# CLT – European Experience
## Idea & Development
## Technology & Applications

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Institute of Timber Engineering and Wood Technology
Graz University of Technology

Presentation in the frame of the
**CLT Forum 2013 in TOKYO**

Tokyo, 24nd October 2013

- Introduction
- Idea & Development
- Technology & Production
- Applications

- **Introduction**
- Idea & Development
- Technology & Production
- Applications

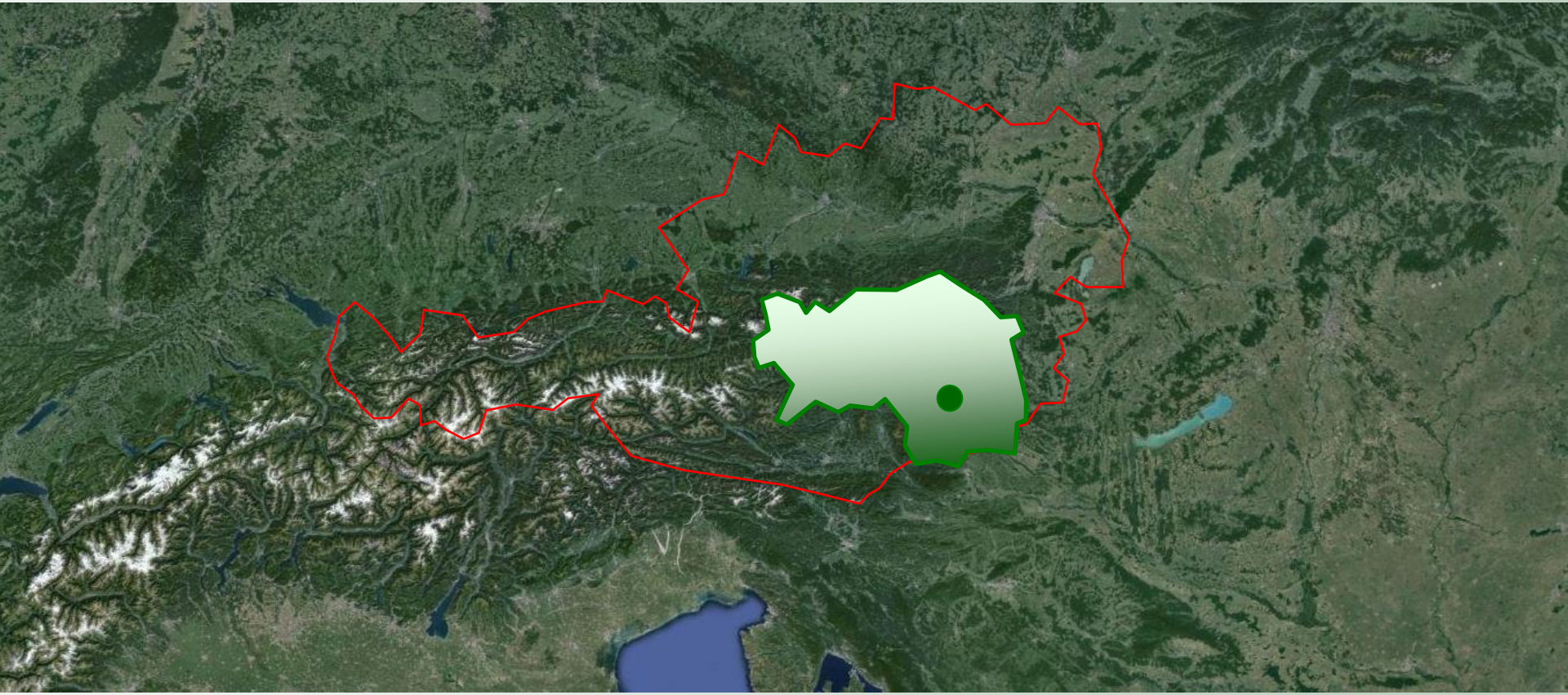
# GRAZ UNIVERSITY OF TECHNOLOGY

Austria / Europe

**AUSTRIA - 8.5 mio. inhabitants - Capitol: Vienna - 9 provinces**
**48% forest vegetation**

# GRAZ UNIVERSITY OF TECHNOLOGY

Styria / Austria



**Styria - 1.2 mio. inhabitants - capitol: Graz - 13 districts**
**61% forest vegetation**

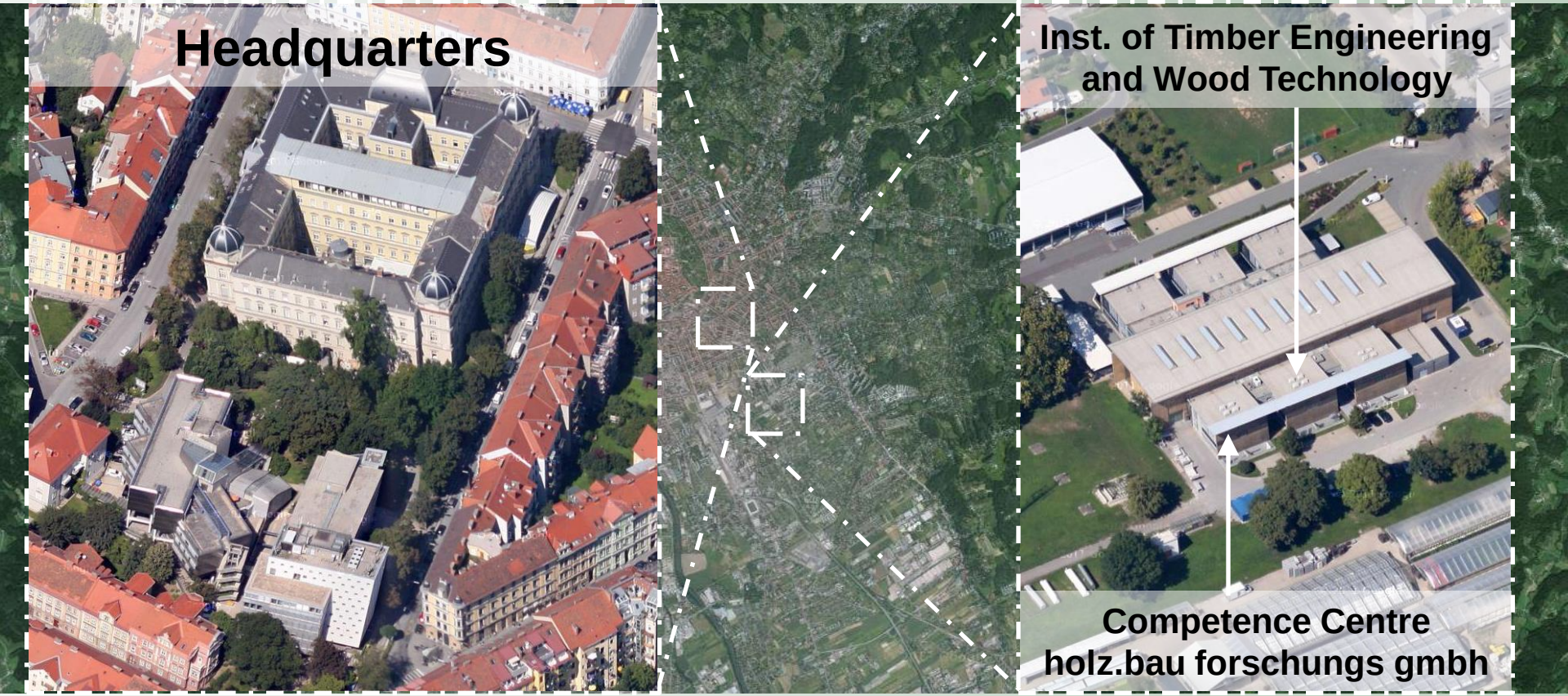
# GRAZ UNIVERSITY OF TECHNOLOGY

Graz / Styria

**Graz - 0.3 mio. inhabitants**

# GRAZ UNIVERSITY OF TECHNOLOGY

Graz / Styria




**CAMPUS "ALTE TECHNIK"**

**CAMPUS "INFFELDGASSE"**

# GRAZ UNIVERSITY OF TECHNOLOGY

Graz / Styria

**7 faculties | 12,323 students | staff 2,269** (2012)
budget: **€ 170 Mill.** (1/3 3rd party budget)

## Faculty of Civil Engineering Sciences

**17 institutes | about 1.400 students** (2012)

### Institute of Timber Engineering and Wood Technology

1991: Chair for Timber Engineering

10|2004: **Institute Timber Engineering and Wood Technology**

Scientific staff: **4.8 FTE** | 3rd party-budget: **€ 270,000** (2012)

### Competence Centre holz.bau forschungs gmbh

12|2002 **Competence Centre holz.bau forschungs gmbh**

11|2012 3rd acceptance of a 4-year-funded programme: COMET-Project "**focus_sts**"

Scientific staff: **7.2 FTE** | budget: **€ 940,000** (2013)

AREA 1

# SOLID TIMBER SOLUTIONS AND COMPONENTS (STSC)

## 1.1 High performance CLT Timber hybrids for large span elements

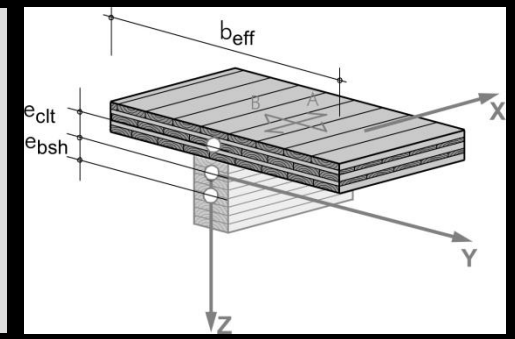
## 1.2 Optimised CLT ceilings and standardised, target-oriented leading details

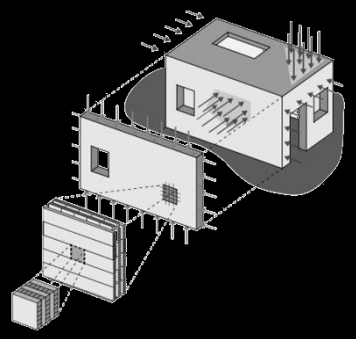
AREA 2

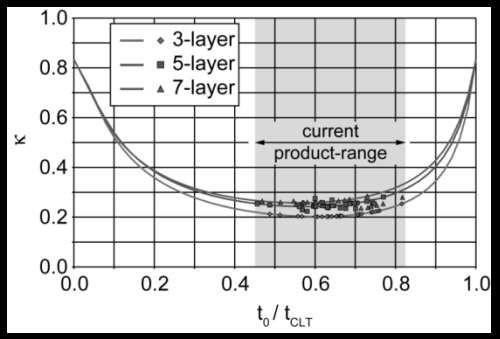
# ADVANCED PRODCUTION, MODELLING AND DESIGN (APMD)

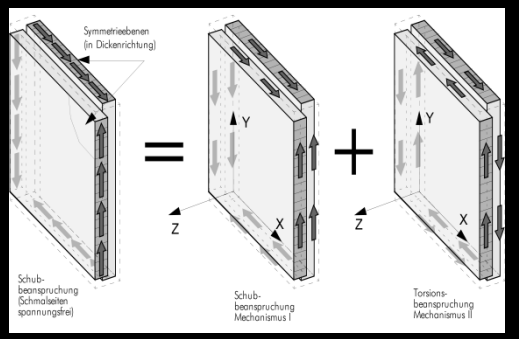
## 2.1 Determination of characteristic strength and stiffness values of CLT-elements

## 2.2 Development of load bearing models for CLT elements



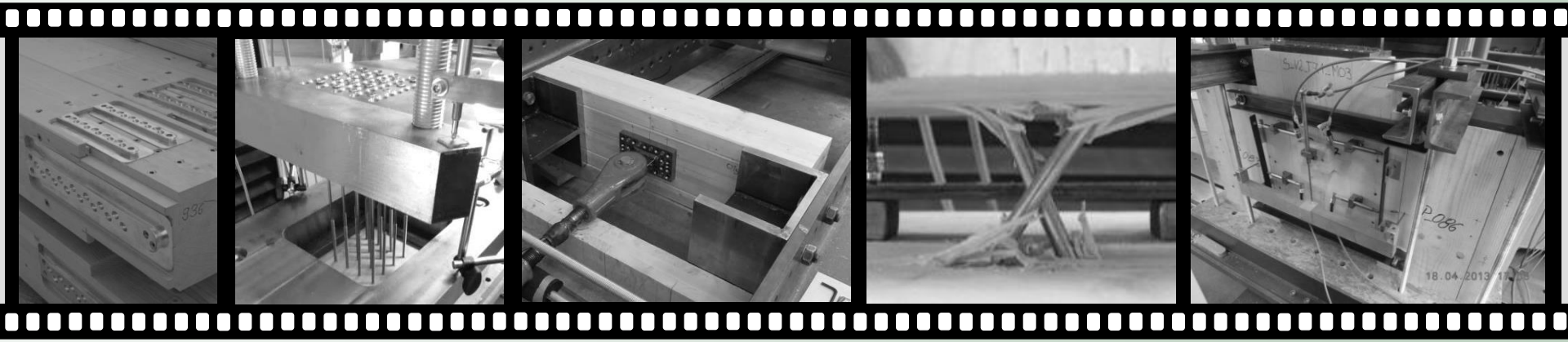


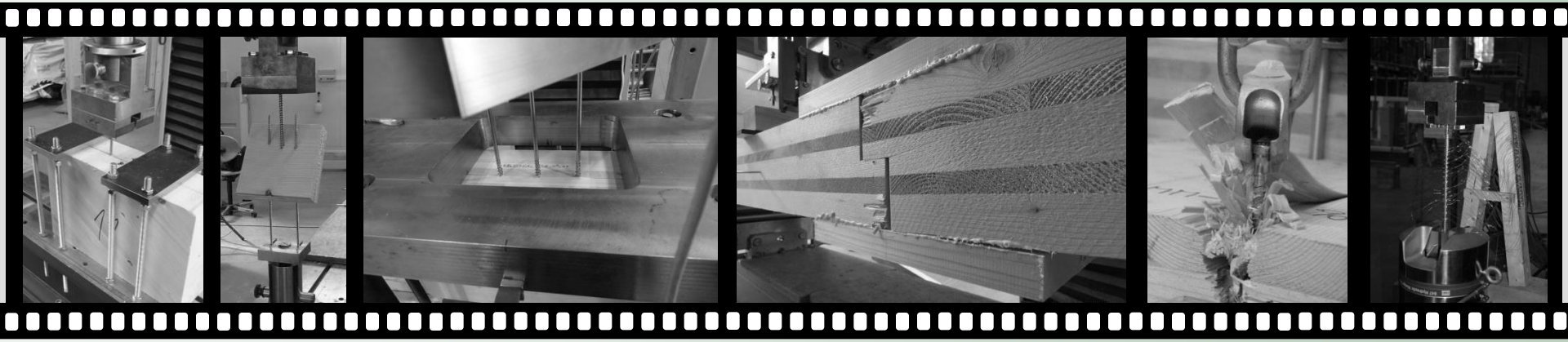
AREA 3

# SCREWING, GLUING AND SYSTEM CONNECTIONS (SGSC)

## 3.1 Axial and transversal loaded joints and system connectors



## 3.2 Screwing and gluing technology for STC system with CLT



- Introduction
- **Idea & Development**
- Technology & Production
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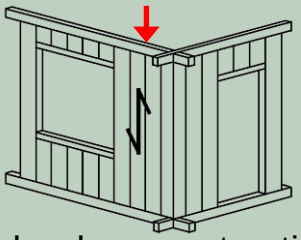
# Solid Timber Construction (STC) – INNOVATION based on TRADITION

## load transfer

tradition

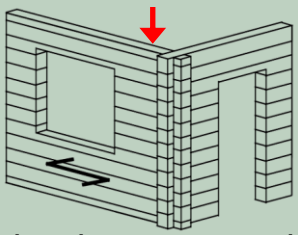
**bar-like**
(parallel to grain)



timber bar construction
(especially in Scandinavia)

stave church

**bar-like**
(perp. to grain)

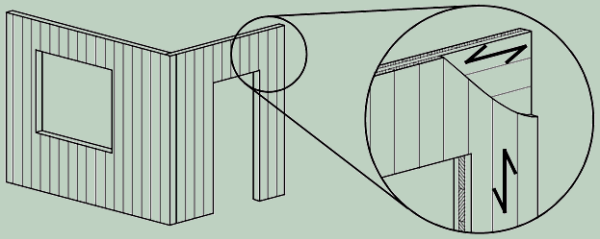


timber log construction
(especially in Alpine Space)

chalet

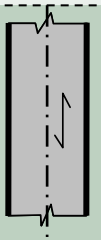
innovation

**slab-like**
(interaction of “parallel” and “perp.” to grain)



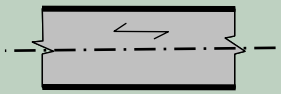
Solid Timber Construction with CLT

detached house Jeitler



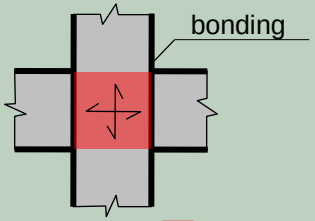
vertical

+



horizontal

=

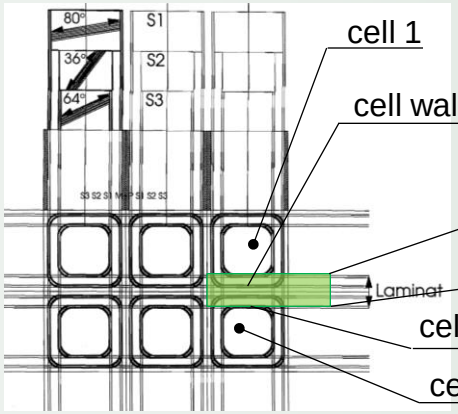



**Cross Laminated Timber (CLT)**
[rigidly connected]

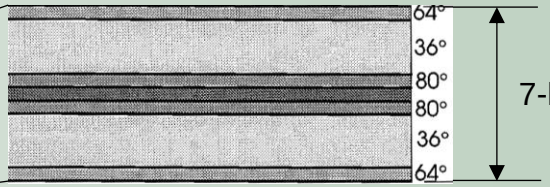
# Analogies between Wood and Fibre-Plastic Composites

## Scientific Activities [doctoral thesis] | 1989 ÷ 1994

lay-up of the load carrying system of a wood cell…



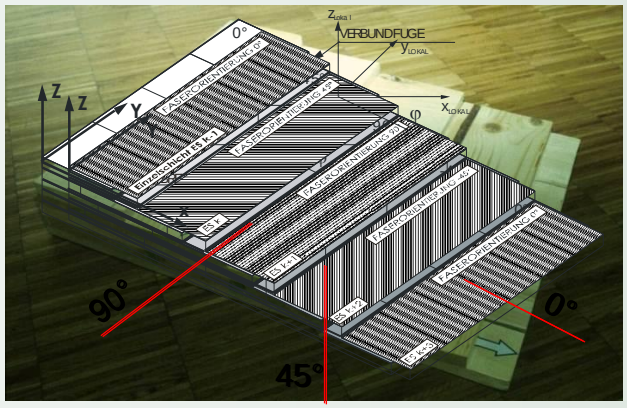

… is similar to the lay-up of fibre plastic composites




ANALOGY

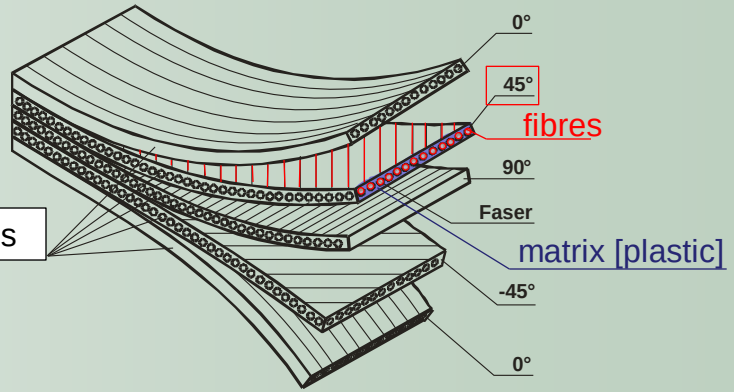
analysis is based on the
`**C**lassical **L**aminate **T**heory´ **(CLT)**
[see also A.P. Schniewind | J.D. Barrett (1969)]

~~5-layered panel~~ fibre plastic composites e.g. 5-layered panel




ANALOGY

single layers



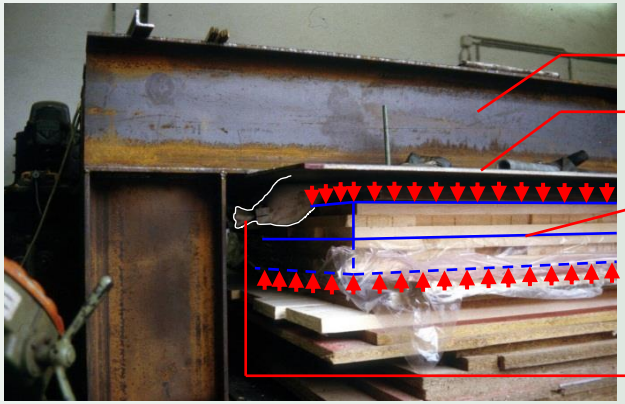

wood fibres + matrix
(lignin + adhesive between the layers)

glas-, aramid-, carbon fibres + matrix [plastic]

# Product Development

Project between 1995 and 1998

tryout press … and … one of the first CLT panels produced by KLH | Austria, 1996 …




… 15 years later – 2011|2012 – KLH Massivholz GmbH is the world largest CLT producer


www.klh.at | Katsch/Mur | Austria

# Product Development

## Approvals and Standardisation

**1st STEP**
**National approvals**

**2nd STEP**
**ETAs**

**3rd STEP**
**Standardisation**

Austria



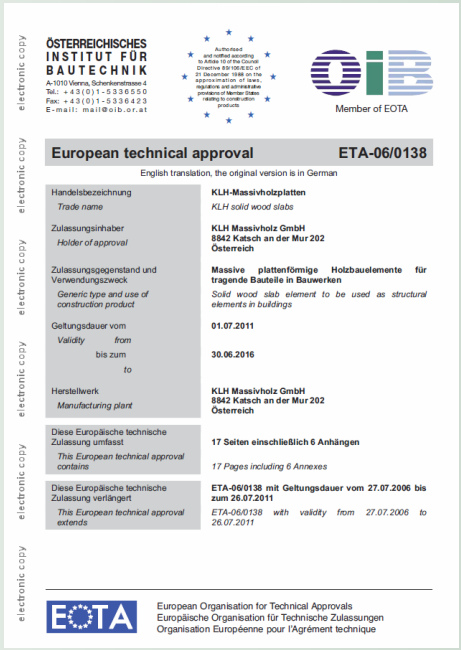

France

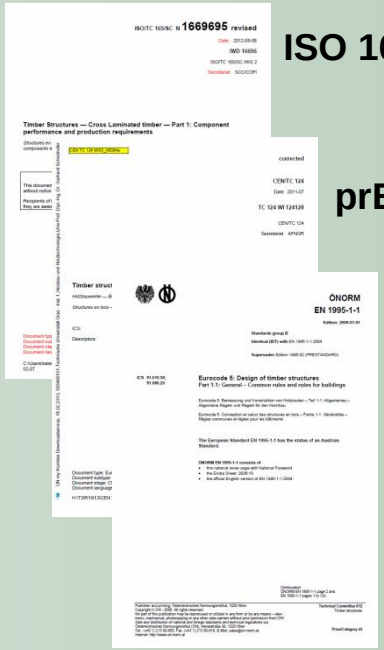



Germany


Russia

Spain



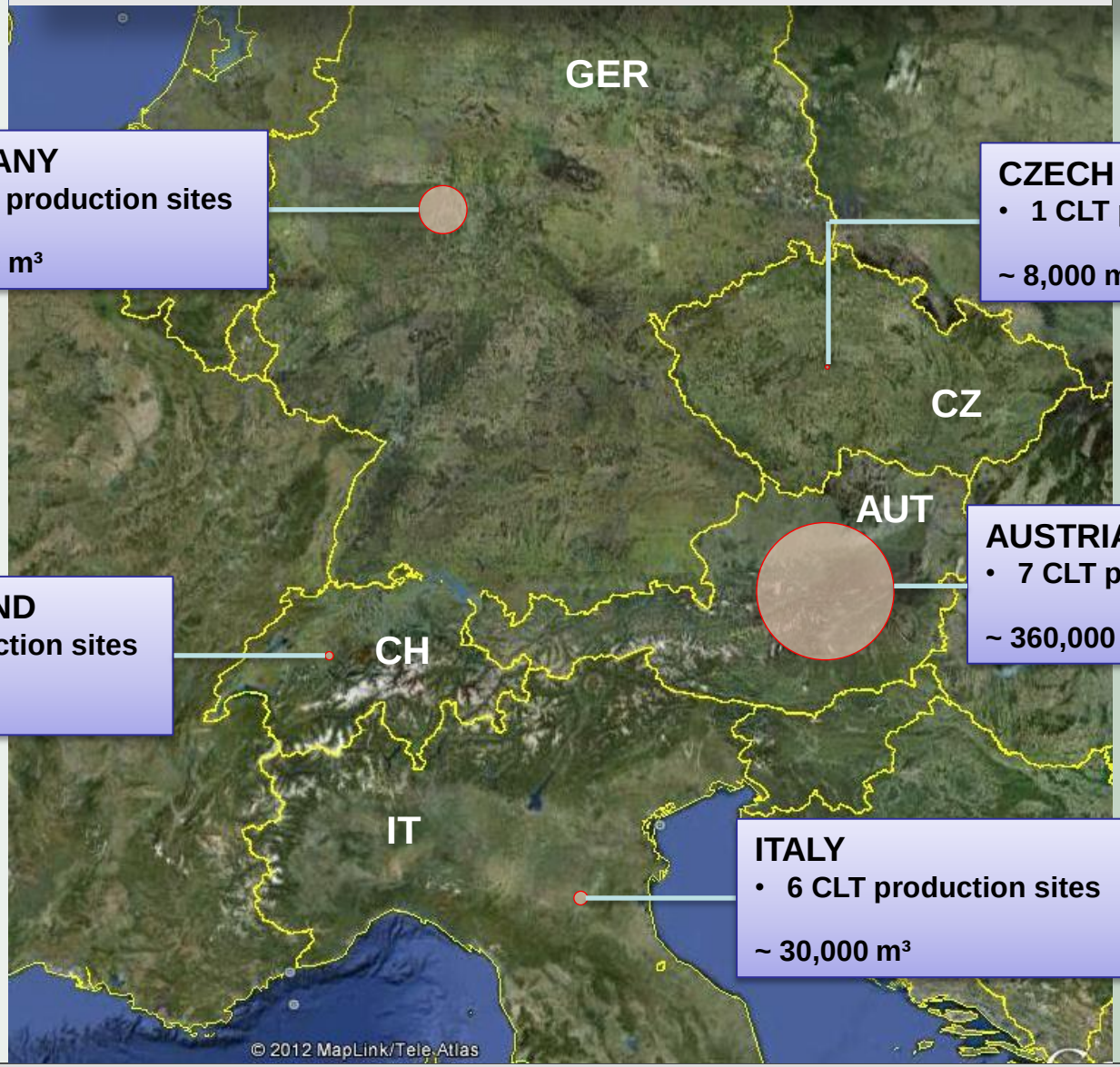




ISO 165

prEN 16351

EN 1995

# Central Europe
# Production 2011 ~ 450.000 m³




**GERMANY**
- 8 CLT production sites

~ 90,000 m³

**CZECH REPUBLIC**
- 1 CLT production site

~ 8,000 m³

**AUSTRIA**
- 7 CLT production sites

~ 360,000 m³

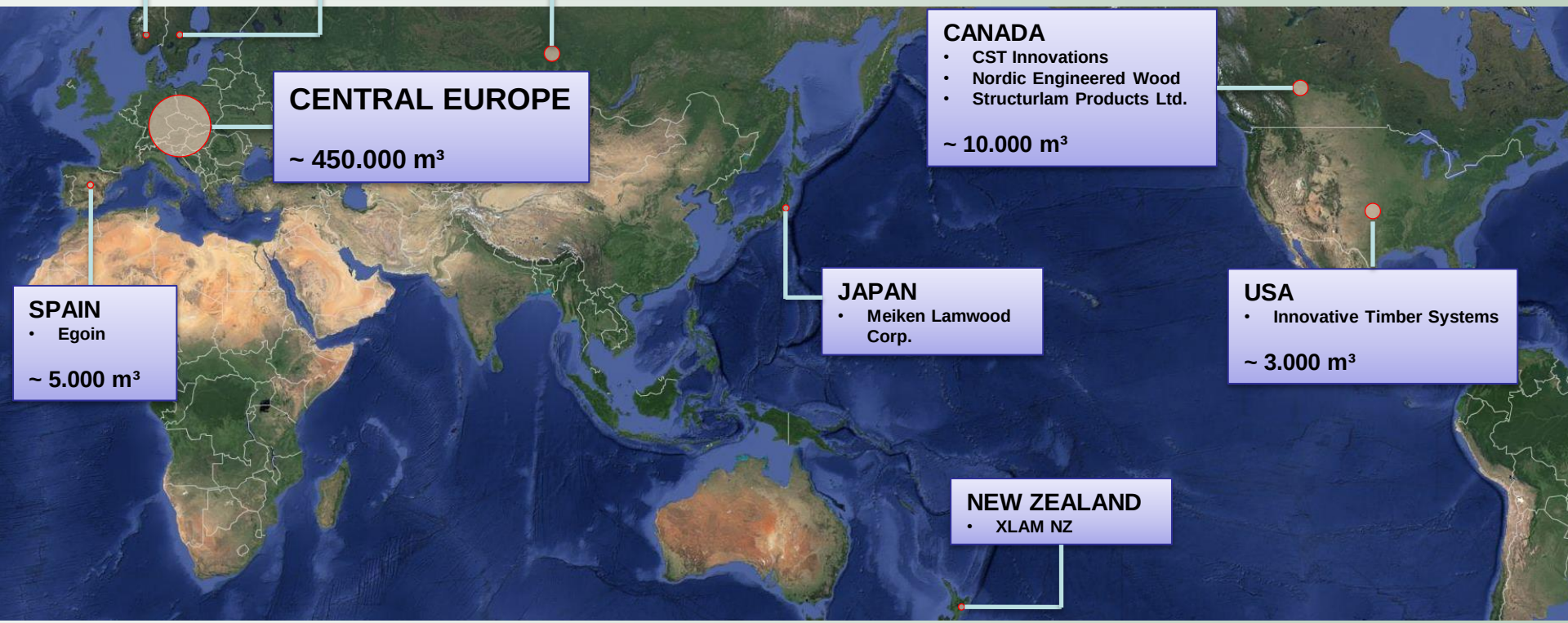
**SWITZERLAND**
- 2 CLT production sites

~ 18,000 m³

**ITALY**
- 6 CLT production sites

~ 30,000 m³

# Worldwide
# Production 2011 ~ 475.000 m³

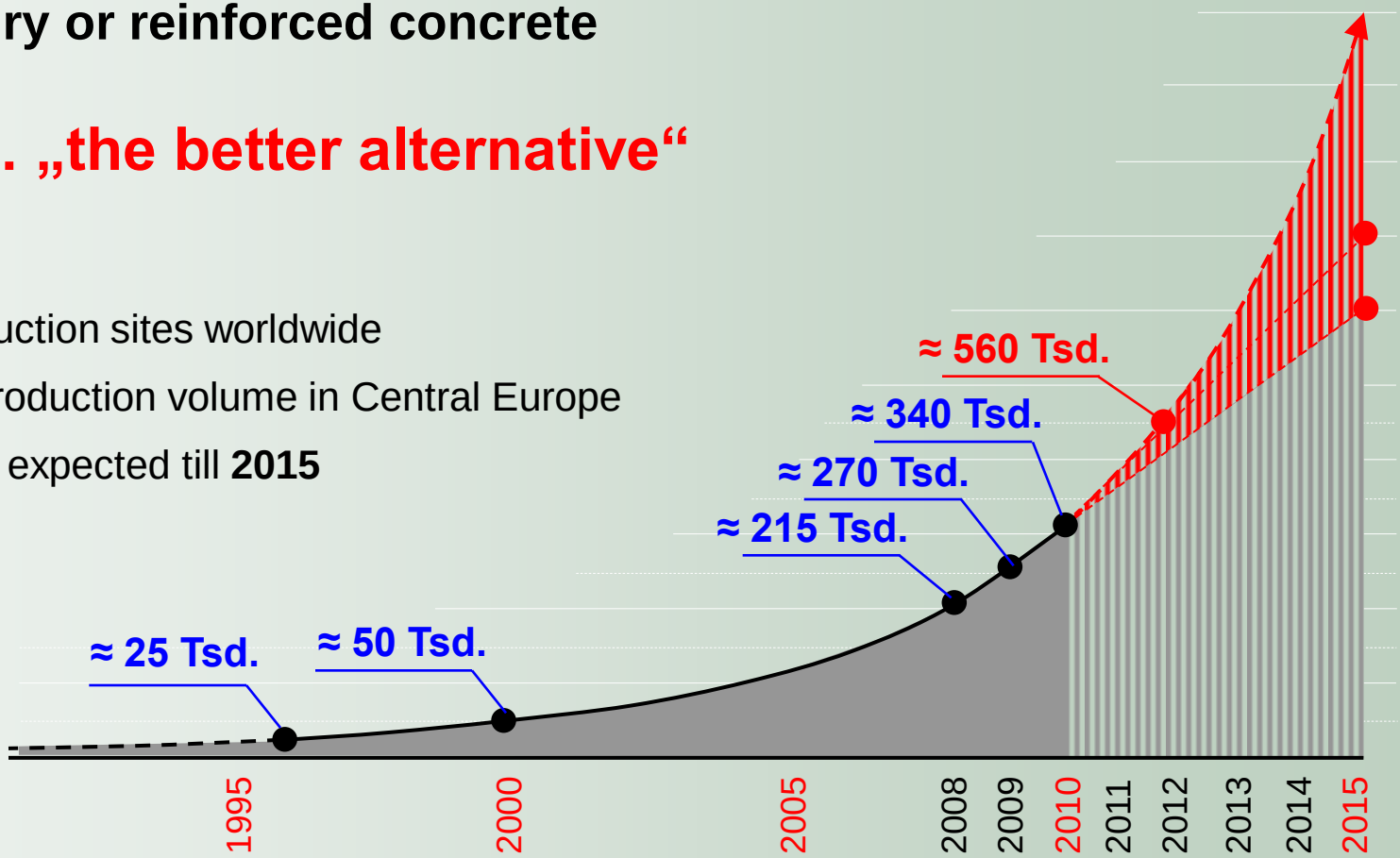


# Re-organisation | shifting market shares → ~~concrete~~ | CLT

- **CLT is not competing with current | past timber engineering**
- **… but substitutes mineral based building products like masonry or reinforced concrete**

**→ CLT, … „the better alternative“**

- > 35 production sites worldwide
- 95 % of production volume in Central Europe
- **1 Mio. m³** expected till **2015**



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# Cross Laminated Timber (CLT) composed as …

## FLEXIBLE composite

- **ring-shank nails** (e.g. MHM-wall elements | Z-9.1-602)
- **metal brackets**, **screws**, …
- **hardwood dowels** (e.g. THOMA-Holz 100 | Z-9.1-574)
- **hardwood screws** (e.g. Rombach Bauholz+Abbund GmbH | ETA-11/0338)

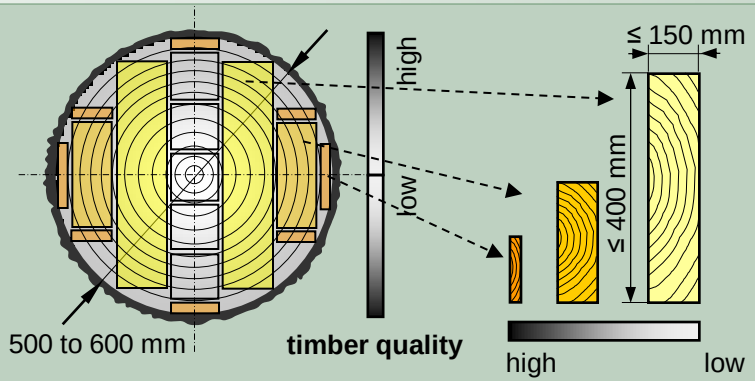
## RIGID composite

- by surface bonding enabled by
  - **hydraulic / pneumatic / vacuum press facilities** (→ pressure “globally”)
  - **screws, brackets or nails** (→ pressure „locally“)

**FOCUS: CLT as rigid composite product !**

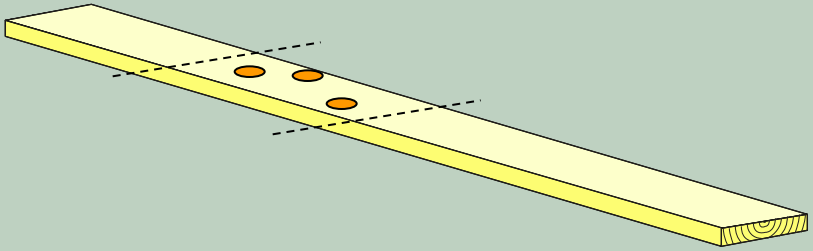
# STEPs intermediate products | steps in production

**STEP I**
log



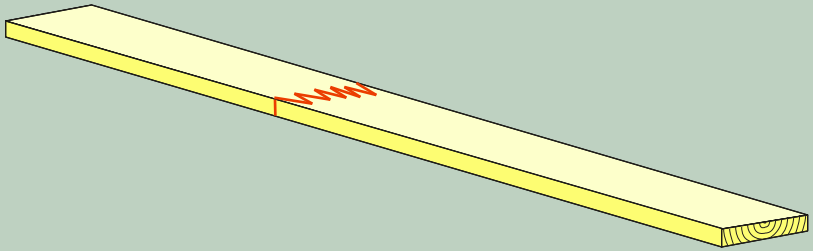

**breakdown**

**STEP II**
board



**classification / grading**
**trimming**

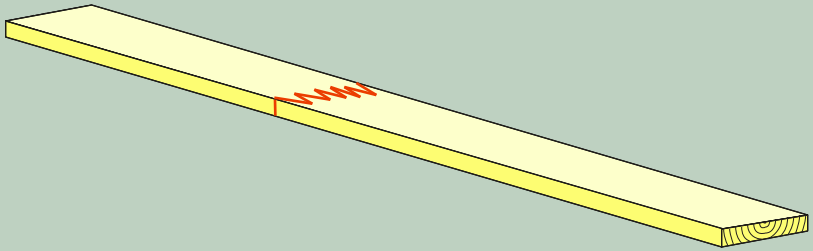
**STEP III**
finger jointed lamella



**finger jointing**

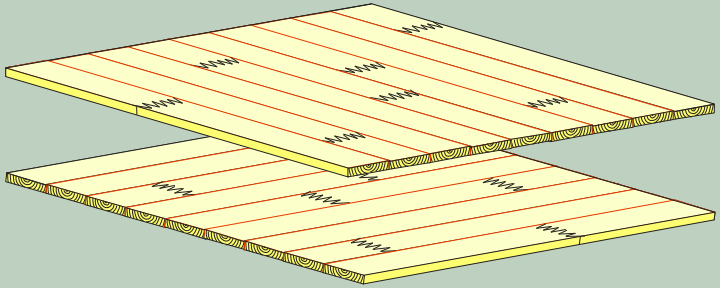
# STEPs intermediate products | steps in production

**STEP III**
finger jointed lamella



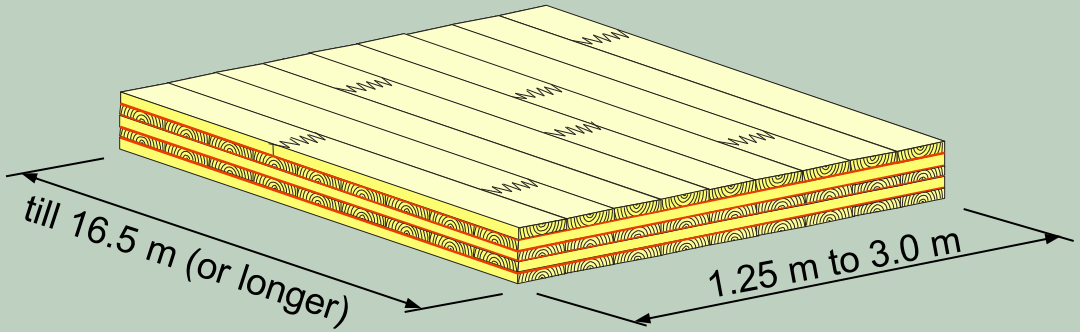
**finger jointing**

**intermediate STEP**
single-layer panel



**edge bonding**

**STEP IV**
cross laminated timber (CLT)




**surface bonding**

# Requirements on the BASE MATERIAL (boards) …

- **strength / stiffness graded** C24 (C16) acc. to **EN 338** (bending !)
  - ➔ classification acc. tensile properties, e.g. **T14 E11.0**, recommended !
  - ➔ **stiffness grading +** compliance criteria to fulfil **minimum requirements on strength** (e.g. proof loading) recommended !

- **dimensions**
  - $t_B$ = (12 to 45) mm; **standard layers: $t_B$ = (20, 30, 40) mm**
  - $w_B$ = (40 to 300) mm; **$w_B$ / $t_B$ ≥ 4**; **$w_{B,ref}$ = 150 mm** recommended!
  - edges prismatic or with profiling → shadow gaps

# Requirements on the BASE MATERIAL (boards) …

- **species** mainly softwoods; primary Norway spruce; **u = (12 ± 2) %**

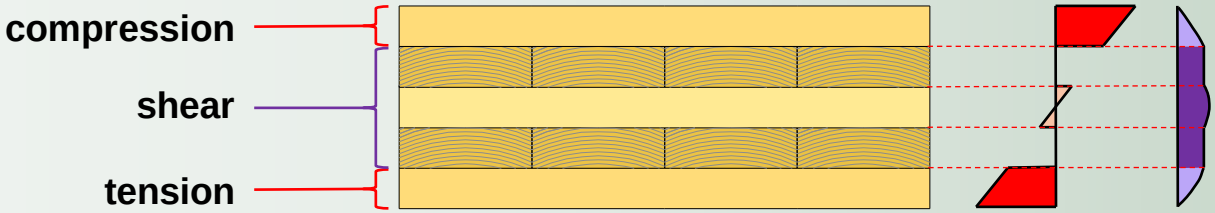
➔ **use or combination with other species (e.g. hardwoods) for optimising e.g.**

  - bending strength / stiffness
  - rolling shear modulus and strength

} e.g. birch, ash, eucalyptus, …

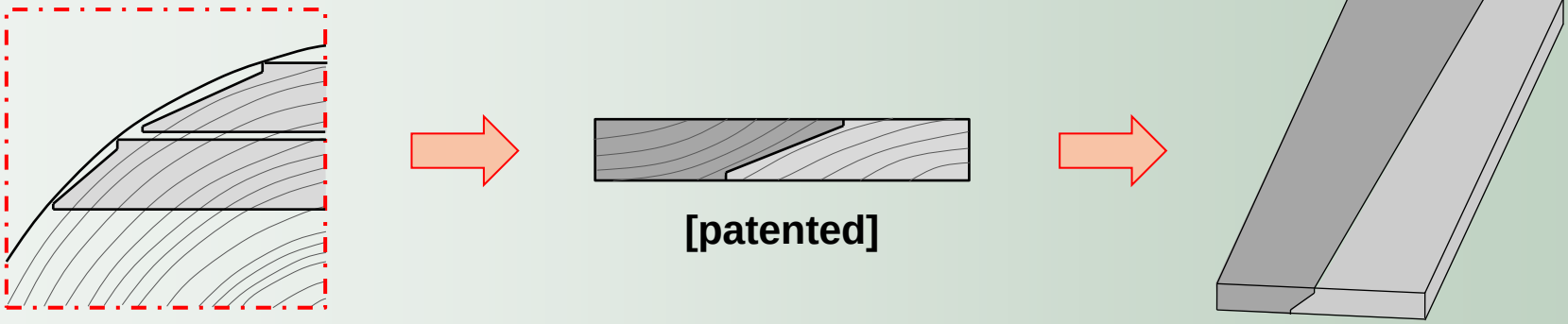
# Requirements on the BASE MATERIAL (boards) …

- **optimisation of cross section by:**
  - applying different strength classes of one material
  - applying different species





- **further optimisation:**
  - applying of new cutting patterns



# Requirements on FINGER JOINTS …

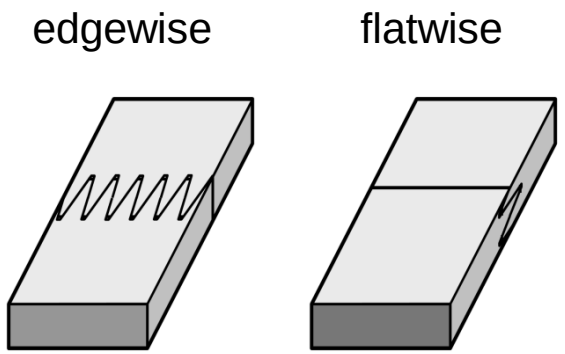
- economical approach for joining graded board segments longitudinally !
- position of finger joints …
  - **edgewise** (common in GLT)
  - **flatwise** (higher appearance quality)
- production & FPC regulations **EN 385**, **DIN 1052**, **prEN 16351**
- common adhesives: **1K-PUR (90% of CLT producers) | MUF (10%)**

- **minimum requirements on strength** related to the base material

proposal

$$f_{t,0,FJ,05} \geq \zeta_{05} \cdot f_{t,0,B,05}$$

| | |
|---|---|
| $\zeta_{05} \geq 1.40$ | for CV[$f_{t,0,B}$] = (35 ± 5) % |
| $\zeta_{05} \geq 1.20$ | for CV[$f_{t,0,B}$] = (25 ± 5) % |



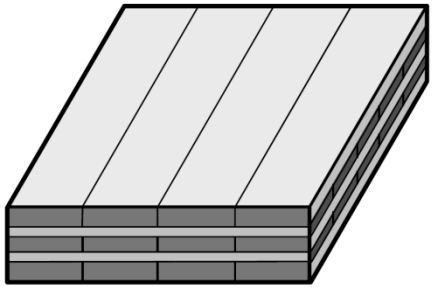
# LAYUP of CLT

- **symmetrical !** → if additional layers, **counteracting layers** recommended
- a layer can be of …
  - **single (finger jointed) boards** / lamellas with / without **relieves**
  - **single-layer panels** of boards or **EWP**s

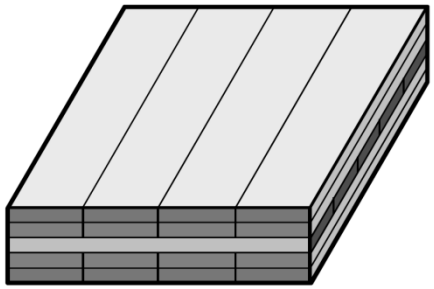
→ **double or triple layers** possible → resistance in bending, fire, …

→ **mechanical properties of the layer** shall be defined by the lowest quality of the used base material !

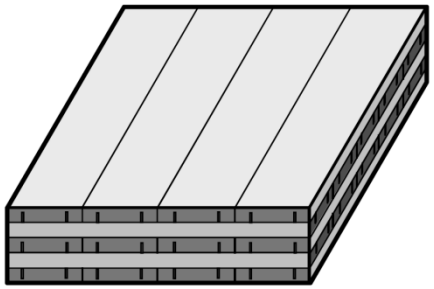
common layup



double outer layers



stress relieves



# Gaps between boards

- currently **top layers ≤ 2(3) mm**; **core layers ≤ 4(6) mm**
- some approvals allow gaps **≤ 10 mm!**

- **gaps** have a negative influence on …
  - **mechanical behaviour**, e. g. rolling shear
  - **building physics**, e. g. fire design, airborne sound, air tightness
  - **joining technique**, i. e. pin-shaped fasteners
  - **appearance** quality

➔ **AIM: minimising gaps !**

# Single-layer panels vs. single lamellas: PROS & CONS

**PROS** of single-layer panels

- gaps minimised
- lower requirements
  - $w_P/t_P \geq 4$ even when $w_B/t_P < 4$
  - surface bonding pressure
- building physics, joining technique, appearance

**CONS** of single-layer panels

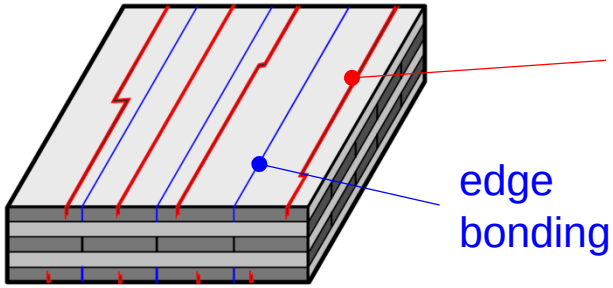
- **swelling / shrinkage !**

  → irregular pattern of cracks (appearance !)
  - reduced properties in building physics
  - relativization of $w_B/t_P < 4$

➔ **smaller gaps with thinner top layers !**

**edge bonded top layers**

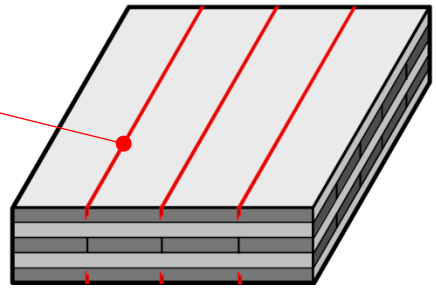
risk of irregular pattern of cracks




gaps

**top layers without edge bonding**

regular pattern of (shadow) cracks



# Single-layer panels: several possibilities

## edge bonding of boards / lamellas

- **strength / stiffness graded base material** continuously joined to endless plates by edge bonding; $w_B / t_P \geq 4$
- homogenisation of physical properties → **system effects**

## single-layer panels acc. to EN 13986

- $w_P / t_P \geq 4$; no specific requirements on the base material
  → adequate quality assurance for **classification / grading of the panels** required!
- no additional homogenisation effects; single-layer panels already homogenised!

## axial splitting of glulam

- $w_P / t_P \geq 4$; splitting of **homogeneous glulam**
- strength grading performed on base material for glulam invalid !
  → adequate quality assurance for **classification / grading of the panels** required!
- no additional homogenisation effects; single-layer panels already homogenised!

# Excursus: requirements on bonding pressure

➔ theoretically no bonding pressure required !

**minimum requirements** depending on …

- **surface quality** of adherends
  → flatness, roughness, warp, twist, …
  → **thickness tolerances ➔ ≤ (± 0.1 mm) recommended !**
- **adhesive system**
  → swelling (e.g. PUR) vs. shrinking adhesives (e.g. MUF)
  → „close contact“ (e.g. 1K-PUR) vs. gap-filling“ adhesives (e.g. MUF, 2K-PUR)
- **adhesive application system**: line-wise application common !
  → complete wetting required !
- **stiffness of adherends** against deflection (longitudinal & transverse) and torsion

# Excursus: requirements on bonding pressure

**upper limits** determined by the timber species

- **crushing of adherend's surfaces**
  → reduces penetration and resistances, e.g. in shear

## Conclusions for Norway spruce

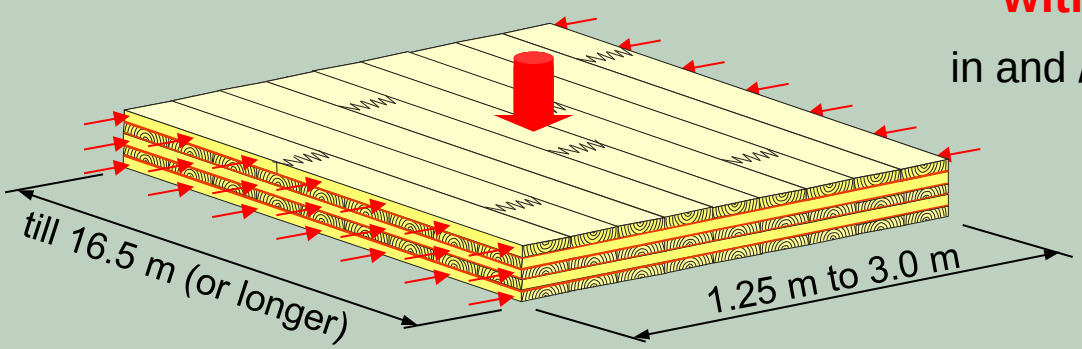
→ recommended to limit internal pressure to ≤ 1.0 N/mm²
(Baumann & Marian, 1961)

→ damage of cell structure and decrease in shear strength
at ≥ 0.40 N/mm² (radially) and ≥ 1.0 N/mm² (tangentially)
(Wassipaul, 1982)

**→ p ≤ (0.4 ÷ 0.6) N/mm² recommended !**

# Possibilities for surface bonding …

- **continuously by press facilities**
  - hydraulic (pneumatic) press (0.10 to 1.00) N/mm²
  - vacuum press (0.05 to 0.10) N/mm²
- **discontinuously by pin-shaped fasteners**
  - pressing with screws, nails or brackets (0.01 to 0.20) N/mm²

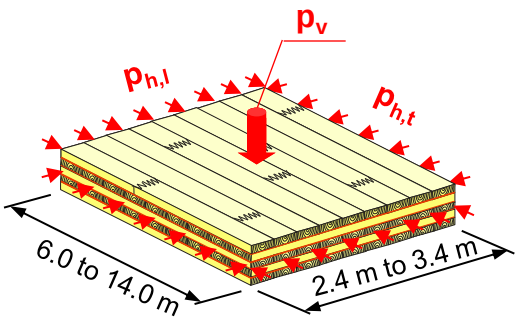



**with / without transverse pressure**

in and / or across the direction of production

# Examples of hydraulic press facilities …

| | | **MINDA** "CLT press" (G) | **Kallesoe** "CLT press" (DK) |
|---|---|---|---|
| CLT dimensions | | l = (**6.0 to 18.0**) m<br>w = (**2.1 to 3.5**) m<br>t = (**70 to 400**) mm | l = (**4.0 to 20.0**) m<br>w = (**2.2 to 3.2**) m<br>t = (**60 to 400**) mm |
| type of press system | | hydraulic, continuous | hydraulic, discontinuous<br>high frequency press |
| bonding pressure | vertical, $\mathbf{p_v}$ | (**0.4 to 0.6** (0.8)) N/mm² | **≤ 1.0** N/mm² |
| | horizontal transverse, $\mathbf{p_{h,t}}$ | 10 kN/m | available |
| | horizontal lengthwise, $\mathbf{p_{h,l}}$ | 45 kN | available |





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Schickhofer G (2012) Presentation, Edinburgh, Scotland, 30th October 2012; adapted

# Further CLT-press producers …

SPRINGER (AT) | LEISSE (G) | LEDINEK (SLO) | WEINIG GROUP (G) | WOODTEC Fankhauser (vacuum press) (CH) | SORMEC (IT) | …

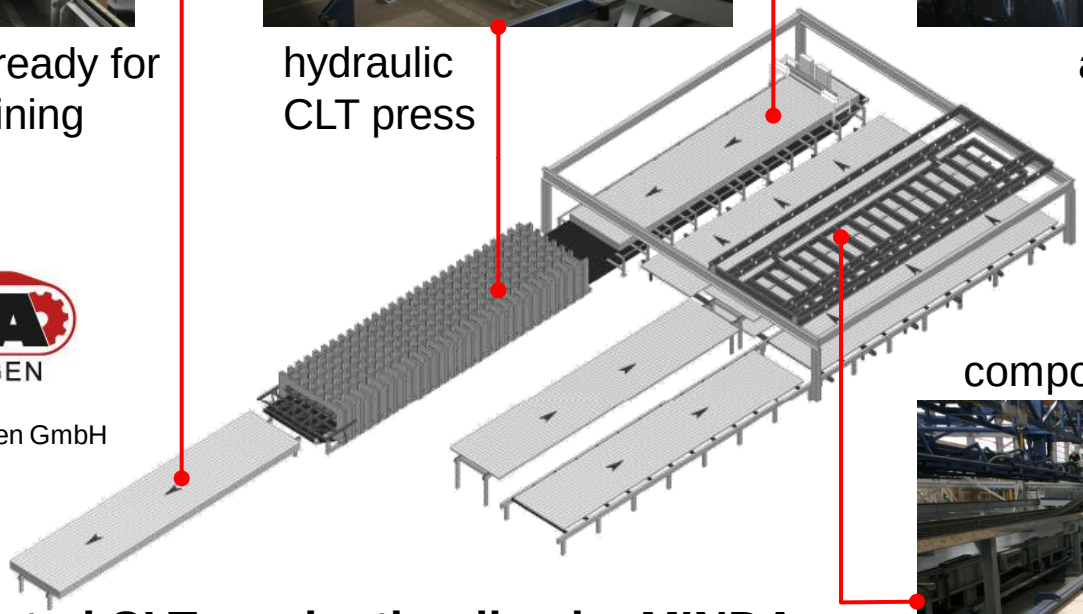
# Latest developments …

- **modular production lines**, e.g. MINDA
  - BASIC 1 hydraulic press & manual feeding 2 to 3 press cycles / shift
  - STEP I 1 hydraulic press & automated feeding 5 to 6 press cycles / shift
  - STEP II 2 hydraulic press & automated feeding 10 to 12 press cycles / shift
- **flexible production lines**
  - CLT composed of loose boards / lamellas
  - CLT composed of single-layer panels
  - CLT including door & window openings
    - adapted adhesive application system
    - discretely adapted surface pressure
- **high frequency CLT press**

CLT element ready for cutting and joining

hydraulic CLT press

adhesive application next layer stand-by



MINDA INDUSTRIEANLAGEN



cross layers composing & compressing

**fully automated CLT production line by MINDA**

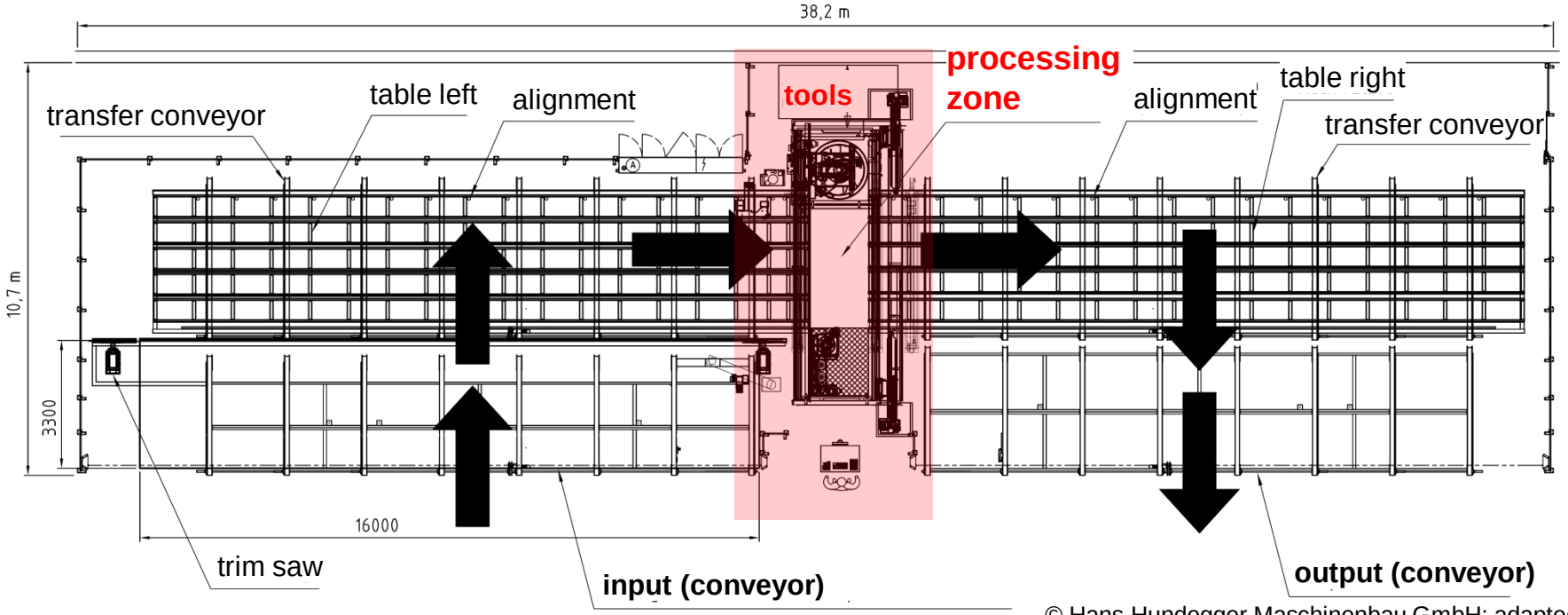
- CLT production of single lamellas
- ≤ 14 press cycles / shift; 1K-PUR (Purbond)
- ≈ 20 TSD m³ / shift / year

Schickhofer G (2011) Presentation, Zurich, Switzerland, 25th October 2011; adapted

# CNC cutting and joining ➔ customising !

→ cutting | trimming | joining | milling (e.g. for connection technique)

**portal processing centre „PBA-drive“** | Hans Hundegger Maschinenbau GmbH






- **“throughfeed processing” on all surfaces and edges**
- element dimensions: **l = (2.5 to 16.0) m | w = (0.625 to 4.0) m | t ≤ 350 mm**

## processing zone

**„PBA-drive“**

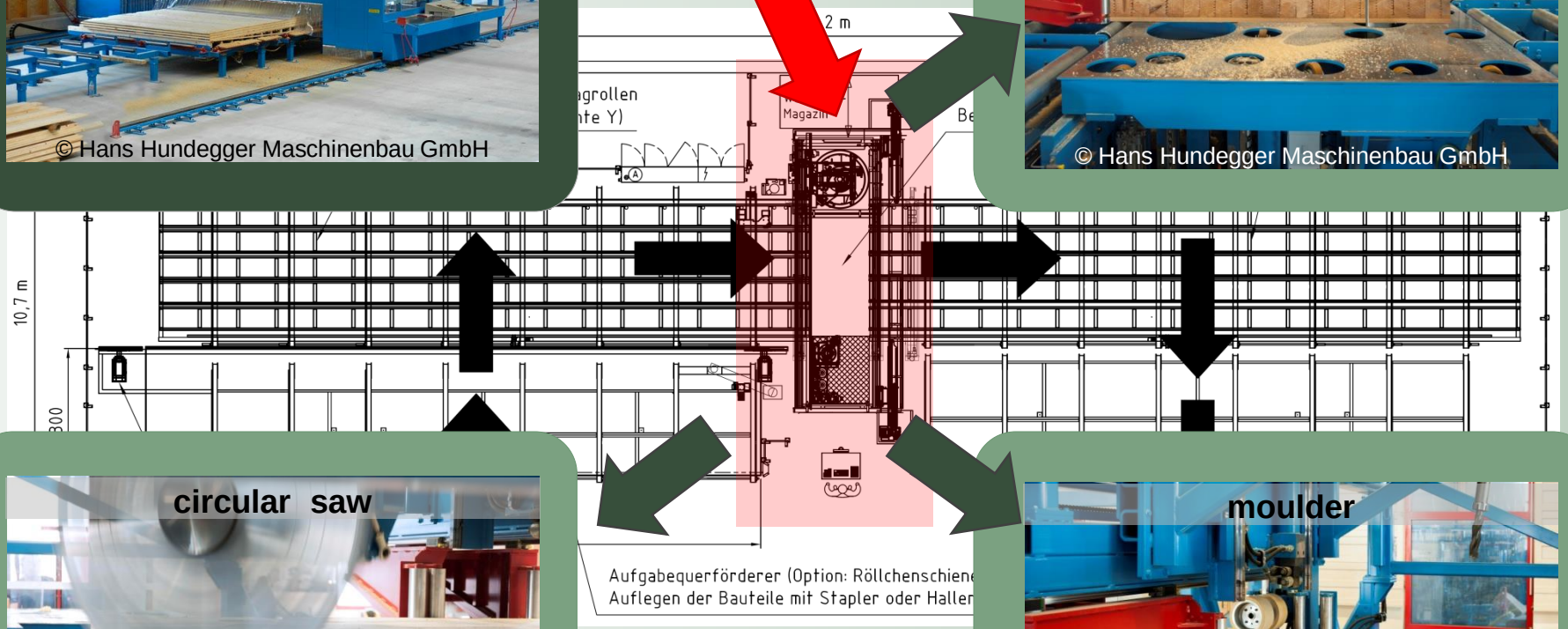
Hans Hundegger Maschinenbau GmbH

### portal processing centre


© Hans Hundegger Maschinenbau GmbH

### chain saw

© Hans Hundegger Maschinenbau GmbH




### circular saw

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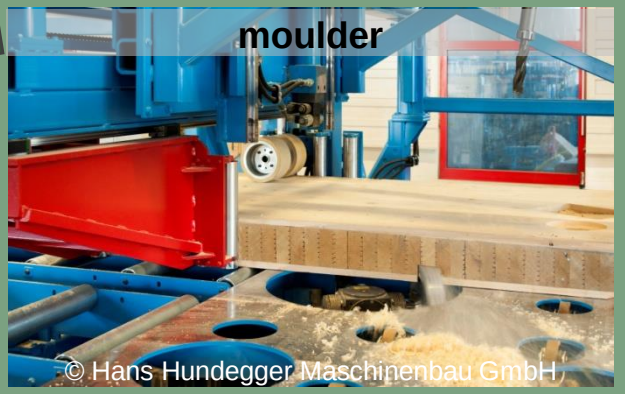
### moulder



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Hundegger
Innovationen für den Holzbau

Schickhofer G (2012) Presentation, Edinburgh, Scotland, 30th October 2012; adapted

# Transport & Assembling …


storage (production site)


charging and transport


discharging (building site)


assembling of roof elements


assembling of ceiling elements


assembling of wall elements

Schickhofer G (2012) Presentation, Edinburgh, Scotland, 30th October 2012, adapted