Production and Technology of Cross Laminated Timber (CLT): A state-of-the-art Report

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CLT Training Course
in the frame of COST Action FP1004
University of Trento, 15th April 2014, Trento | Italy

CONTENT

- Introduction
- Production
- FPC Requirements
- Customising
- Conclusions

CONTENT

Cross Laminated Timber (CLT) is a …

- **plate-like engineering timber product**, composed of an uneven number of crosswise layers → locking effect
- **2D & 1D product** for load bearing in-plane and out-of-plane & as linear member
- used for **large-sized wall and floor elements**, …, and for linear structural components

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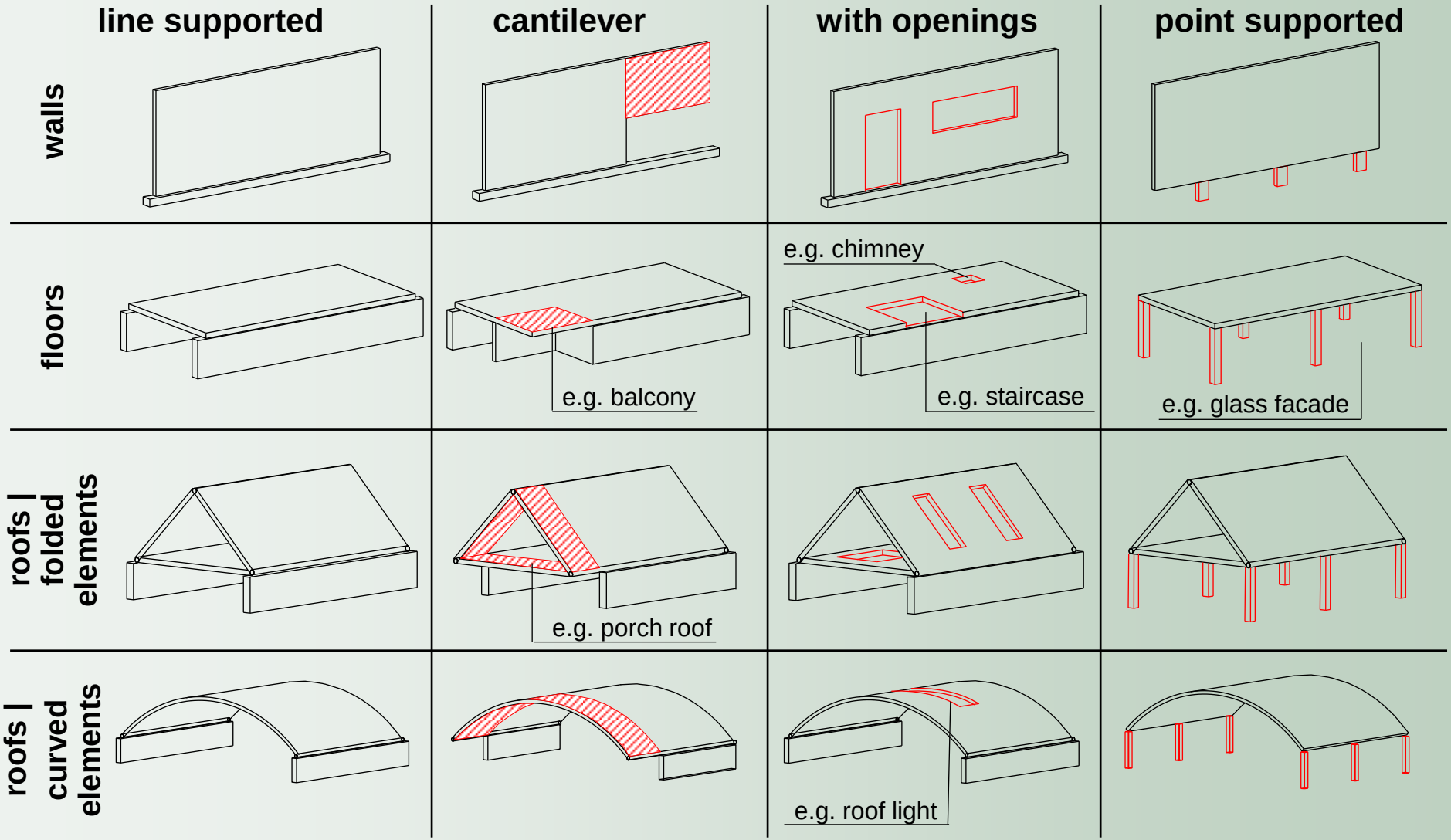
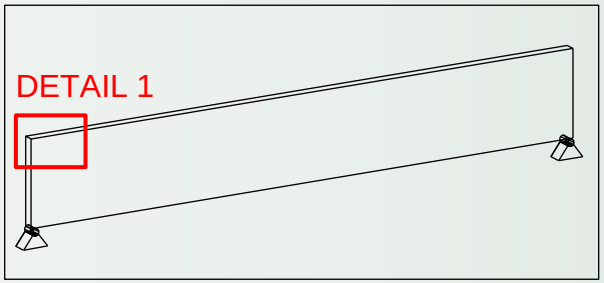
Cross Laminated Timber (CLT) as 2D-Element …

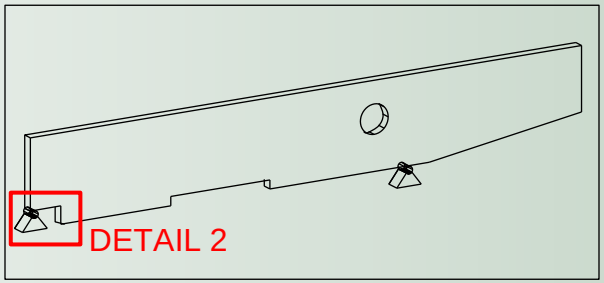


Schickhofer G (2012) Presentation, Edinburgh, Scotland, 30th October 2012; adapted

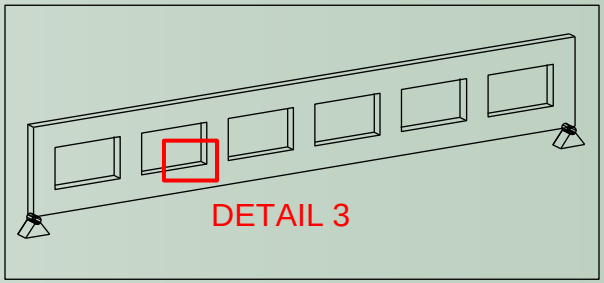
Cross Laminated Timber (CLT) as 1D-Element …



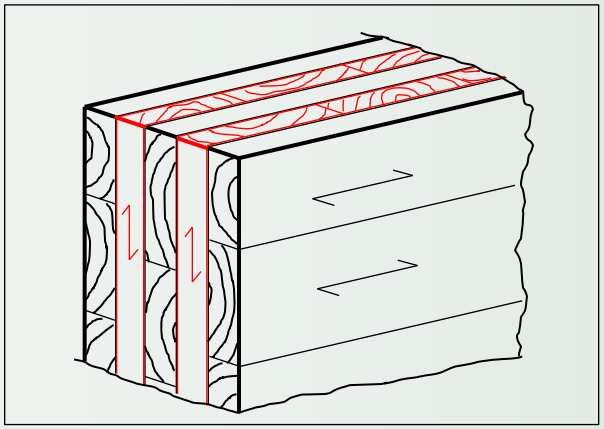
girder without openings



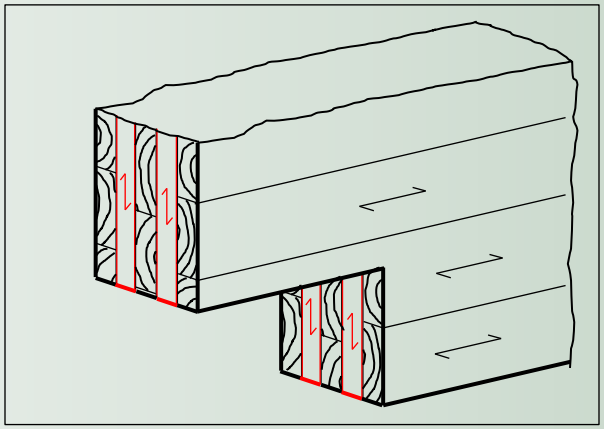
tapered girder with notched support and openings



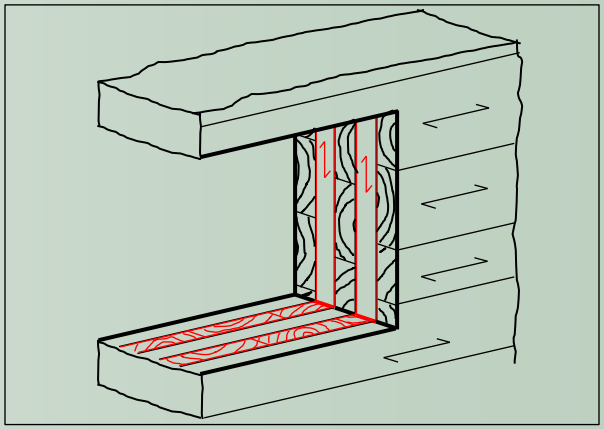
Vierendeel girder



detail 1: 5-layered CLT-element



detail 2: notched support



detail 3: opening

→ **cross-layers as reinforcement**

→ **increases resistance in shear and tension perp. to grain!**

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

Cross Laminated Timber (CLT) …

- **opens new dimensions in timber engineering**
  (e.g. monolithic buildings)
  - high degree and accuracy in pre-fabrication
  - dry and clean construction sites
  - short erection times
- **in comparison to light-weight timber structures …**
  - clear separation of load bearing, insulation & installation layers
  - building physics: air permeability, specific storage capacity (humidity, temp.)
  - independence of a modular dimension for window / door openings & fastening of furniture
- **substitute for reinforced concrete, brick, …**

➔ **SOLID TIMBER CONSTRUCTION TECHNIQUE IN CLT !**

Development of CLT production volume – internationally

- 2013 more than 35 production sites worldwide
- currently roughly 95 % of the production volume in Central Europa
  - Austria (~ 63 %)
  - Germany (~ 26 %)
  - Switzerland (~ 6 %)
- **550 Tsd. m³ production volume 2013**

➔ **need for standardisation!**

- production & testing
- design & joining
- construction

➔ **prEN 16351**

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- **Production**
- FPC Requirements
- Customising
- Conclusions

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)

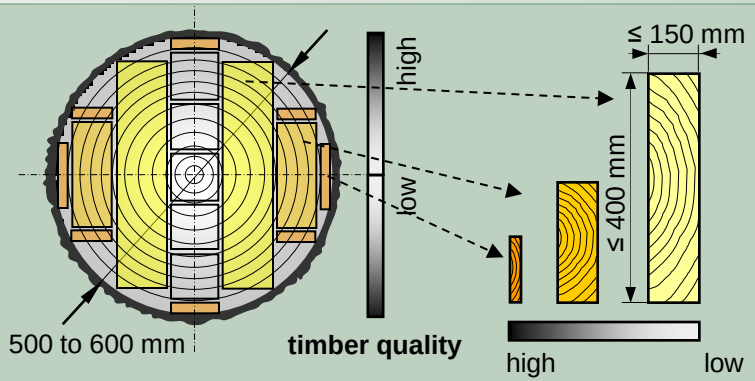
RIGID composite

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

FOCUS: CLT as rigid composite product !

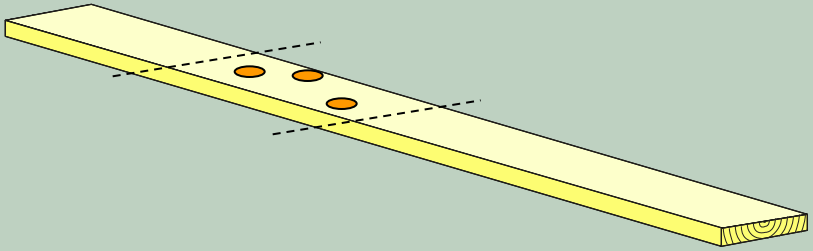
STEPs — intermediate products | steps in production

STEP I
log



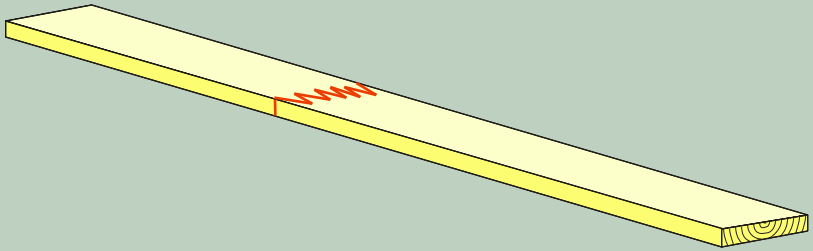
breakdown

STEP II
board



classification / grading
trimming

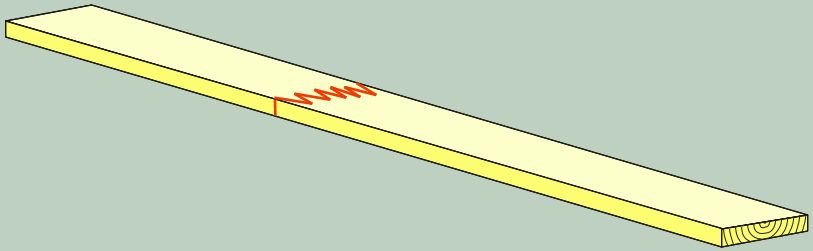
STEP III
finger jointed lamella



finger jointing

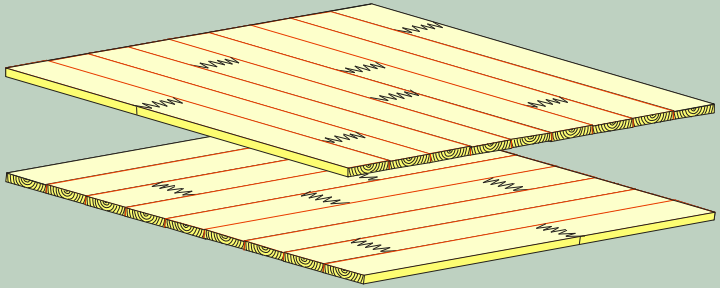
STEPs intermediate products | steps in production

STEP III
finger jointed lamella



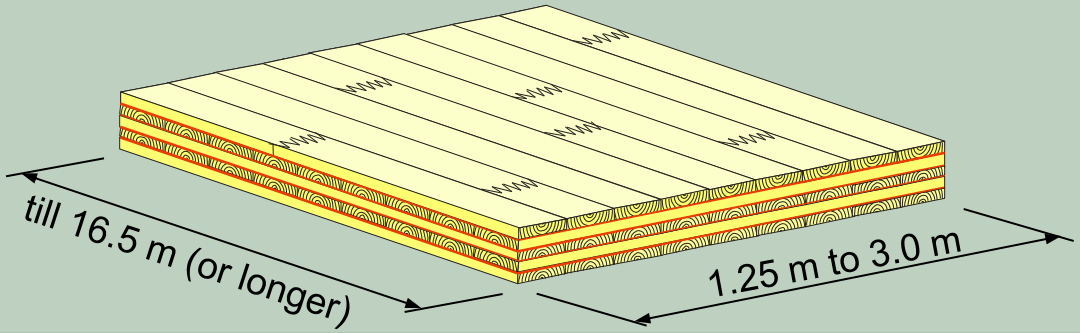
finger jointing

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 FINGER JOINTS …

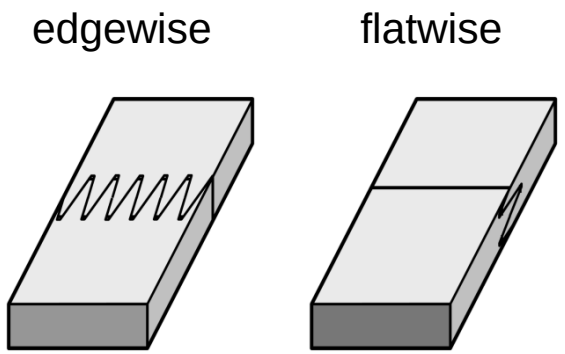
- economical approach for joining graded board segments longitudinally !
- position of finger joints …
  - **edgewise** (common in GLT)
  - **flatwise** (higher appearance quality)
- production & FPC regulations **EN 385**, **DIN 1052**, **prEN 16351**
- common adhesives: **MUF**, **1K-PUR**

- **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) %



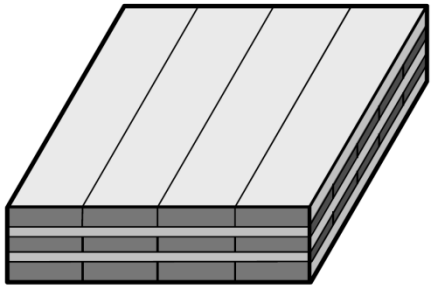
LAYUP of CLT

- **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

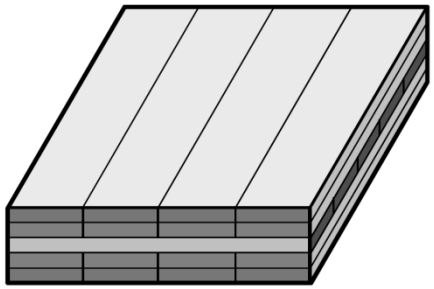
→ **double or triple layers** possible → resistance in bending, fire, …

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

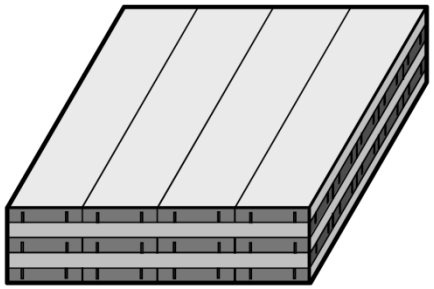
common layup



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 …
  - **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

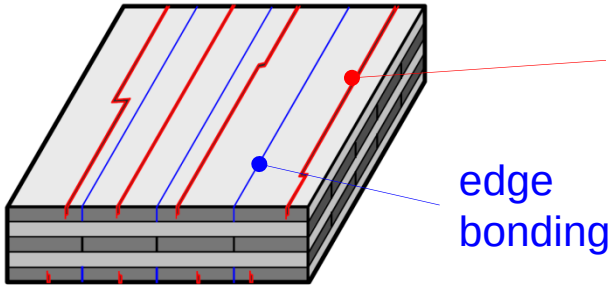
- **swelling / shrinkage !**

  → 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

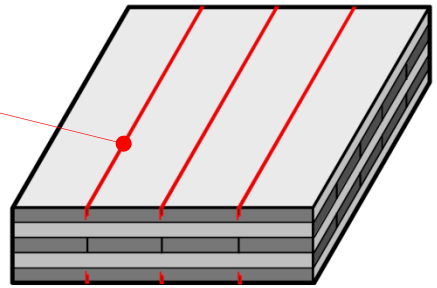
risk of irregular pattern of cracks



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

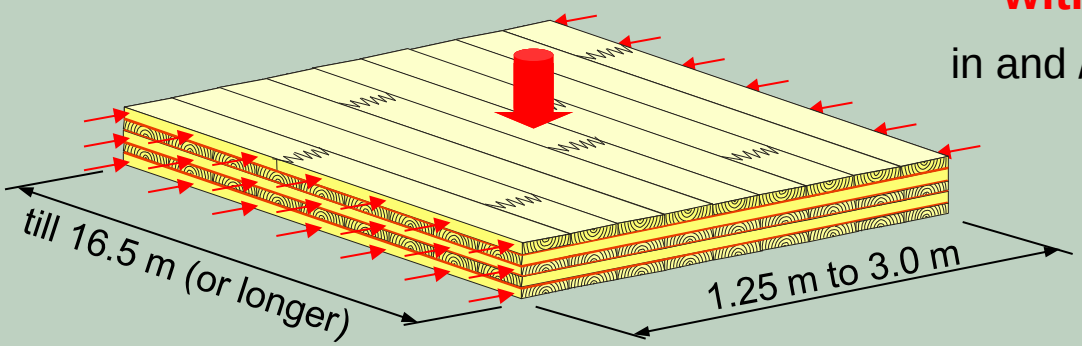
→ recommended to limit internal pressure to ≤ 1.0 N/mm²
(Baumann & Marian, 1961)

→ 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 to 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

PROS	CONS

Bracket, nail or screw pressing

small productions | minor investments | primary manual production

- curved, shaped CLT elements
- on-site bonding
- limited bonding pressure
- damage of tools by fasteners

Vacuum press equipment

medium productions | medium investments | semi-mechanical production

- curved, shaped CLT or composite elements (box-beams or rib floors)
- limited bonding pressure
- stress relieves
- limited layer thickness and/or species

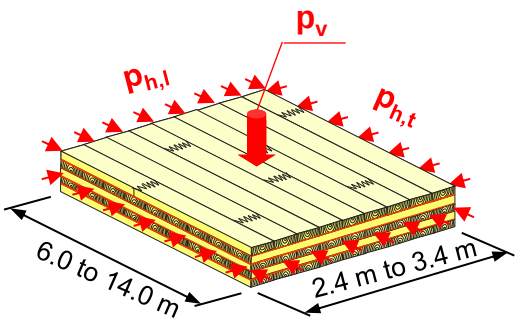
Hydraulic (pneumatic) press equipment

medium to large productions | high investments | semi-mech. to automated production

- flexibility in bonding pressure
- specific edge pressure possible
- flexibility in automation
- restricted to even, straight elements
- limited possibility to balance local unevenness or thickness deviations

Examples of hydraulic press facilities …

		MINDA "CLT press" (G)	**Kallesoe** "CLT press" (DK)
CLT dimensions		l = (**6.0 to 18.0**) m w = (**2.1 to 3.5**) m t = (**70 to 400**) mm	l = (**4.0 to 20.0**) m w = (**2.2 to 3.2**) m t = (**60 to 400**) mm
type of press system		hydraulic, continuous	hydraulic, discontinuous 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

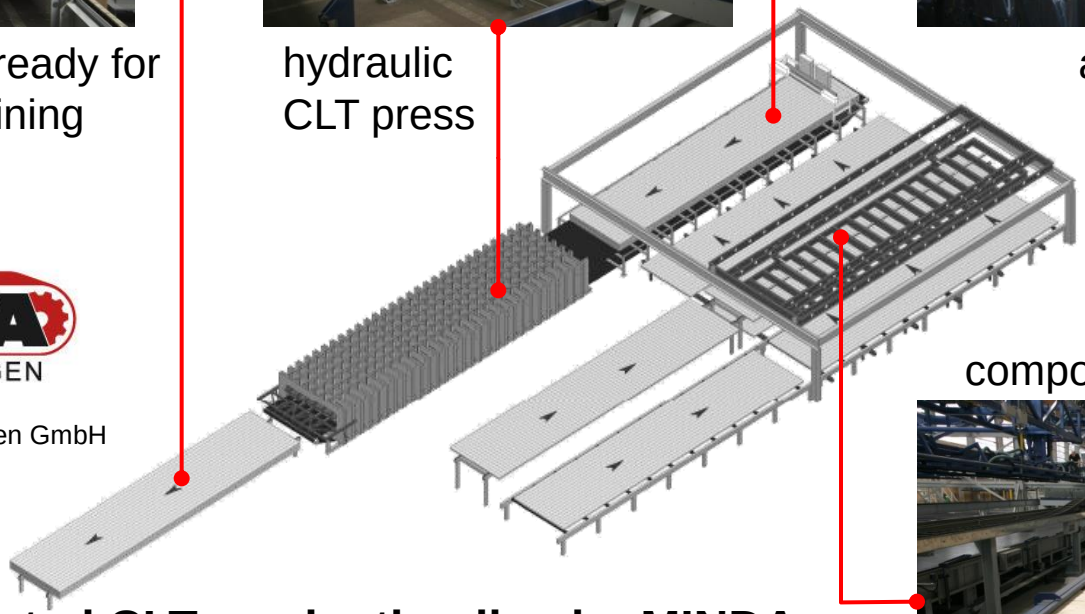
  } adapted adhesive application system; discretely adapted surface pressure
- **high frequency CLT press**

PRODUCTION: fully automatic CLT production line

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

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- **FPC Requirements**
- Customising
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Factory production control (FPC): excerpt (prEN 16351)

- **climatic conditions** during production

  → min. requirements on temperature and rel. humidity!

- control of **adhesives**

  → appropriateness: type I; load bearing

- control of **base material** (grading; strength class)

  → following EN 14081-1

  → ≤ 10 % of base material per layer may be ≤ 35 % below the declared strengths parallel to grain

- **finger joint** strength

  → min. requirements | testing in bending or tension II

Factory production control (FPC): excerpt (prEN 16351)

- **large finger joint** strength
  - → min. requirements | bending test acc. to EN 408
  - → „gap-filling" adhesives (e.g. MUF: $t_{glue\ line} \leq 0.5$ mm, 1K-PUR: $t_{glue\ line} \leq 0.3$ mm)
  - → $f_{m,LFJ,k} \geq 0.75 \cdot f_{m,B,k}$ (German approvals)

- **edge bonding**
  - → min. requirements | testing in block shear
  - → testing of bond-line thickness
  - → shear strength requirements related to share of wood fracture (WF)

	average value			single value		
f_v [N/mm²]	6.0	8.0	≥ 11.0	4.0 to 6.0	6.0	≥ 10.0
WF [%]	≥ 90 %	≥ 72 %	≥ 45 %	100 %	≥ 74 %	≥ 20 %

Factory production control (FPC): excerpt (prEN 16351)

- **surface bonding**

  → delamination tests

  → specific climatic conditions (submerged + vacuum + pressure + drying)

  → **delamination**

  $delam_{max} = l_{max,delam} / l_{glue\ line} \leq 40\ \%$

  $delam_{tot} = l_{tot,delam} / l_{tot,glue\ line} \leq 10\ \%$

  } if not fulfilled

  $A_{delam,max} \leq 50\ \% \mid A_{delam,mean} \leq 30\ \%$

Excursus: surface bonding | specifications & tests

- **surface pressure** (SP; 3 levels)
- **climatic cycles** (CC; 3 levels)
- **climate varied weekly**
  u = 12 % to 17 %
- 5 tests **rolling shear** &
  10 tests **delamination**
- **1K PUR**

Excursus: surface bonding | results & discussion

➔ $CV[A_{delam,max}] << CV[delam_{max}]$

→ $A_{delam,max}$ more stable !

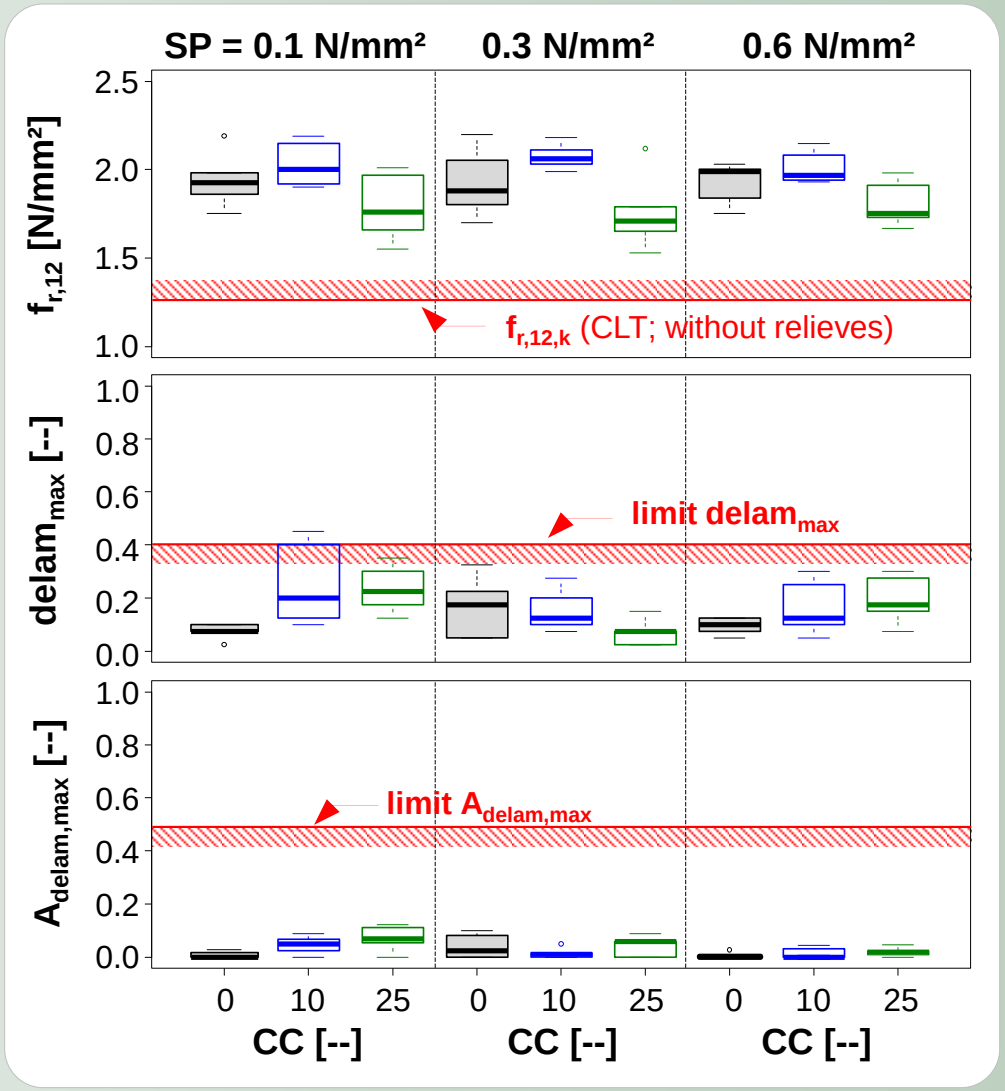
➔ delamination result vs. real expositions

→ missing link !

→ limits base on experience !

➔ delaminated bond lines & delaminated surfaces

→ combined judgement !



Factory production control (FPC): excerpt (prEN 16351)

- **bond-line thickness**

  → for aminoplast- and phenoplast-adhesives:

  $t_{bond\ line,max}$ = 0.6 mm for combined application of resin & hardener

  $t_{bond\ line,max}$ = 0.3 mm for separate application of resin & hardener

  → for 1K PUR $t_{bond\ line,max}$ = 0.3 mm

- **rolling shear** strength of CLT elements (German approvals)

  → bending test acc. to EN 408, $l_{span} \geq 15 \cdot t_{CLT}$ ($\geq 12 \cdot t_{CLT}$ proposed !)

- **additional requirements**

  → e.g. timber species, durability of base material, preservative treatments, fire resistance, dimensions, assembly, release of formaldehyde and other harmful agents

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- **Customising**
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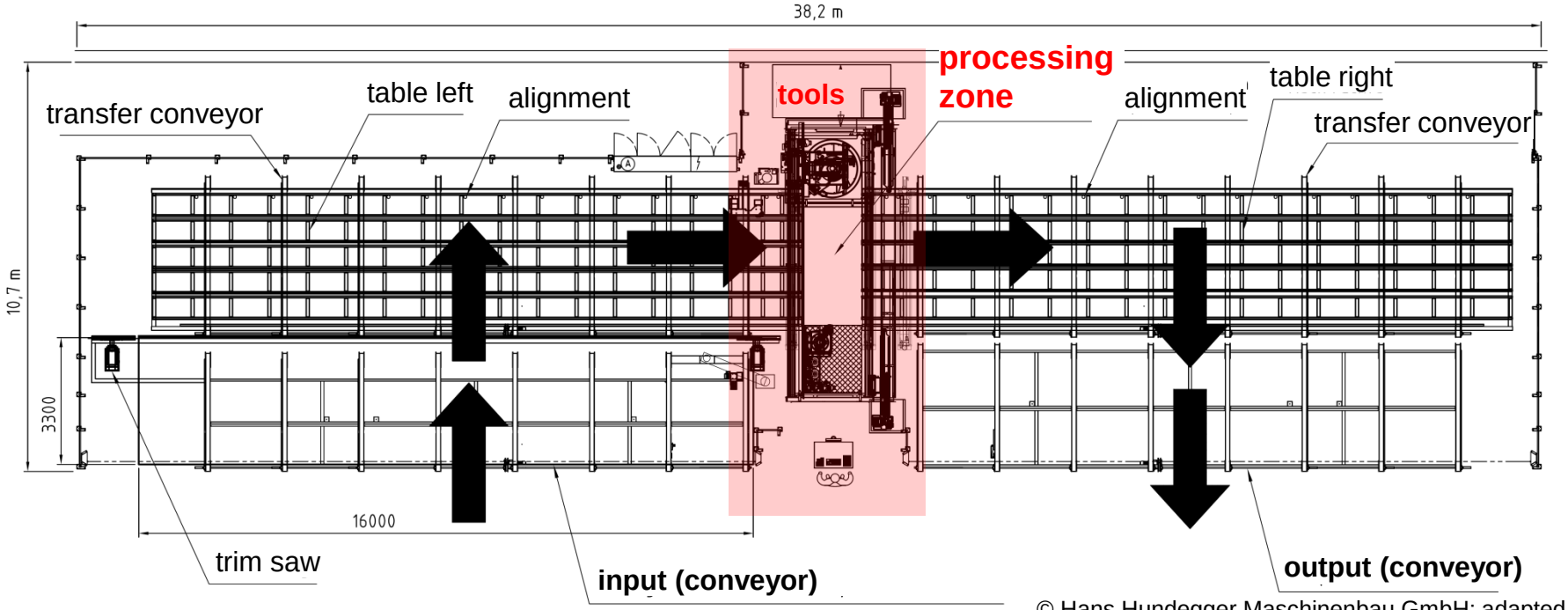
CNC cutting and joining ➔ customising !

→ 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**

CUTTING & JOINING: processing centre

processing zone

„PBA-drive“

Hans Hundegger Maschinenbau GmbH

portal processing centre

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chain saw

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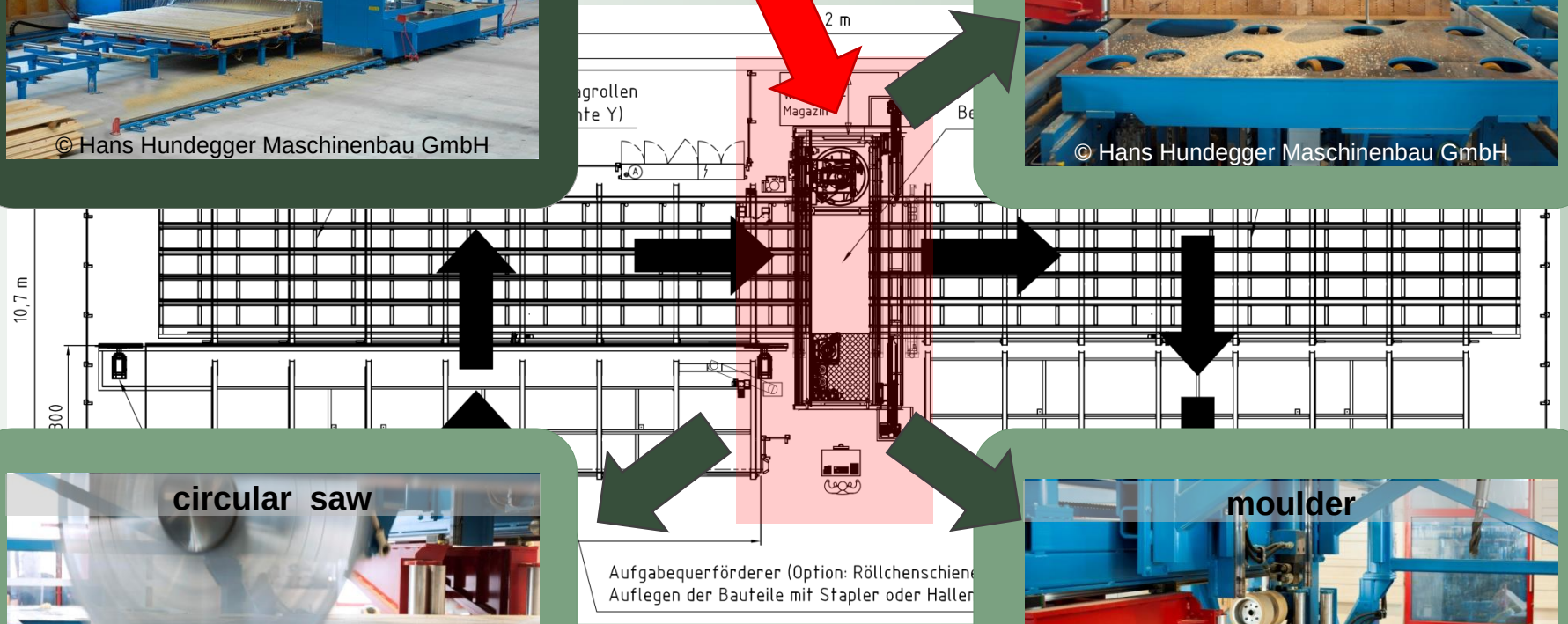

circular saw

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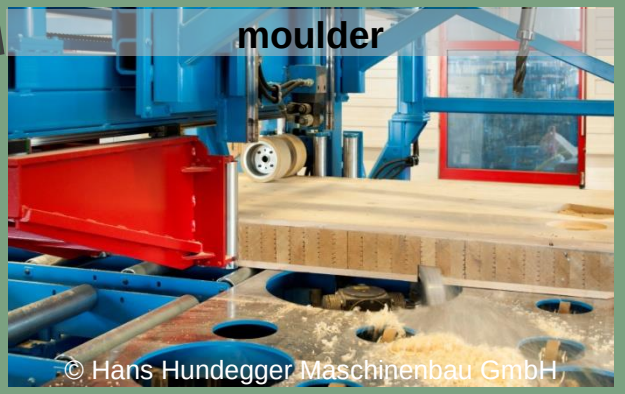
moulder



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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

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- Customising
- **Conclusions**

Concluding remarks | outlook …

- **further standardisation and harmonisation required !**

  → prEN 16351; t_L = 20, 30, 40 mm; …

- aim on **reducing gap width** solved by latest press systems (3D pressure)

- some **machine manufacturers** provide **licences** for CLT production

Concluding remarks | outlook …

- **vertical extension** of CLT production lines
  - **assembling stations** for composing whole wall and floor elements, including insulation, installation, doors and windows
- **horizontal extension**
  - **establishment of own / close cooperation with engineering offices**

- **further establishment and densification of small and medium scale CLT productions**
  - → added value regionally
  - → CLT produced of locally available **timber species**

Concluding remarks | outlook …

- **renaissance of timber in our cities !**

  ➔ CLT as increasing **competitor of mineral building products** multi-storey buildings → exceeding the boarder of high-rise buildings

  ➔ development of **building systems** **„Solid Timber Construction Technique with CLT“**

  ➔ **ATTENTION !** Peculiarities of timber as building material e.g. vulnerability in context with **moisture** !

MANY THANKS !

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THANK YOU FOR YOUR ATTENTION !

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