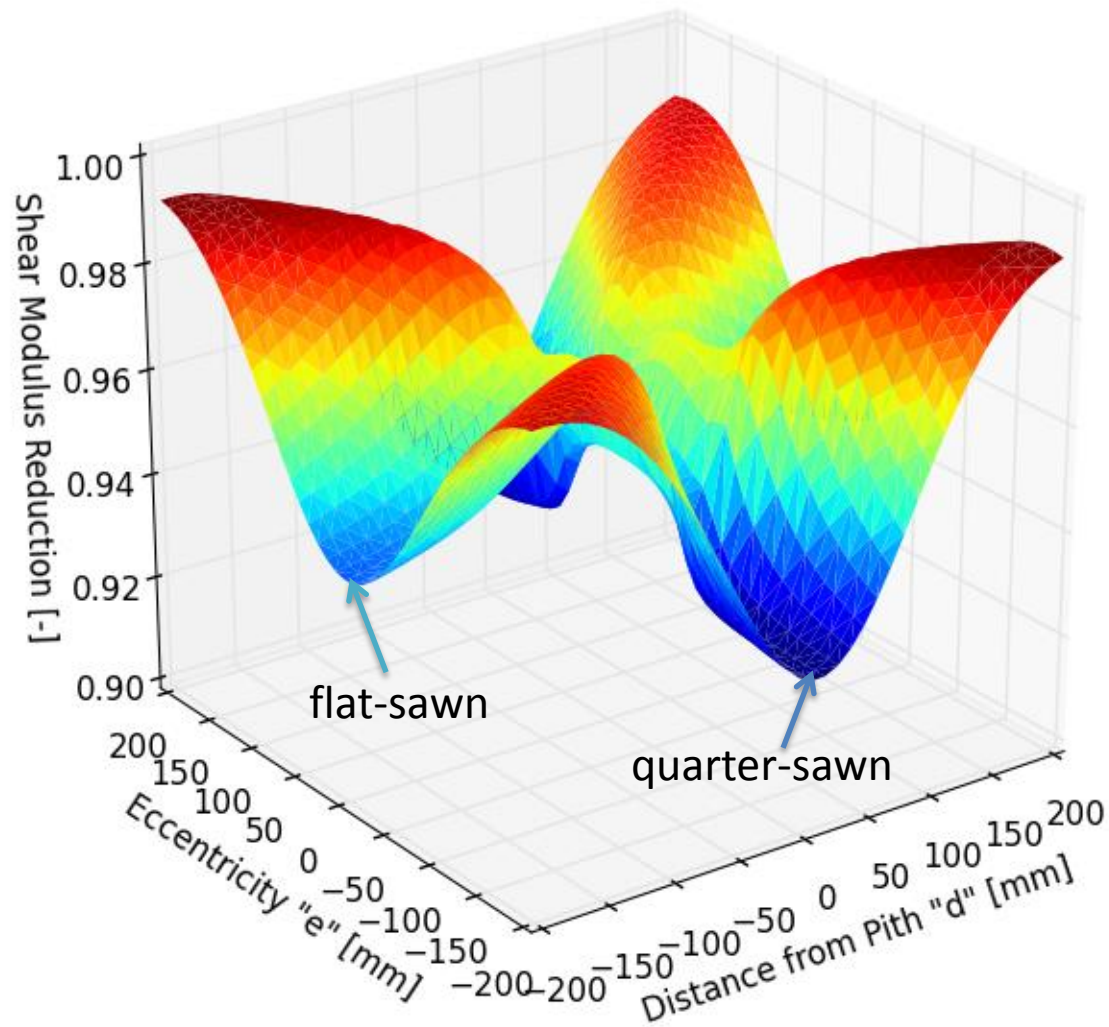based on EN 789          based on EN 408          example of failure

# First results of the rolling shear tests

| No. [-] | Density $\rho$ [kg/m³] | Scan of the specimen [-] | Rolling shear strength $f_{v,RT}$ [N/mm²] | Rolling shear stiffness $G_{RT}$ [N/mm²] |
|---|---|---|---|---|
| 1 | 694 |  | 6,5 | 380 |
| 2 | 670 |  | 6,8 | 430 |
| 3 | 673 |  | 5,3 | 310 |
| Mean | 679 | - | 6,2 | 370 |
| Spruce | 420 | - | 1,0 – 1,4 | 40 - 70 |

# First results of modelling

# Deflection of hybrid CLT vs. spruce CLT

Maximum deflection of a cantilevered-distributed loaded beam made of 3-layered (hybrid) CLT

(Calculation acc. to the shear analogy method of Kreuzinger)

| Surface layers | Middle layer | Beam length to height ratio l/h [-] | | | |
|---|---|---|---|---|---|
| | | 5 | 10 | 20 | 30 |
| spruce | spruce | 1,00 | 1,00 | 1,00 | 1,00 |
| spruce | beech | 0,40 | 0,66 | 0,87 | 0,94 |
| beech | beech | 0,32 | 0,52 | 0,68 | 0,73 |

# Cross laminated hybrid timber

Task:

Characterisation of „high grade" beech wood by

- visual grading

- non-destructive tests

- tensile and compression tests

**Var. B**
high grade beech
in the surface layers
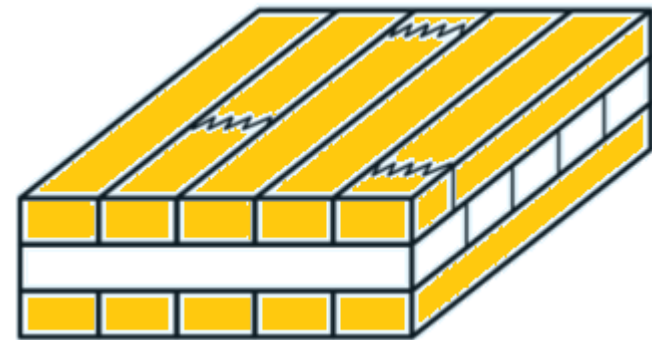
42 boards

(b = 140 mm, t = 38 mm,
l = 4,0 m)

„First impressions":

- partly furniture quality

- redheart

- mainly (semi)- quarter-sawn

- without pith

# Visual grading of the test boards

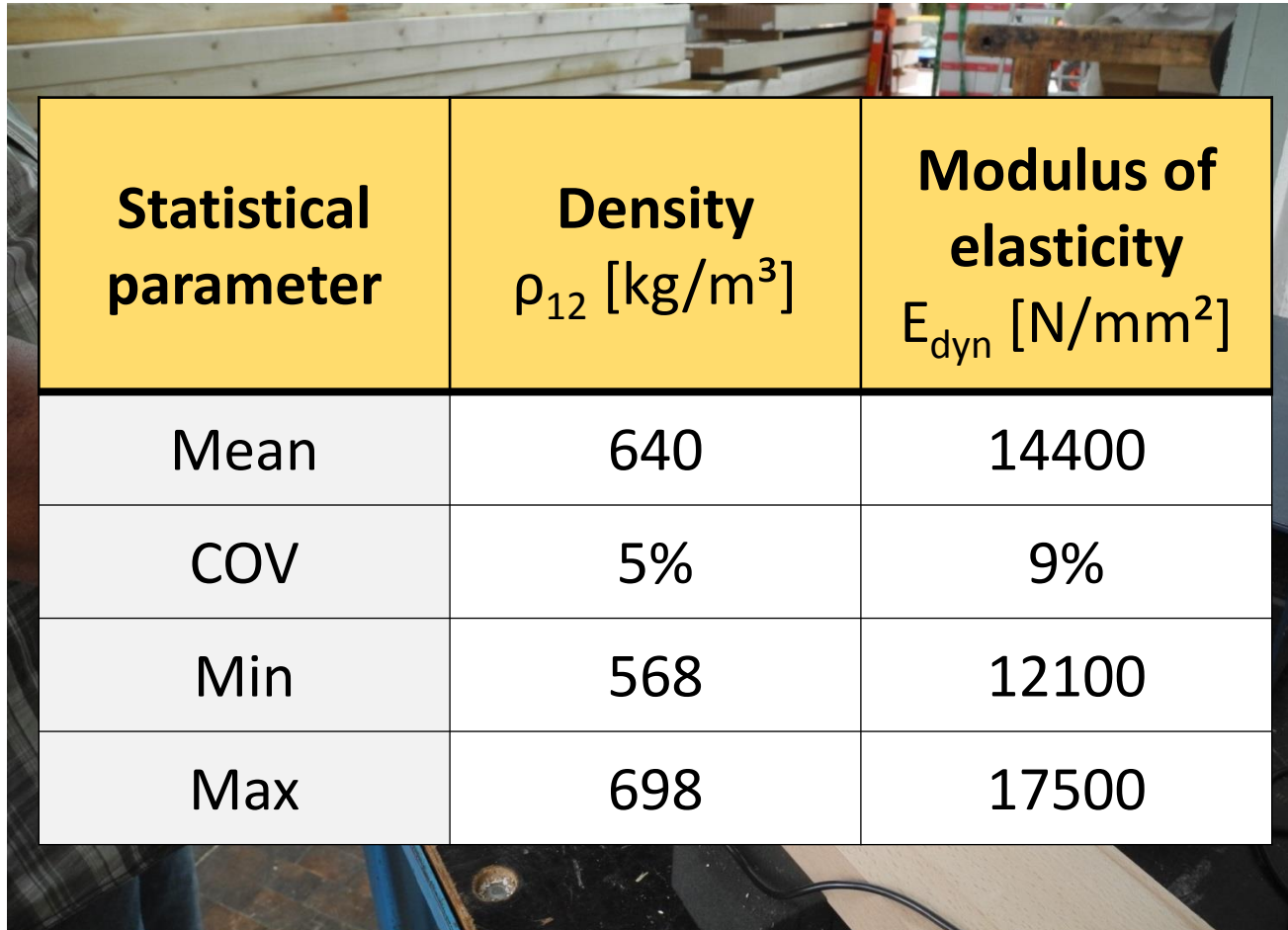Visual grading acc. to DIN 4074-5:

| | |
|---|---|
| 0 x | < LS7 |
| 11 x | LS7 |
| 17 x | LS10 |
| 14 x | LS13 |

Decisive grading criteria:

| | |
|---|---|
| 14 x | longitudinal curvature |
| 8 x | knots |
| 5 x | wane |

| Grading criteria | Grading classes | | |
|---|---|---|---|
| | LS7 | LS10 | LS13 |
| 1. knots | | | |
| – single knot | up to 1/2 | up to 1/3 | up to 1/5 |
| – accumulation of knots | up to 2/3 | up to 1/2 | up to 1/3 |
| – narrow side knot [a] | – | up to 2/3 | up to 1/3 |
| 2. slope of grain [b] | up to 16 % | up to 12 % | up to 7 % |
| 3. pith | not permitted [c] | not permitted | not permitted |
| 4. annual ring width | – | – | – |
| 5. cracks | | | |
| – shrinkage cracks | permitted | permitted | permitted |
| – lightning cracks, frost cracks, ring shakes | not permitted | not permitted | not permitted |
| 6. wane | up to 1/3 | up to 1/4 | up to 1/8 |
| 7. curvature [d] | | | |
| – longitudinal curvature | up to 12 mm | up to 8 mm | up to 8 mm |
| – torsion | 2 mm / 25 mm width | 1 mm / 25 mm widht | 1 mm / 25 mm width |
| – tangential curvature | up to 1/20 | up to 1/30 | up to 1/50 |
| 8. discoloration, decay | | | |
| – nailable brown and red stripes | up to 3/5 | up to 2/5 | up to 1/5 |
| – decay | not permitted | not permitted | not permitted |
| 9. damage from greenwood insects | not permitted | not permitted | not permitted |
| 10. other characteristics | shall be taken into consideration analogously to the other grading criterias | | |

| | |
|---|---|
| [a] | Does not apply for boards for glulam. |
| [b] | This grading criteria should not be considered for beech. |
| [c] | For oak permitted. |
| [d] | These grading criterias should not be considered for not dry-sorted wood. |

# Non-destructive testing

| Statistical parameter | Density $\rho_{12}$ [kg/m³] | Modulus of elasticity $E_{dyn}$ [N/mm²] |
|---|---|---|
| Mean | 640 | 14400 |
| COV | 5% | 9% |
| Min | 568 | 12100 |
| Max | 698 | 17500 |

Natural frequency measurement to determine the dynamic Modulus of elasticity

# Tensile and compression tests
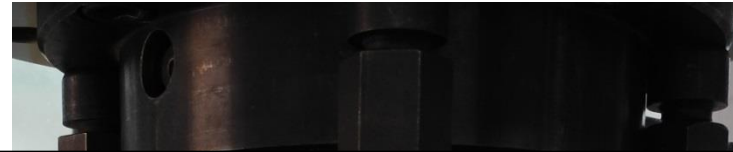
| Statistical parameter | Tensile strength $f_{t,0}$ [N/mm²] | Modulus of elasticity $E_{t,0}$ [N/mm²] | Compressive strength $f_{c,0}$ [N/mm²] |
|---|---|---|---|
| Mean | 94 | 14900 | 64 |
| COV | 17% | 6% | 9% |
| Min | 74 | 13900 | 55 |
| Max | 115 | 16200 | 69 |
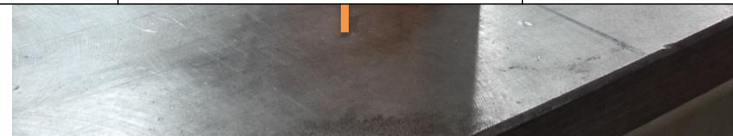
Tension acc. EN 408          Compression acc. EN 408

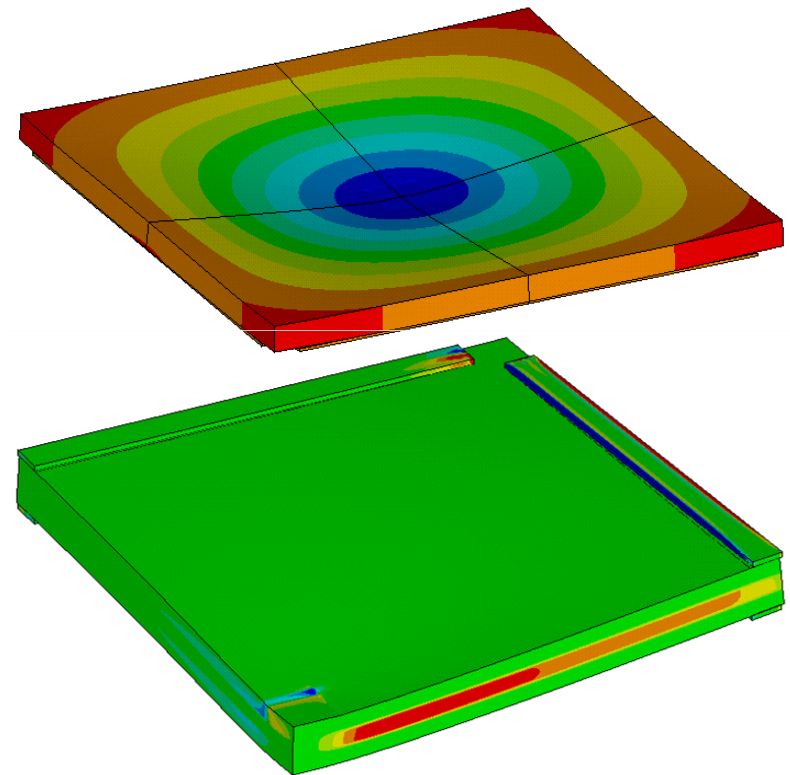Manual fabrication of small-scale CLT-test specimens with high grade beech surface layers and low grade beech middle layer

→ testing and modelling

Industrial fabrication of full-scale hybrid CLT-elements
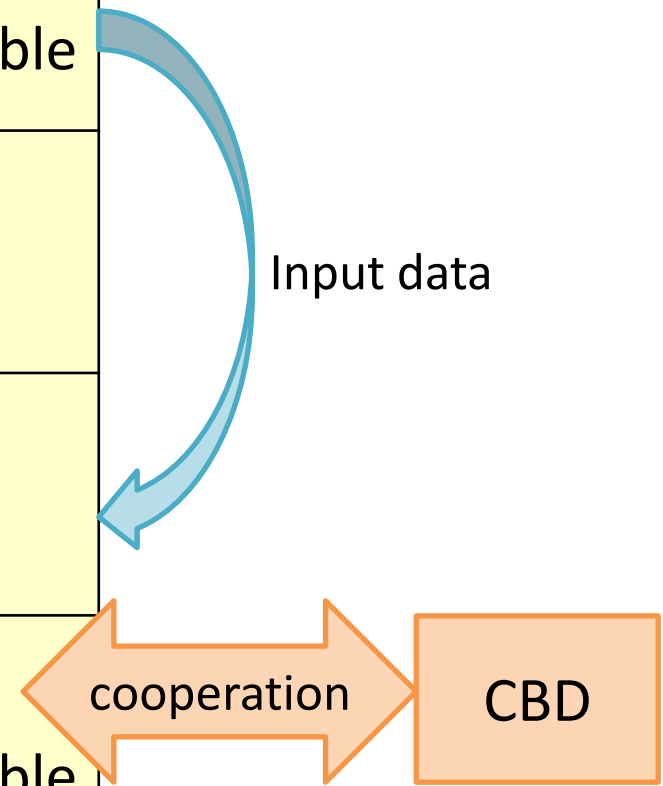→ testing and modelling in cooperation with CBD
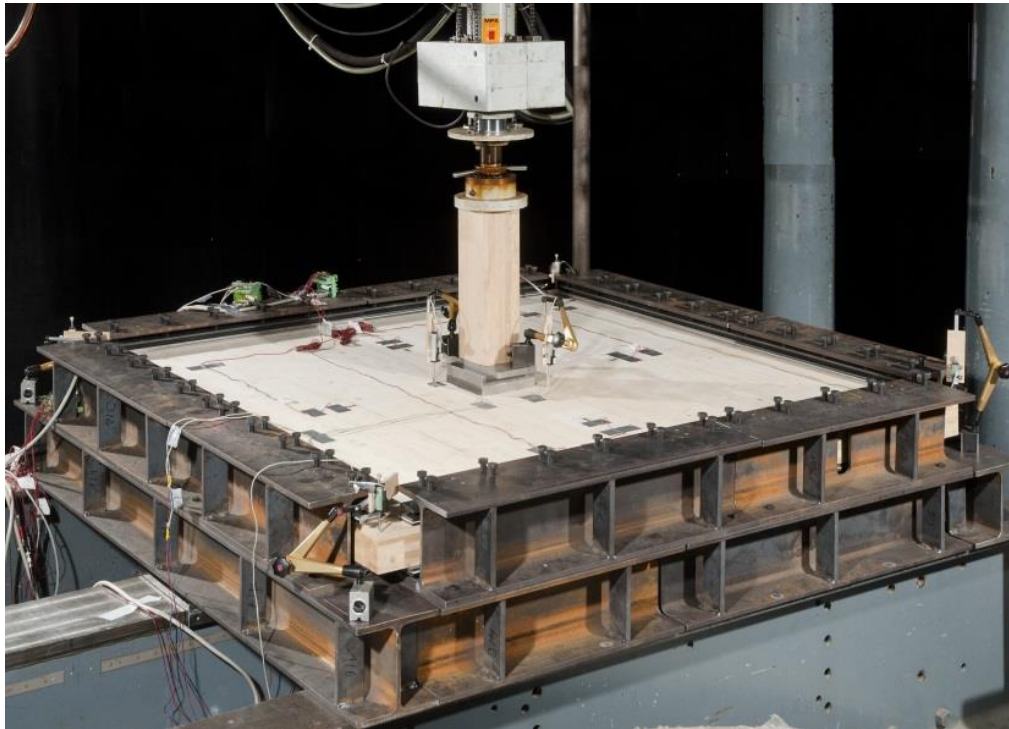


Test setup



Results of FE-modelling
(1) deflection of CLT
(2) rolling shear stress distribution

# Outline of WP 5

| Task | Current status |
|------|----------------|
| Production and testing of small-scale specimens | 05-06/2015 first results available |
| Production and testing of full-scale elements | 06-07/2015 planned |
| Evaluation and modelling | 06-08/2015 |
| Development of a 3D-FE-Model for hybrid CLT | started first results available |

Input data

cooperation → CBD

# Adhesives for structural hardwood bonding

## WP 3

Maren Hirsch, Simon Aicher

# Delamination tests acc. EN 302-2

| Species | Adhesive | Results |
|---------|----------|---------|
| Beech | 1-K-PUR + primer | positive |
| Beech + spruce | 1-K-PUR + primer | positive |
| Beech * | 1-K-PUR + primer | negative |
| Beech | PRF | positive |
| Oak | MUF | partly positive |
| Sweet chestnut | MUF | positive |
| Ash | MUF | extremely negative |
| Beech + birch | MUF | positive |

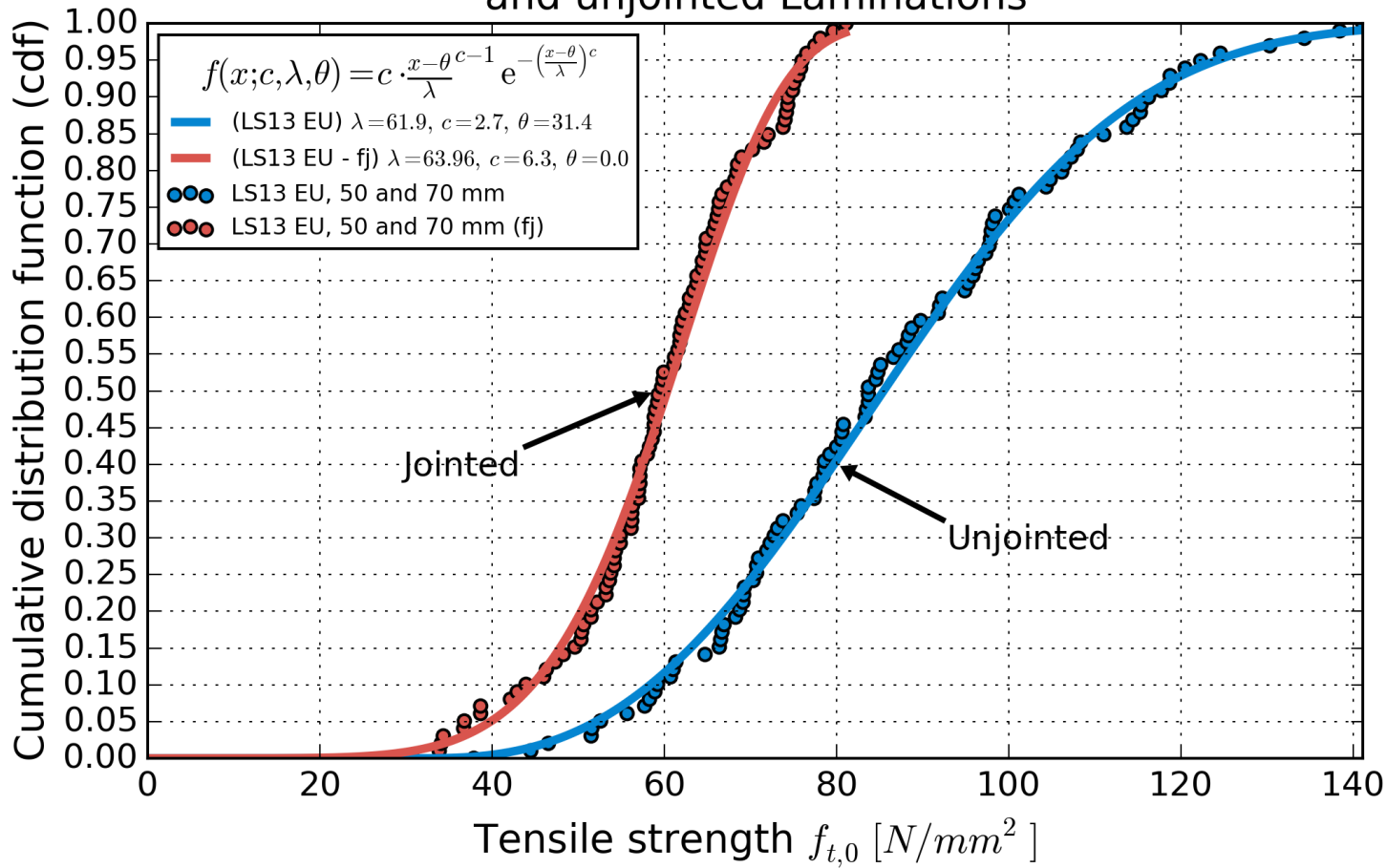* Delamination tests on finger-jointed test-specimens acc. EN 301, annex. A

eu-hardwoods

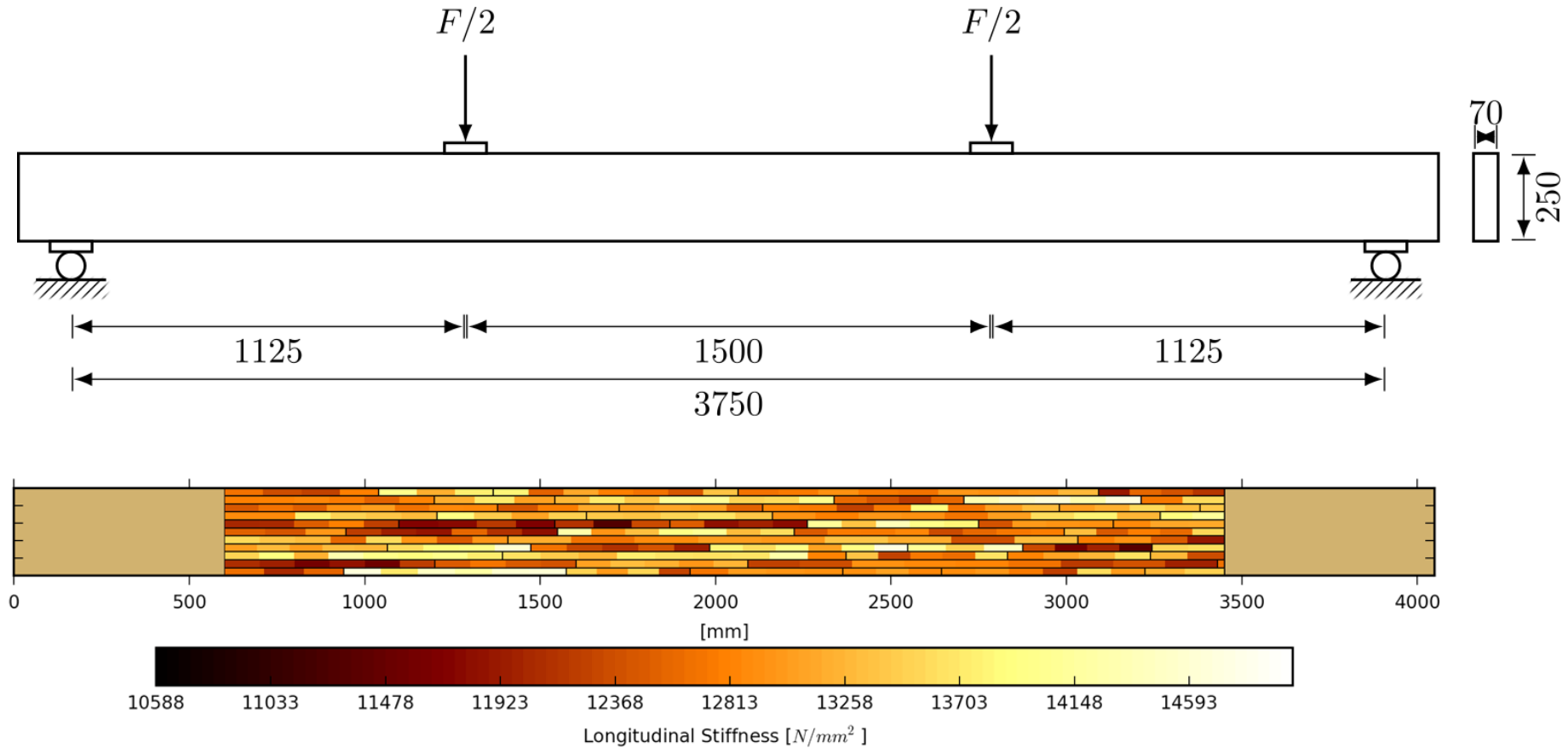# Glulam made of hardwoods or hardwoods and softwoods

WP 4

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**Otto-Graf-Institut**
**Materials Testing Institute University of Stuttgart**

Maren Hirsch, Simon Aicher

# Input – distribution of board lengths



$$P(\ell) = 1.1 \frac{(\ell-279.1)}{330.5}^{0.11} \cdot \exp\left(-\frac{\ell-279.1}{330.5}^{1.1}\right)$$
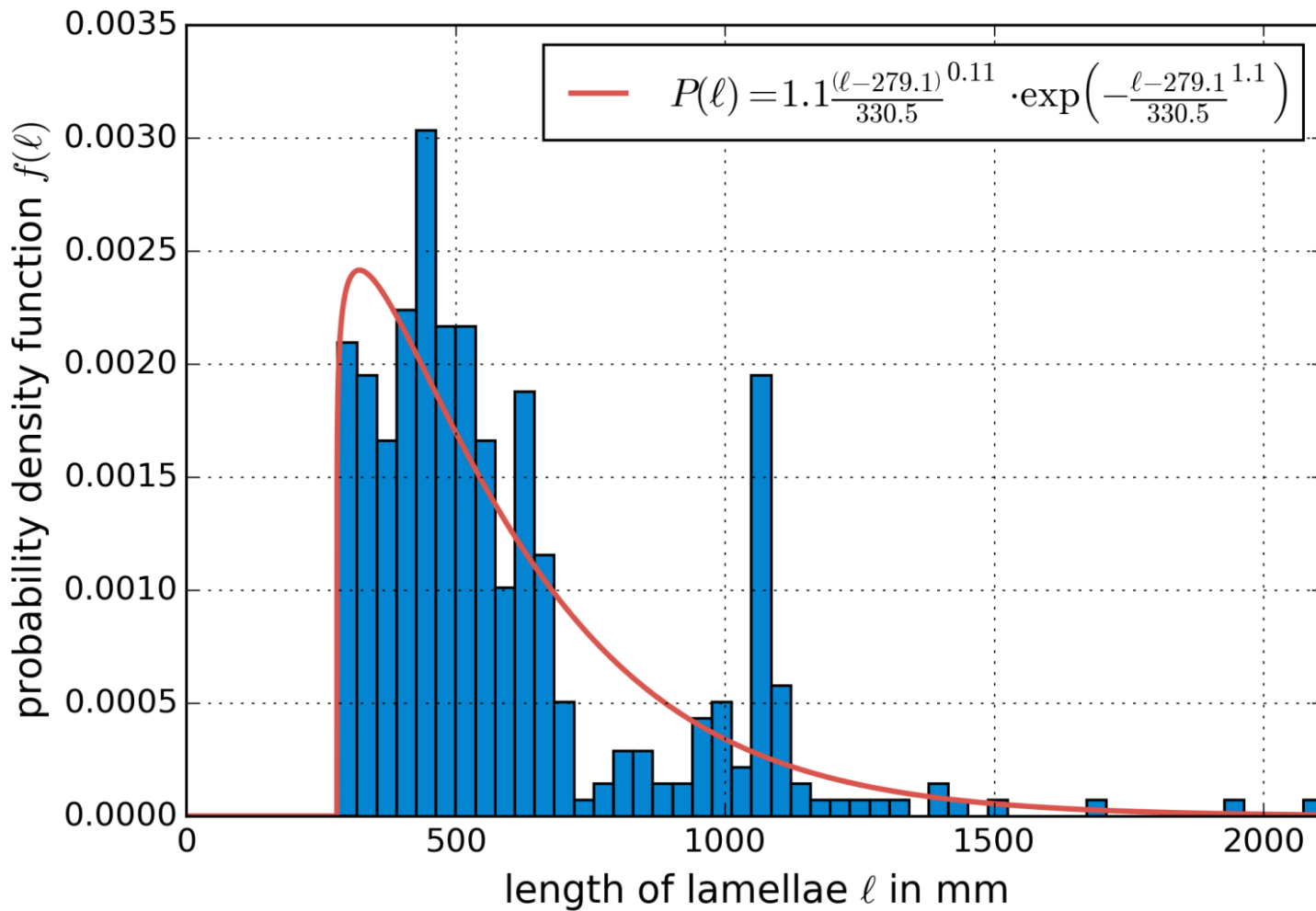
Weibull Distribution of Tensile Strengths for jointed and unjointed Laminations

$$f(x;c,\lambda,\theta) = c \cdot \frac{x-\theta}{\lambda}^{c-1} \mathrm{e}^{-\left(\frac{x-\theta}{\lambda}\right)^c}$$

(LS13 EU) $\lambda = 61.9$, $c = 2.7$, $\theta = 31.4$
(LS13 EU - fj) $\lambda = 63.96$, $c = 6.3$, $\theta = 0.0$
LS13 EU, 50 and 70 mm
LS13 EU, 50 and 70 mm (fj)

# Stochastic FE-Model of glulam beams

- Random variables: Length of board, stiffness, strength ($f_{t,0}$ / $f_{t,j}$)

- Plasticity for elements in the compression zone

- Softening used to simulate tensile failure

- Correlation between random variables:

    - Stiffness between cells within the same board

    - Tensile strength correlated to stiffness (correlation coefficient still needs to be calibrated)

- Tensile strength of jointed boards ($f_{t,j}$) randomly distributed  (later to be correlated to board properties)

- Contact elements between each layer (bounded) to avoid problems with the location of nodes between adjacent boards

Moduli of elasticity of board segments
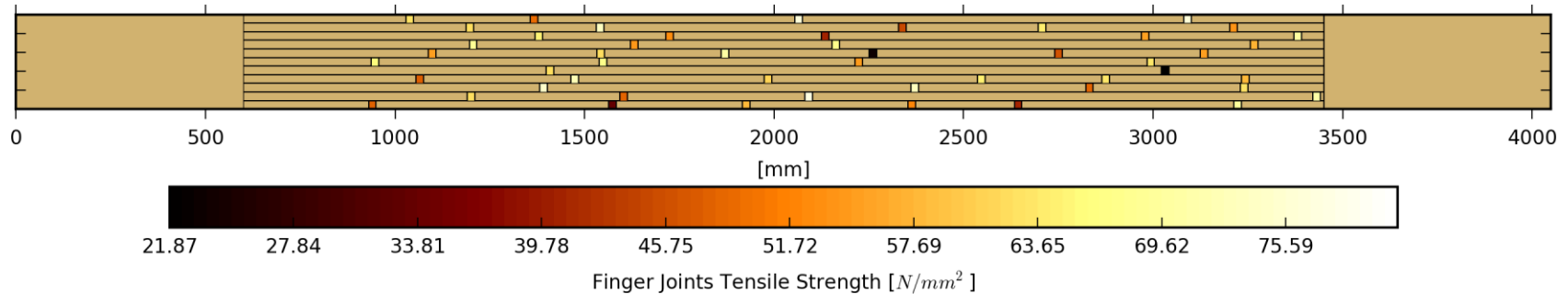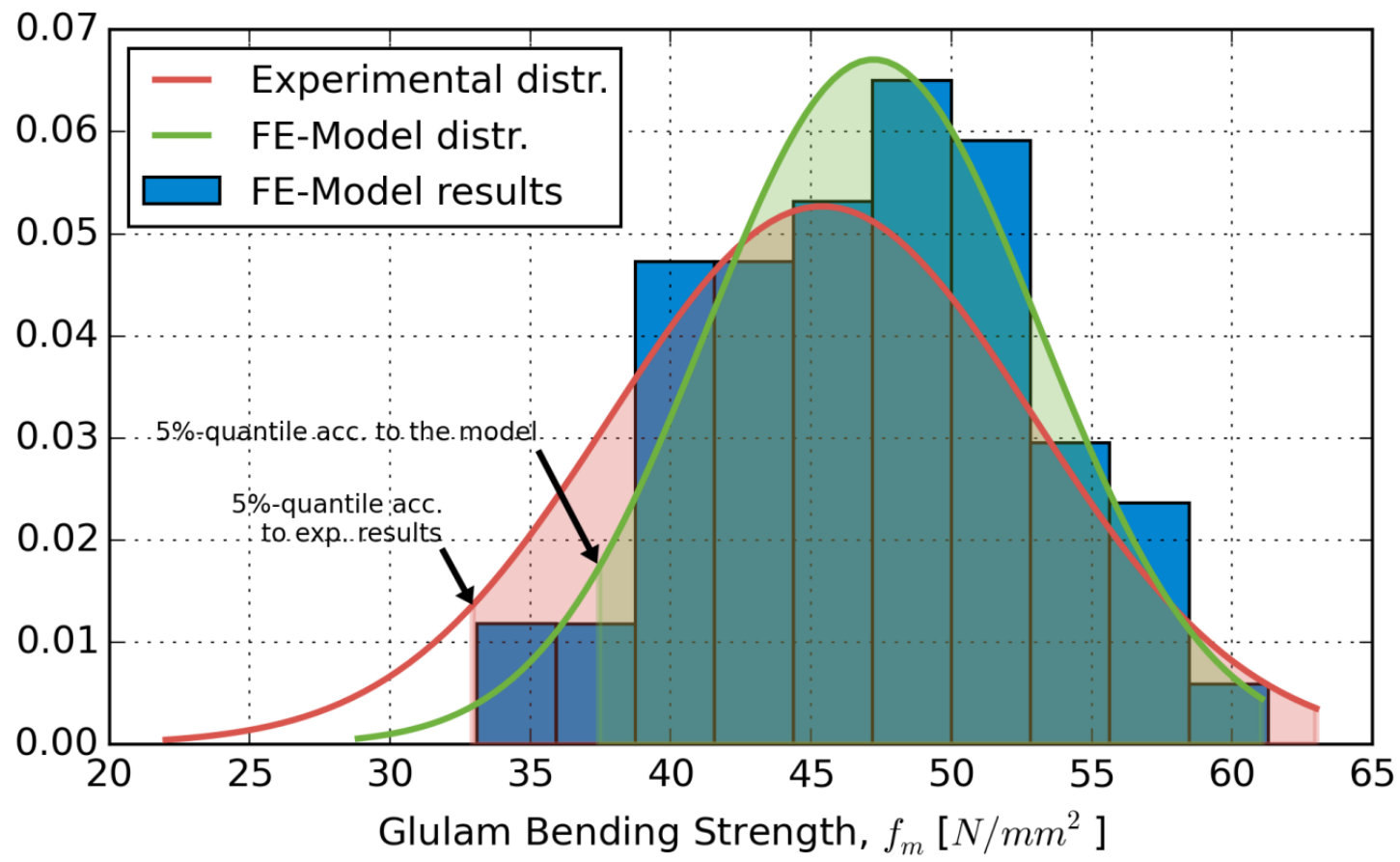
# Distribution of tensile strengths

## Strengths of board segments



Tensile Strength [$N/mm^2$]
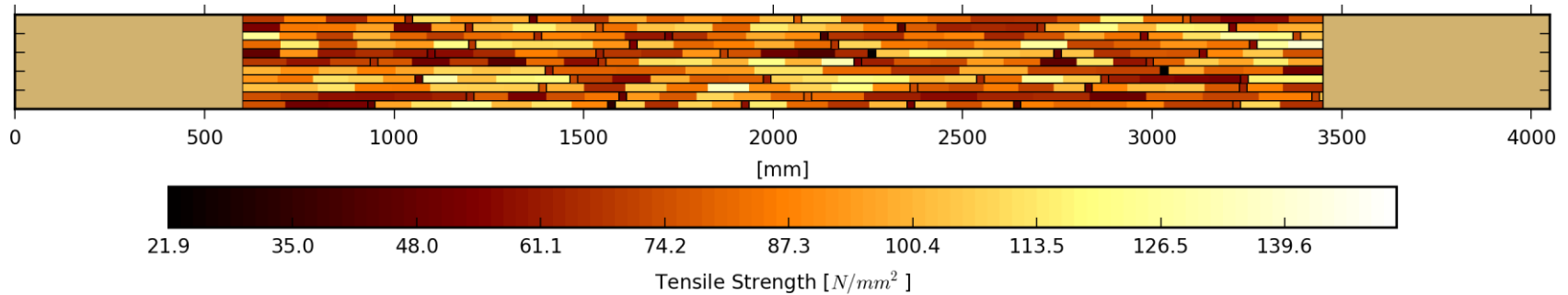
## Strengths of finger joints



Finger Joints Tensile Strength [$N/mm^2$]
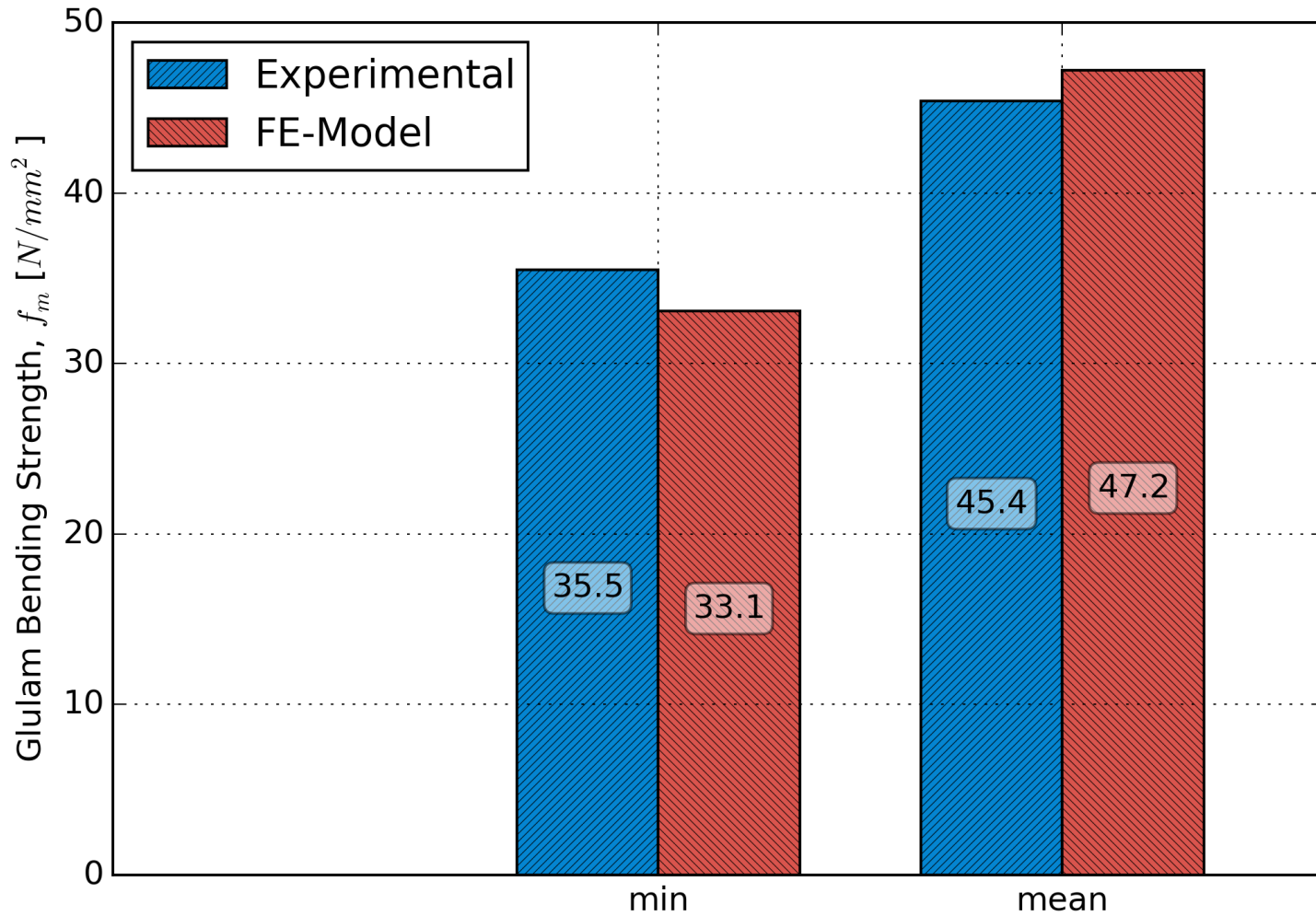
| Task | Current status |
|------|----------------|
| Extension of existing analytical glulam model | started (05/2015) |
| Development of stochastic glulam model | results available, next steps: application to new data; autocorrelation of MOE/strength distribution along board lengths |

**data** ← FCBA
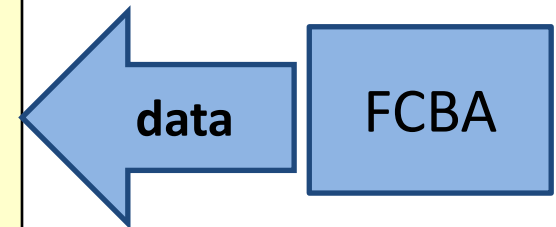
# Thank you for your attention!

Maren Hirsch, Simon Aicher