Lecture #2 – Structural Wood Products & Systems

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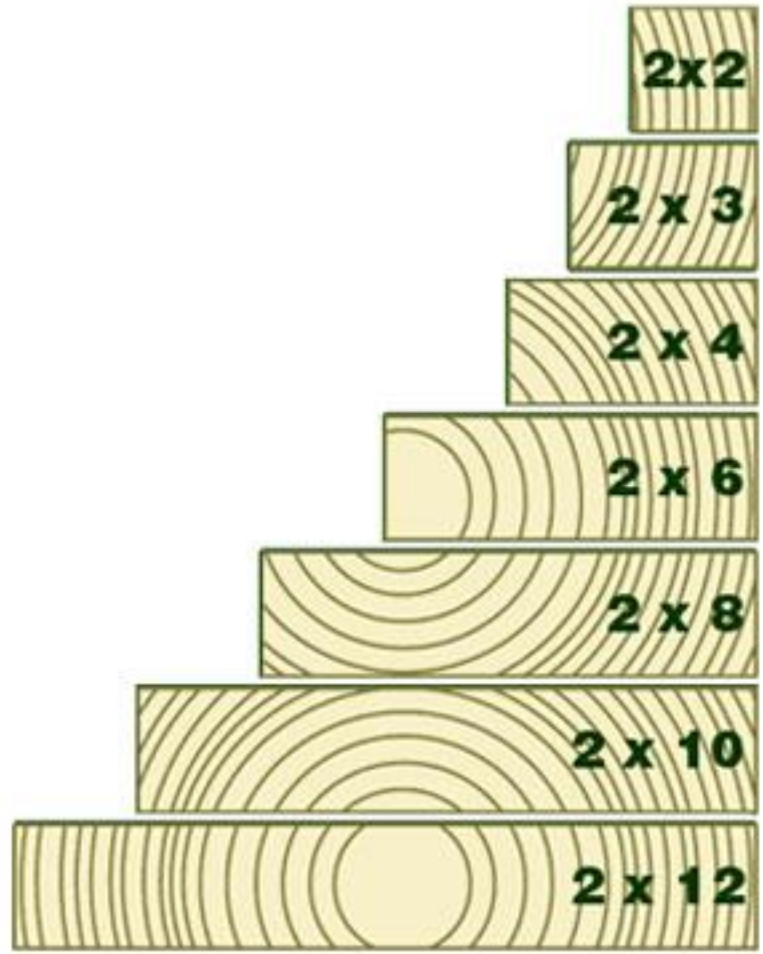
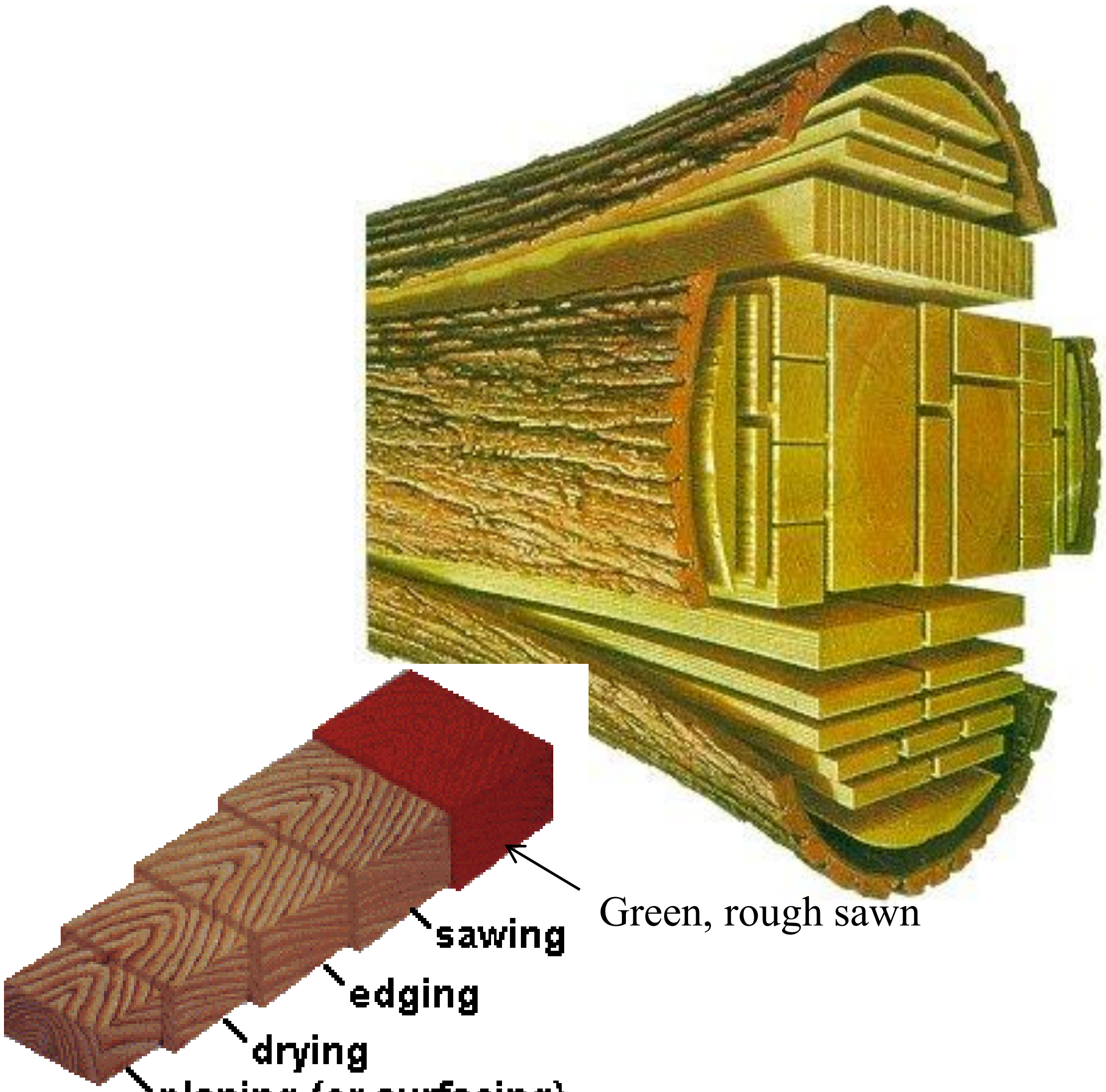
Part I - Structural Wood Products

- Sawn lumber
- Structural panel products
- Engineered wood products (EWP)

Sawn lumber for construction



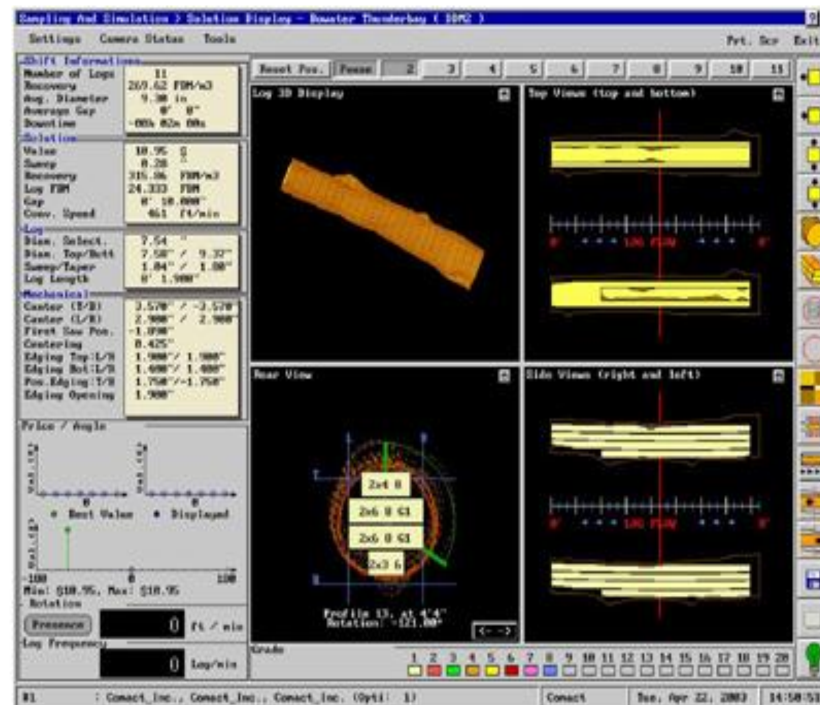
Dimension lumber – Manufacturing process



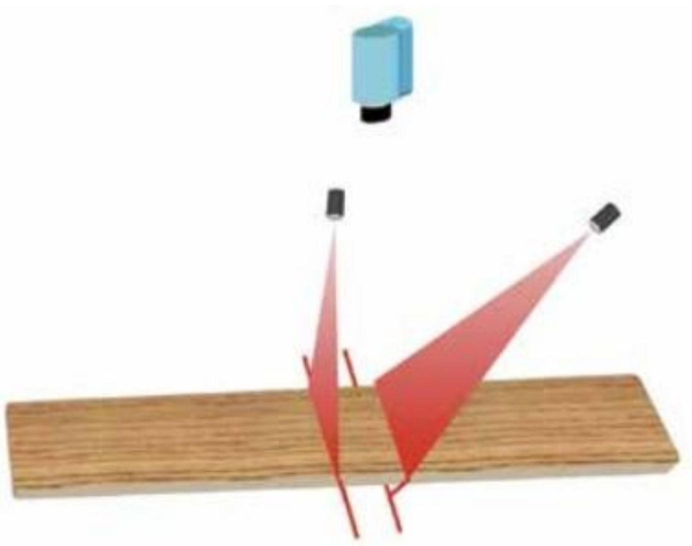
Log
↓
Debarking
↓
Log conversion
↓
Edging
↓
End trimming
↓
Drying
↓
Planing
↓
Grading

Advanced Lumber Production System – scanning machine

Use of advanced scanning system for log
– determine the best way to saw a log

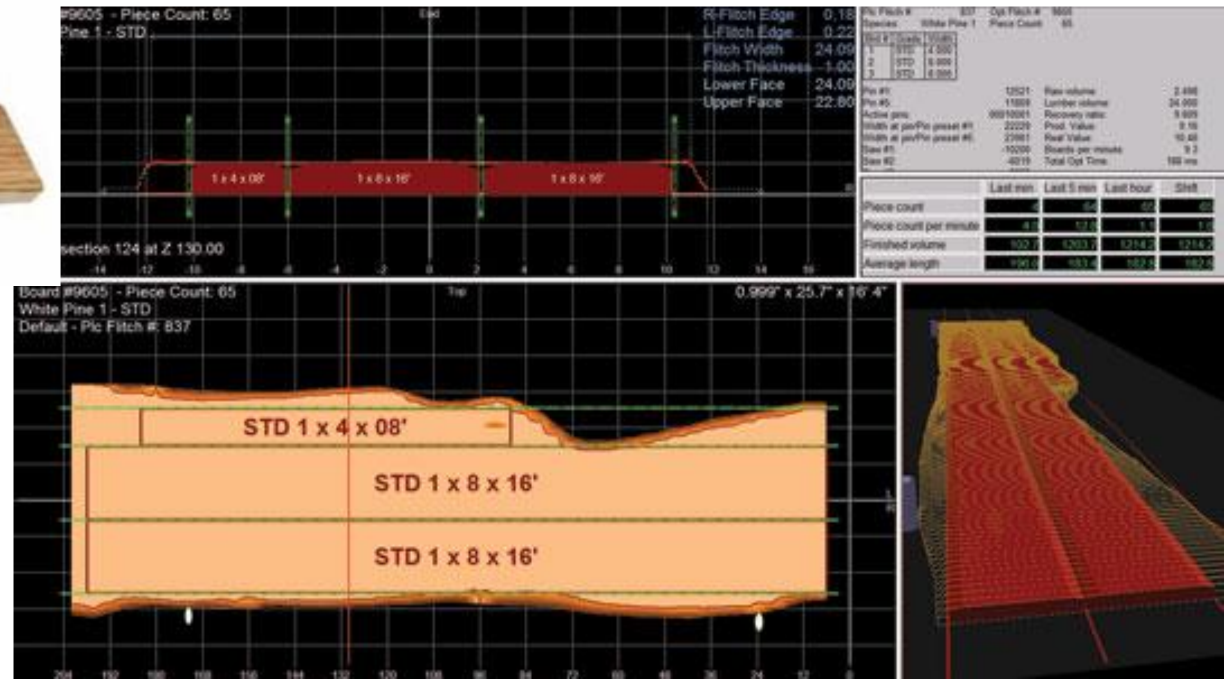


Advanced Lumber Production System – scanning machine



Use of scanning system for edging and trimming of lumber

Trimming



Edging

Sizes for lumber products

A 2x4 is not exactly 2” x 4”!!

Table A.10. American Standard lumber sizes for stress-graded and nonstress-graded lumber for construction

Item	Thickness: Nominal	Thickness: Minimum dressed, Dry	Thickness: Minimum dressed, Green	Face width: Nominal	Face width: Minimum dressed, Dry	Face width: Minimum dressed, Green
			(in.)			
Boards	1	3/4	25/32	2	1 1/2	1 9/16
	1 1/4	1	1 1/32	3	2 1/2	2 9/16
	1 1/2	1 1/4	1 9/32	4	3 1/2	3 9/16
				5	4 1/2	4 5/8
				6	5 1/2	5 5/8
				7	6 1/2	6 5/8
				8	7 1/4	7 1/2
				9	8 1/4	8 1/2
				10	9 1/4	9 1/2
				11	10 1/4	10 1/2
				12	11 1/4	11 1/2
				14	13 1/4	13 1/2
				16	15 1/4	15 1/2
Dimension	2	1 1/2	1 9/16	2	1 1/2	1 9/16
	2 1/2	2	2 1/16	3	2 1/2	2 9/16
	3	2 1/2	2 9/16	4	3 1/2	3 9/16
	3 1/2	3	3 1/16	5	4 1/2	4 5/8
	4	3 1/2	3 9/16	6	5 1/2	5 5/8
	4 1/2	4	4 1/16	8	7 1/4	7 1/2
				10	9 1/4	9 1/2
				12	11 1/4	11 1/2
				14	13 1/4	13 1/2
				16	15 1/4	15 1/2
Timbers	5 and greater		1/2 less than nominal	5 and greater		1/2 less than nominal

½” smaller

½” smaller

3/4” smaller

Note: Nominal sizes in the table are used for convenience. No inference should be drawn that they represent actual sizes.

Lumber species groups

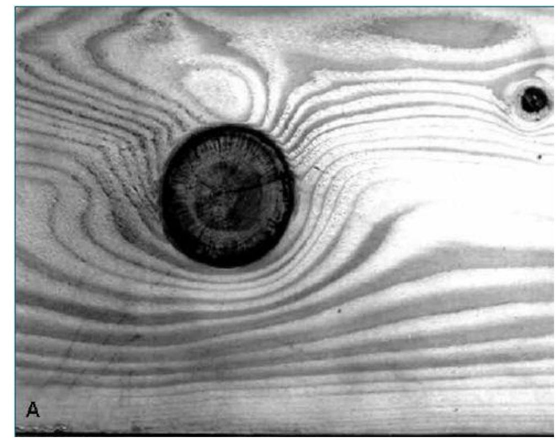
- Canadian structural lumber is marketed under 4 main species groups

Table 6.2.1.2
Species combinations

Species combinations	Stamp identification	Species included in the combination
Douglas Fir-Larch	D Fir-L (N)	Douglas fir, western larch
Hem-Fir	Hem-Fir (N)	Pacific coast hemlock, amabilis fir
Spruce-Pine-Fir	S-P-F	Spruce (all species except coast Sitka spruce), Jack pine, lodgepole pine, balsam fir, alpine fir
Northern Species	North Species	Any Canadian species graded in accordance with the NLGA rules

Natural defects in lumber

- Clear and straight grain wood is the strongest and presence of defects reduces strength
- Knots
  - distortion of the fibres around the knot, resulting in cross grain and stress concentration
  - Primarily reduce bending and tensile strength
- End splits and checks
  - Result of drying
  - Primarily reduces shear strength

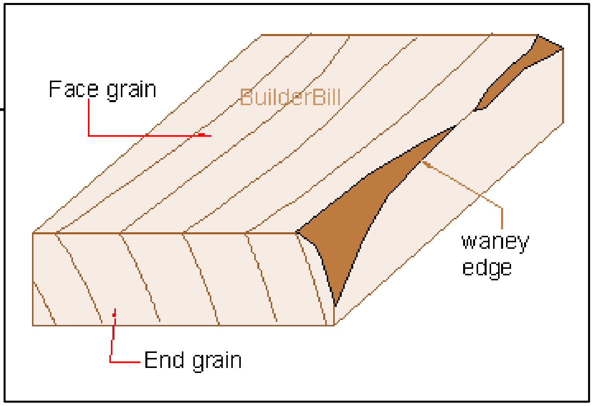


Structural Strength Grading

- Process by which wood product is classified into strength categories (i.e. grades)
- Building code requires that lumber and timber be graded
- Two processes:
  - **Visual grading** – visual inspection of the number and size of natural defects
  - **Machine grading** (Machine-stress rating or MSR) – measurement of strength prediction properties by a machine

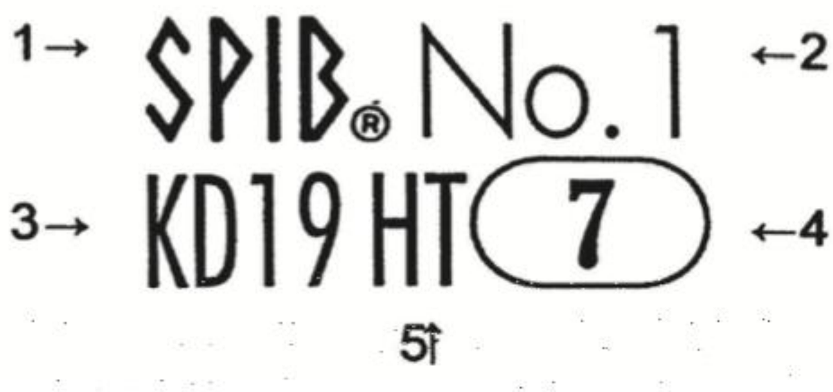
Visual grading process

- Key characteristics used :
  - size and location of knots
  - slope of grain
  - wane
  - size of shakes, splits and checks
- Used to be performed by humans, now vision scanning machines



Visual grade stamp

1. Registered Trademark (Grading agency)
2. Grade of Lumber
3. Moisture Content
4. Mill Identification Number
5. Heat Treatment for Pest Pasteurization

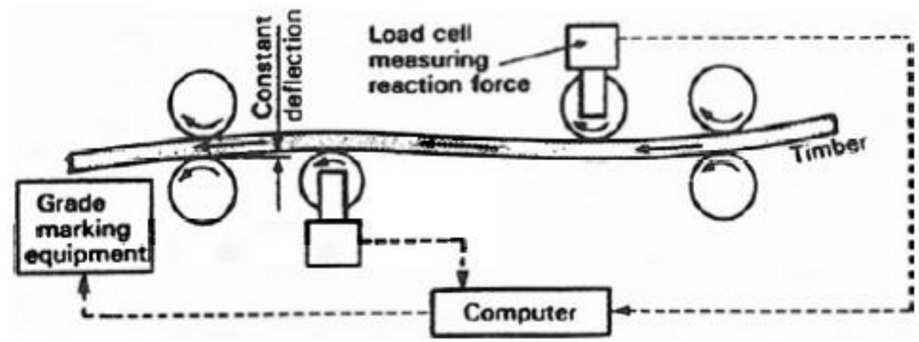


3. KD (Kiln Dried): MC ≤ 19% (on average 15%)
5. HT: Heat treated at 56° C for 30 min minimum to eradicate eggs of bugs and inserts

Machine grading

- Machine to measure a non-destructive property that correlates well with strength

e.g. Modulus of elasticity and density



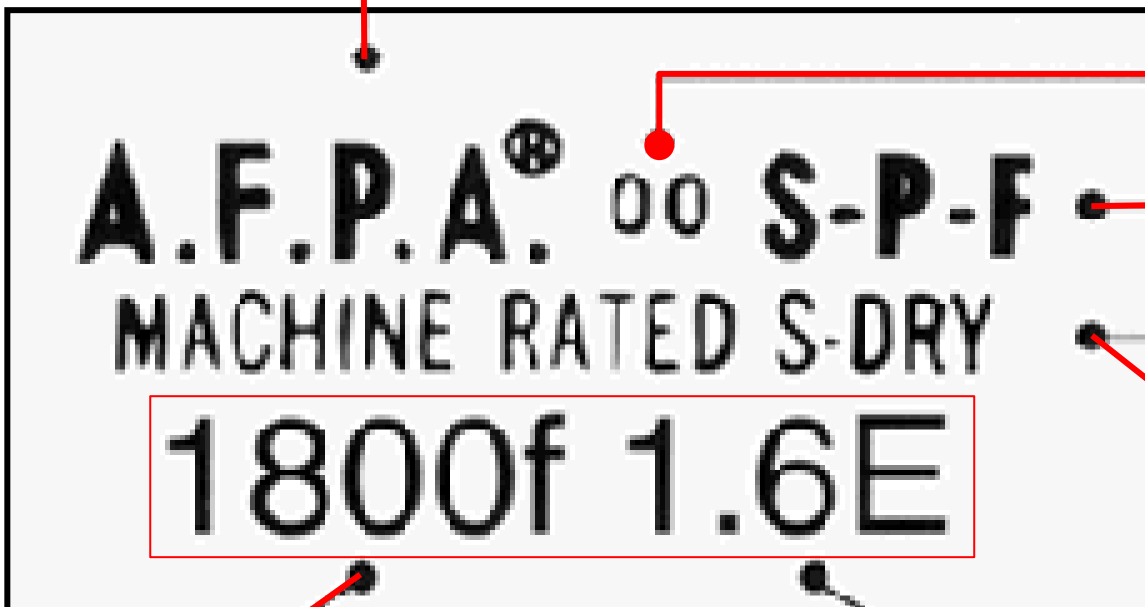
Bending-type grading machine

Picture of a grading machine

Machine Grade Stamp

Grading agency

- Alberta Forest Products Association)



Mill number

Species group

Moisture condition

– Surface dry

Machine grade

-1800 is bending design property in psi

- 1.6E is MOE in million psi

Comparison between visual and machine grading

- **Machine grading (MSR)**
  - Each piece is tested mechanically and qc requires strength testing
  - Faster
  - Can select grades with higher design properties
  - Expensive
- **Visual grading**
  - No mechanical testing
  - Slower process
  - Grading rules are set – rigid system
  - More cost-effective

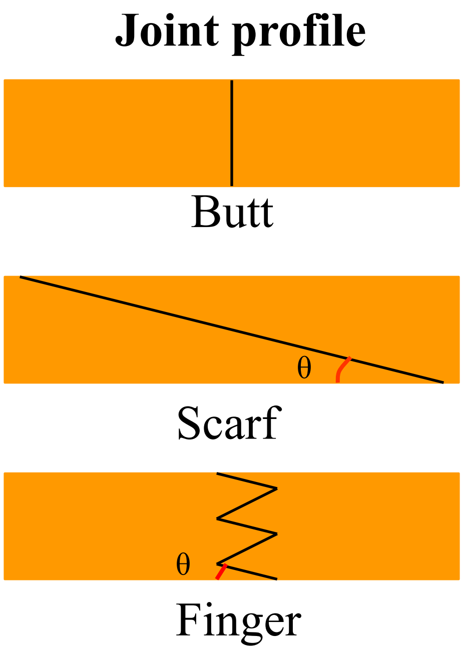
Kiln-drying of lumber

- Lumber used in building construction must have MC ≤19%
- Wet lumber can cause problems in service
  - Lower mechanical properties
  - Shrinkage may cause warping and twisting
  - Potential of mould growth and decay
  - Heavier leading to high shipping cost
- Even kiln-dried lumber (MC 15% - 19%) **will** dry in service (EMC 8% - 12%)

Large dry kiln

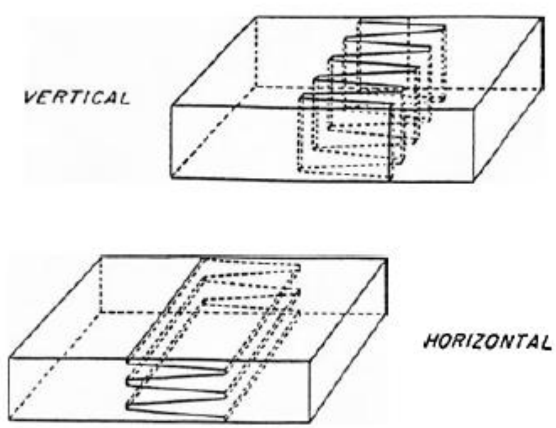
Finger-joined lumber

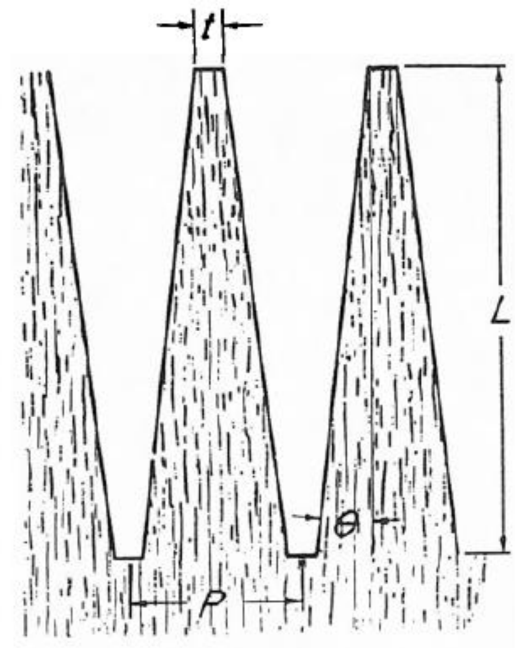
- End grain (butt) joints are weak in tension
- When bond line is sloped, applied force is partly resisted by shear
- Allows short blocks to be end-joined to produce longer, more useful lumber
- Tensile strength can be 80-90% of unjointed wood



Finger joint characteristics

- Finger joint strength is influenced by slope, length and tip width of finger profile
  - Increases with slope (θ)
  - Sharper tip (t) provides higher strength
  - Increases with length (L)





Applications of finger-joined lumber

- Used interchangeably with regular lumber i.e. finger joint is ignored in grading
  - Defects such as knot have bigger impact on strength than finger joints
- A major use is as stud (minimum twisting and warping)
- Wood I-joist flanges
- Laminations in glulam and CLT

https://youtu.be/Bxr96hqBtyw

Structural Panel Products

Plywood – construction sheathing

Plywood

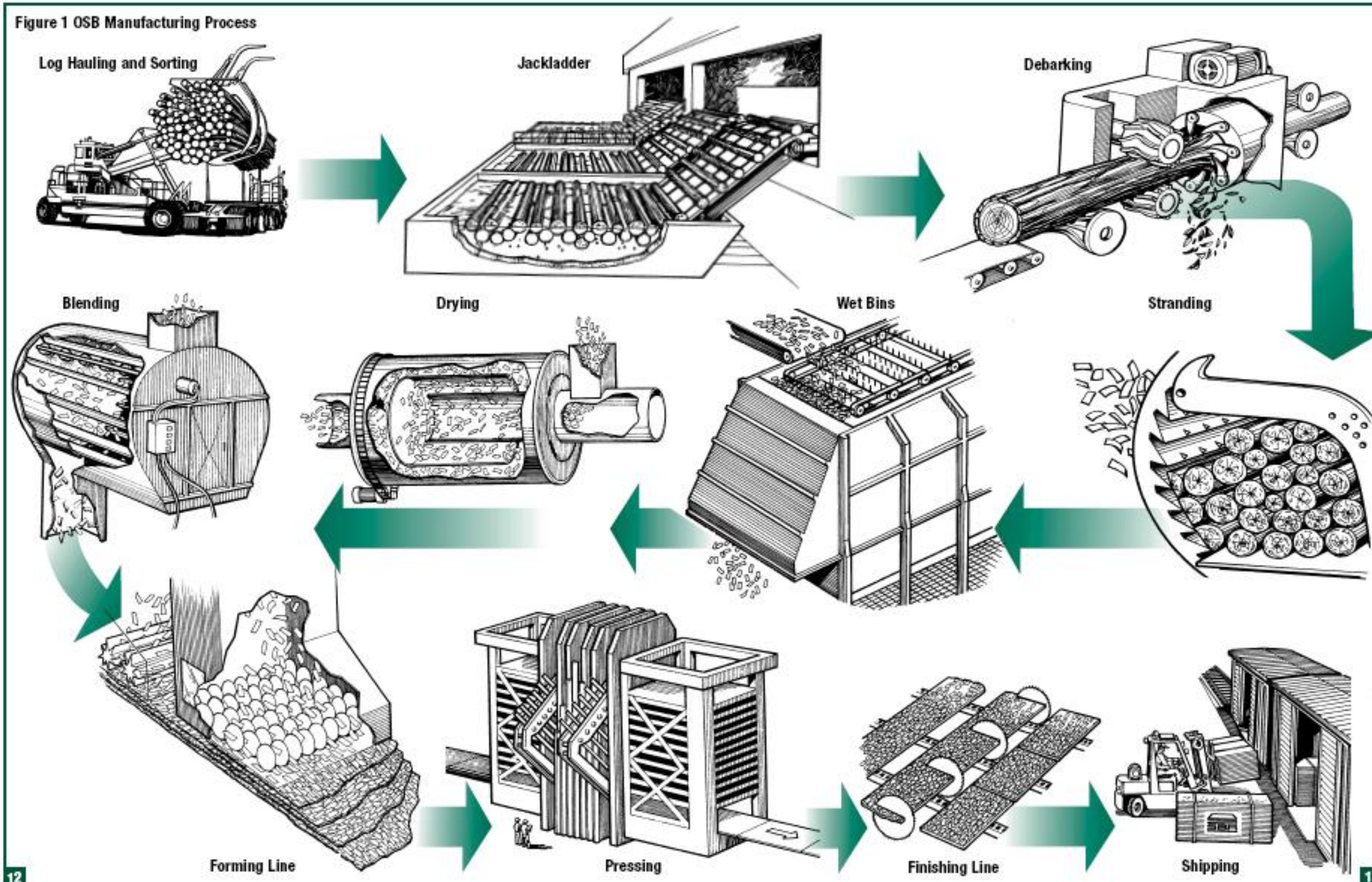
Oriented Strand Board (OSB) –
construction sheathing, I-joist web

Oriented strand board (OSB)

Panel products not intended for structural applications:

- Particleboard – furniture
- Medium density fiberboard (MDF) – furniture, millwork, moulding

OSB

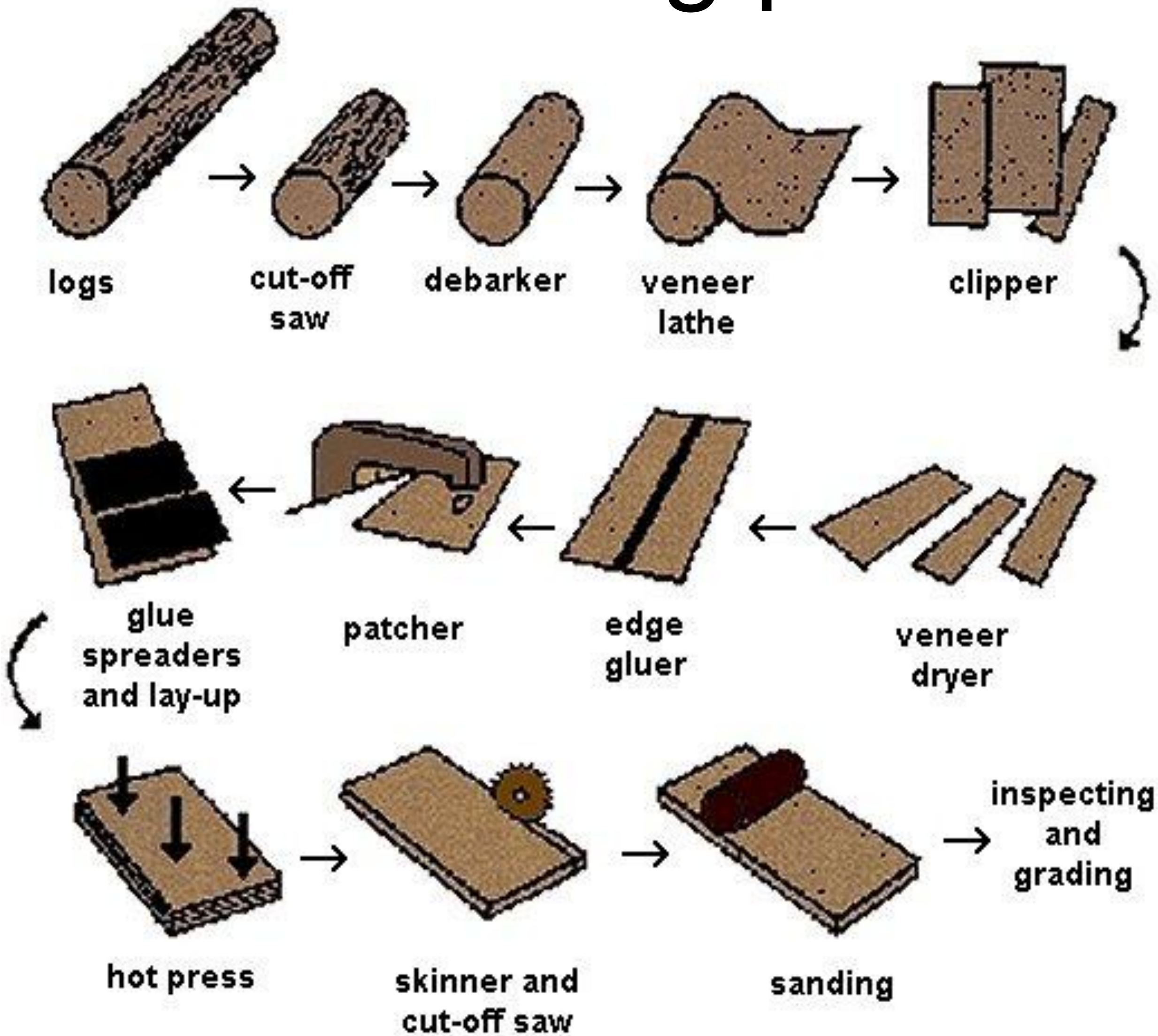


https://youtu.be/kz2_xIV-3Es

Plywood

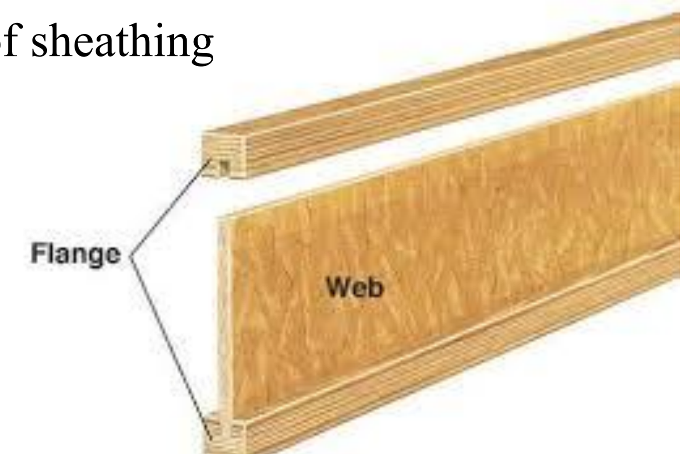
- Thin veneers that are cross-laminated for strength, stiffness and dimensional stability.

Manufacturing process

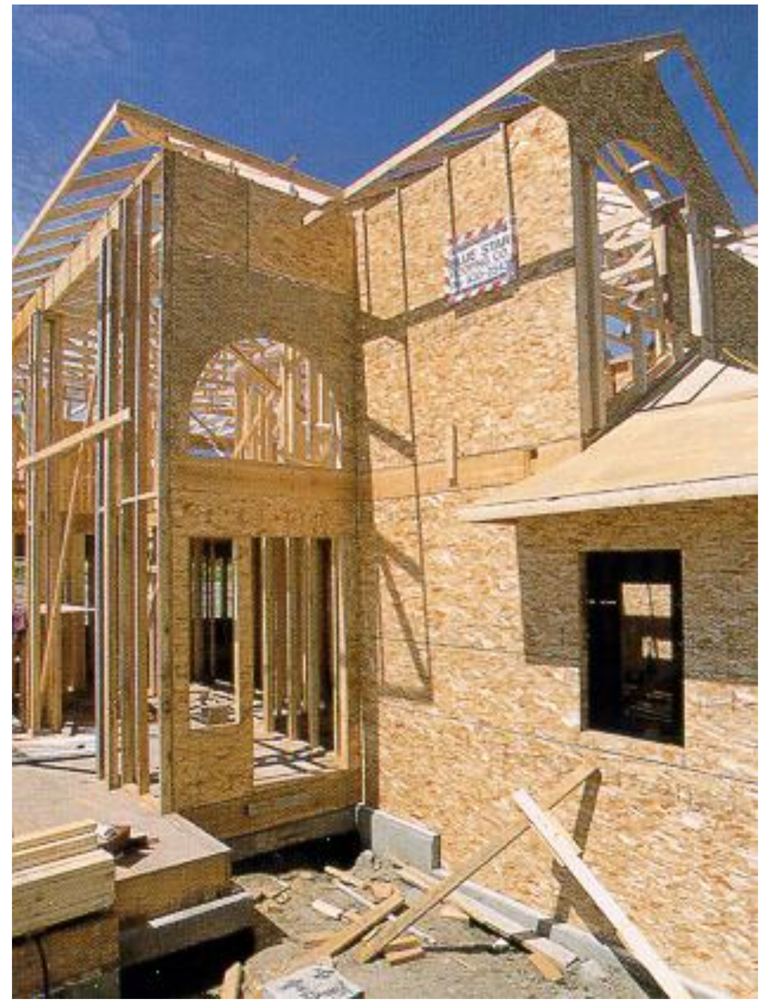


Applications

Floor / Roof sheathing



Web in wood I-joist



Wall sheathing

Comparison between plywood and OSB

- Mechanical properties are similar - OSB tends to have higher shear strength
- OSB swells more than plywood in thickness
- OSB mechanical properties are more affected by moisture than plywood
- OSB is for **dry use** only, whereas plywood can be used in wet applications
- Density : 550 - 650 kg/m^3 for OSB, 450 – 500 kgm^3 for plywood (heavier to handle)

Engineered Wood Products

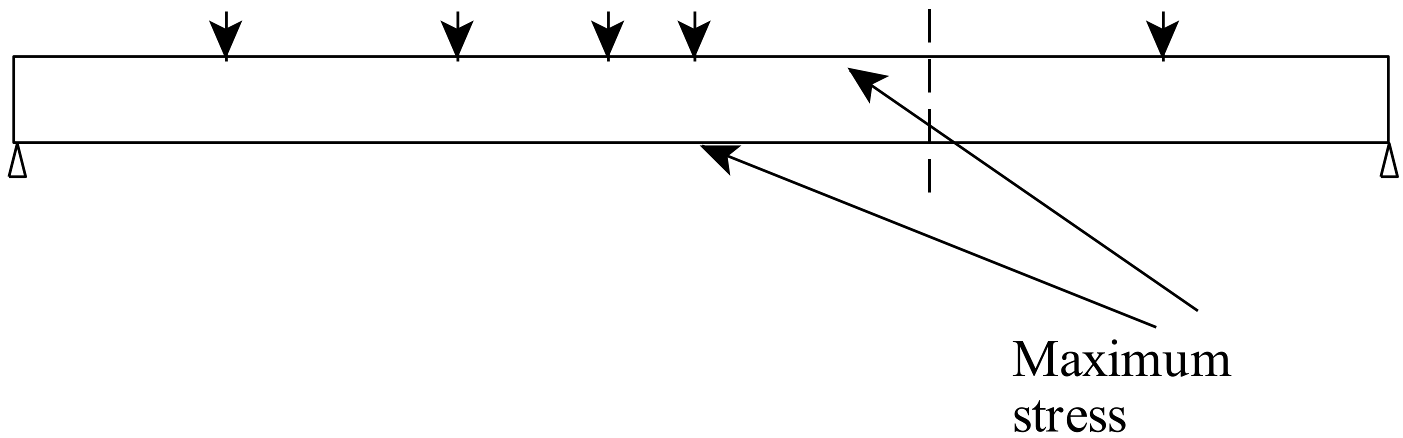
Engineered Wood Products (EWP)

- Glued-laminated timber (glulam)
- Wood I-joist
- Structural composite lumber (SCL)
  - Laminated veneer lumber (LVL)
  - Parallel strand lumber (PSL)
  - Oriented strand lumber (OSL)
  - Laminated strand lumber (LSL)
- Cross laminated timber (CLT)
- Other mass timber panels
  - NLT, GLT and DLT

Characteristics of Product Engineering Process

- Stronger materials are located at most stressed zones
- Large defects are removed and defect sizes are minimized
- Use of glue strengthens product
- Use of heat and pressure for some products improves mechanical properties (densification)
- Drier materials lead to a more stable product

Product Engineering Process



In beams, maximum stresses are at the outer edges

Product Engineering Process

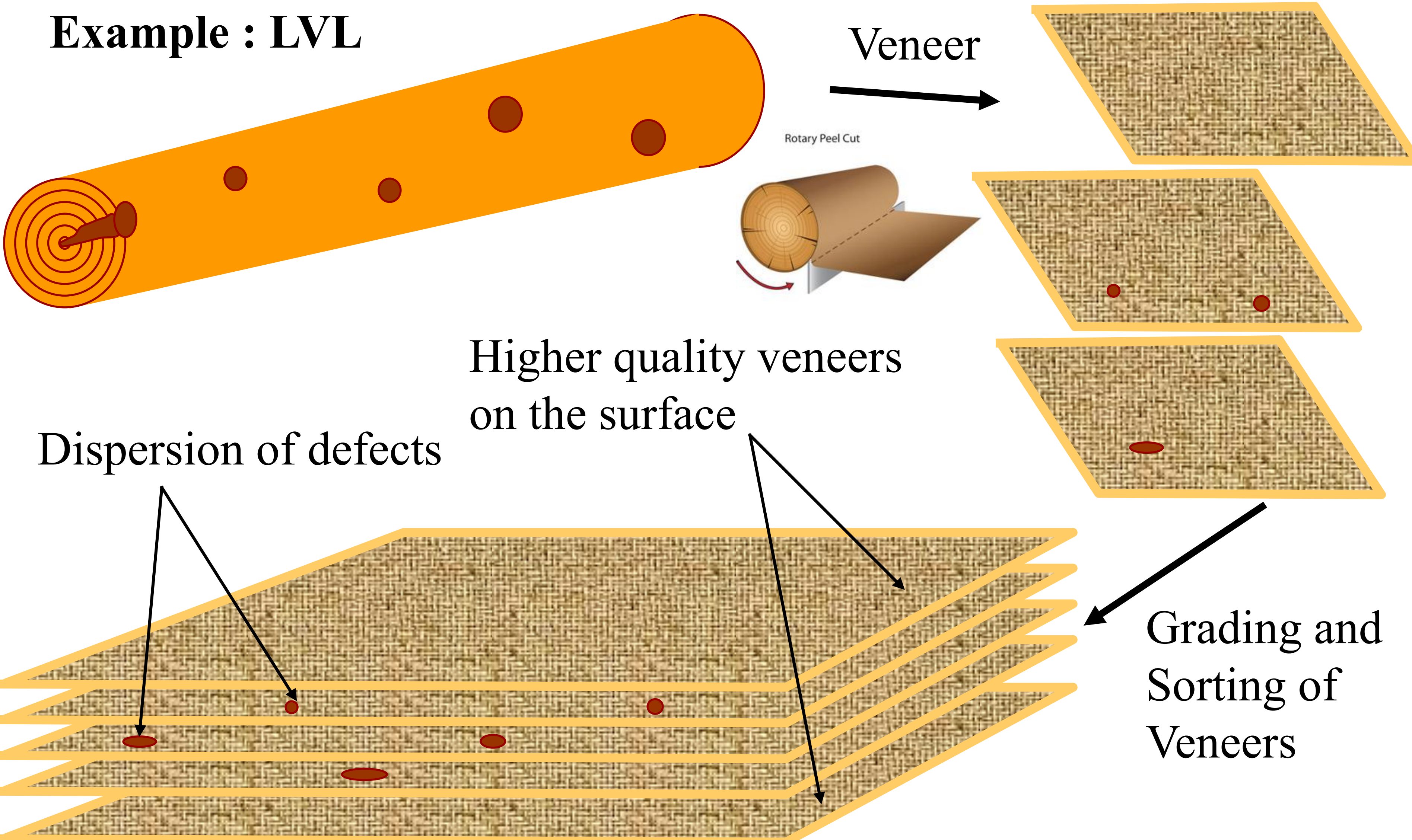
Example : Glulam

Low quality laminates in the middle

Highest quality laminates on outside

Product Engineering Process

Example : LVL



EWP in Residential Construction

Beam and Post

Header

EWP in Bridge Construction

Vehicle bridge

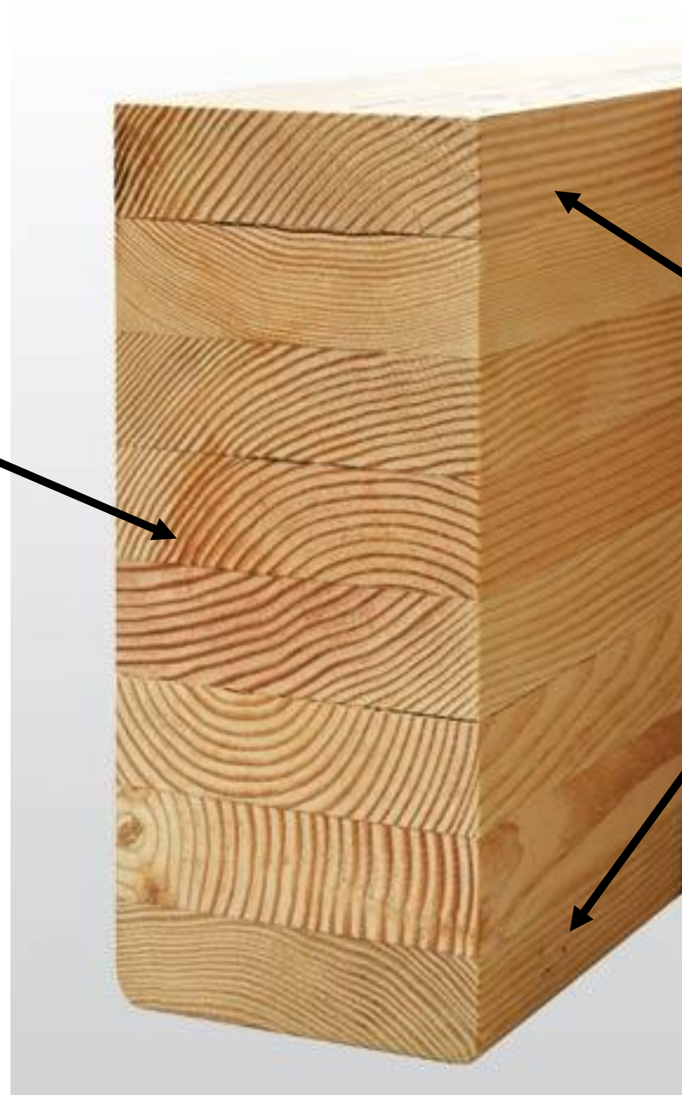
EWP in Commercial Structure

Sports hall

Glued-laminated Timber (Glulam)

The oldest **engineered** wood product – developed in 1903 in Germany

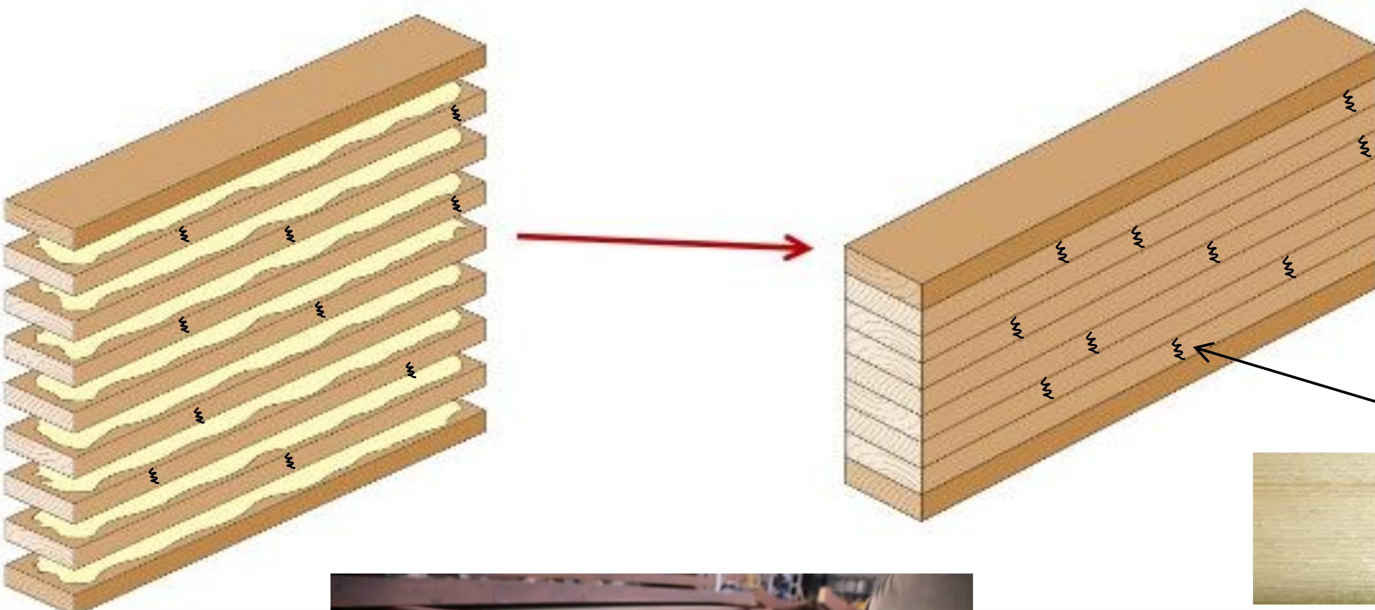
Low quality laminates in the middle



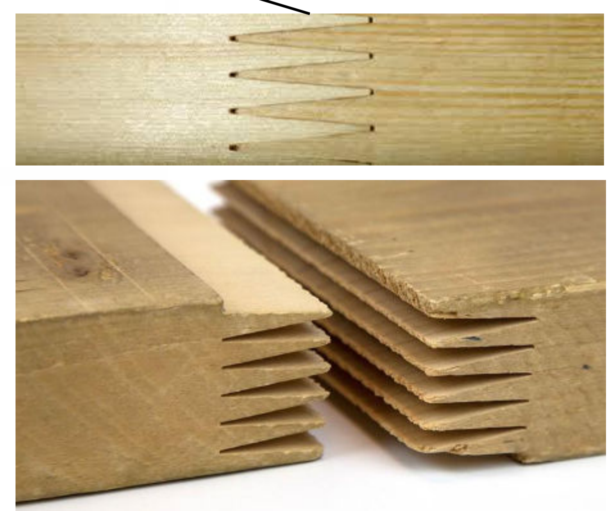
Highest quality laminates on outside

What is Glulam?!

A laminated member made of dimension lumber and a structural adhesive



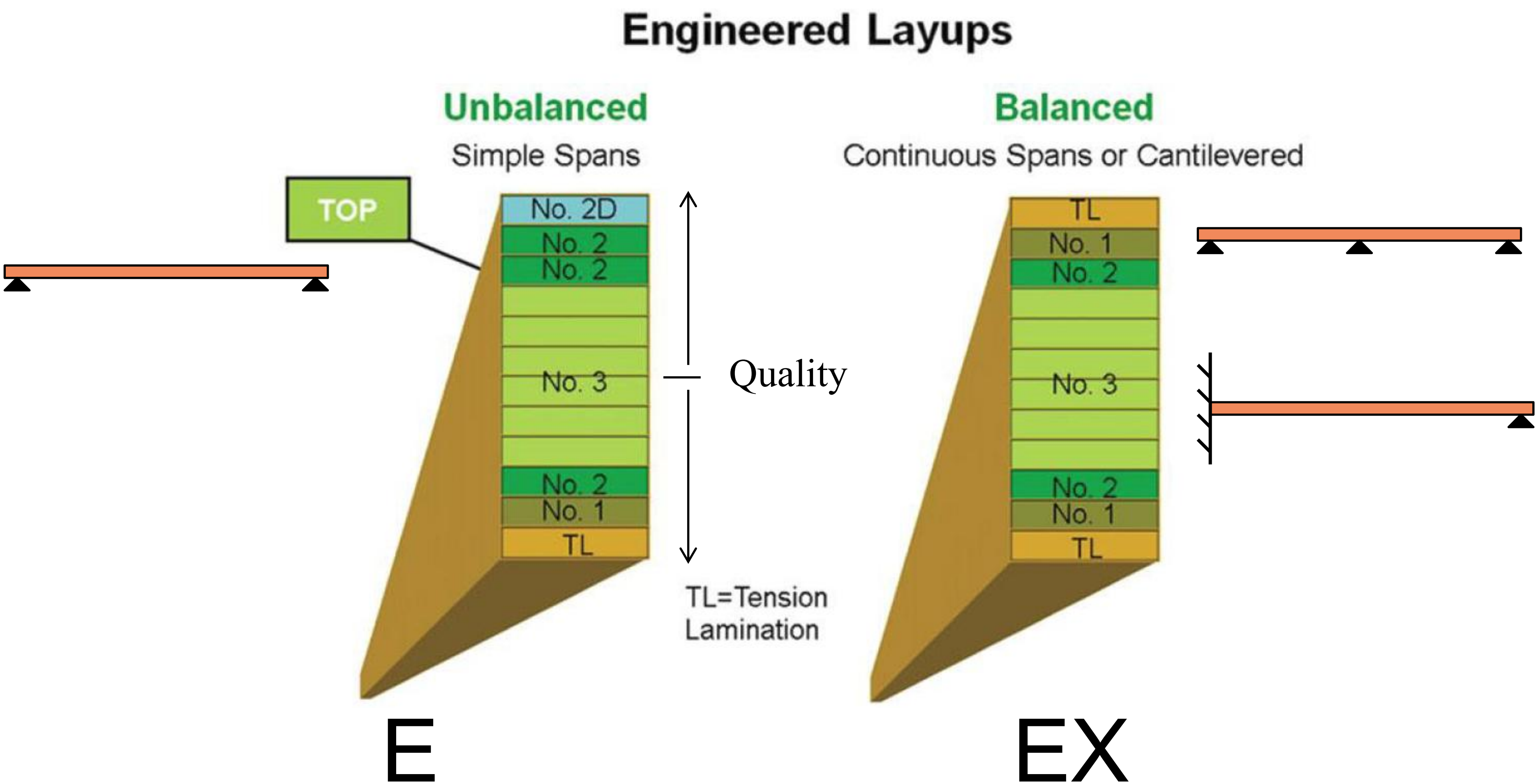
Finger joint



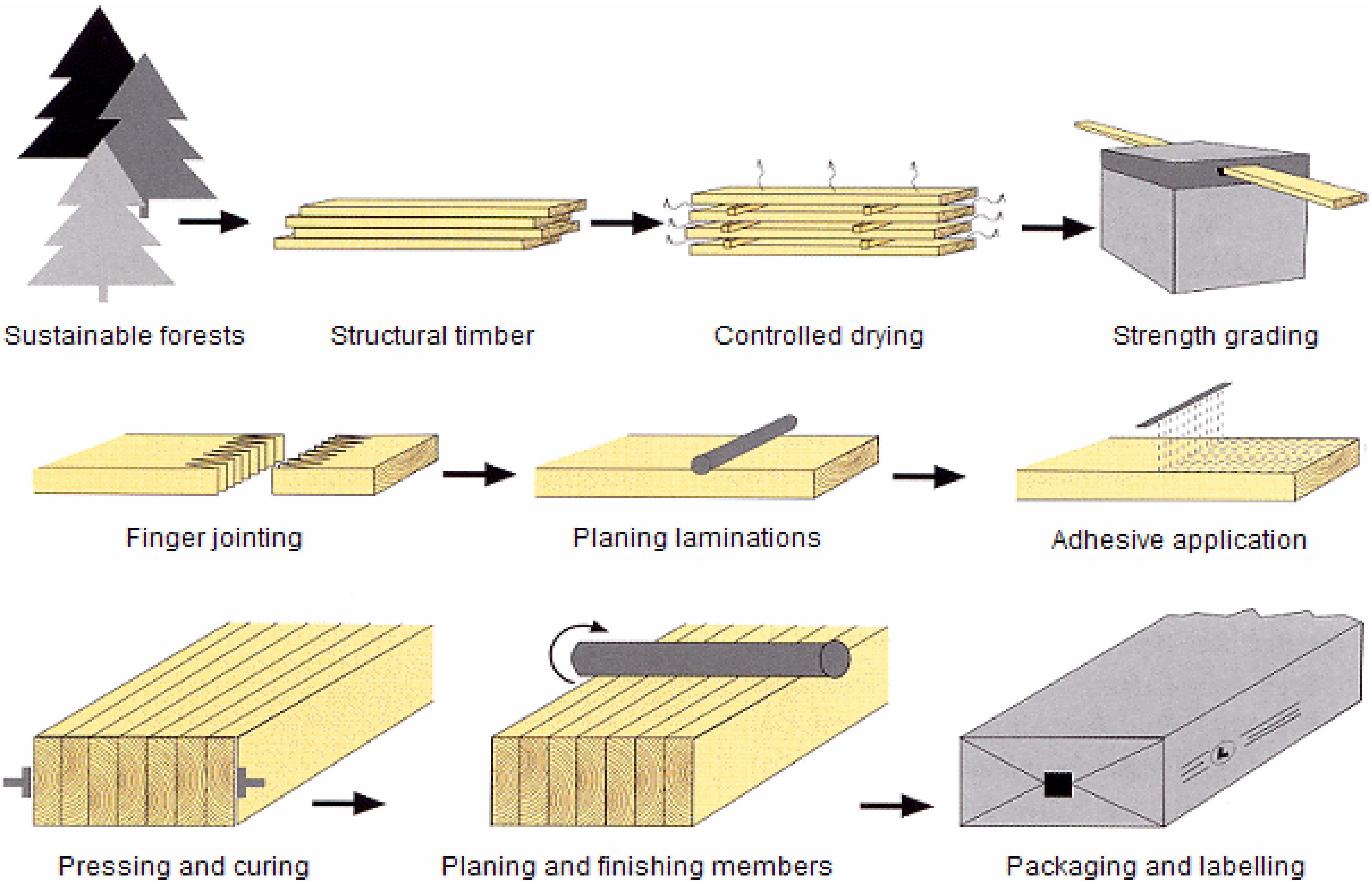
Could be curved

Glued-Laminated Timber (Glulam)

Balanced vs. Unbalanced Layups!



Glulam Manufacturing



It is manufactured as straight members most of the time..

https://youtu.be/OzCWStEJHfs



MTRL

It can also be manufactured to be curved for particular applications such as arches…

Source: Mohammad

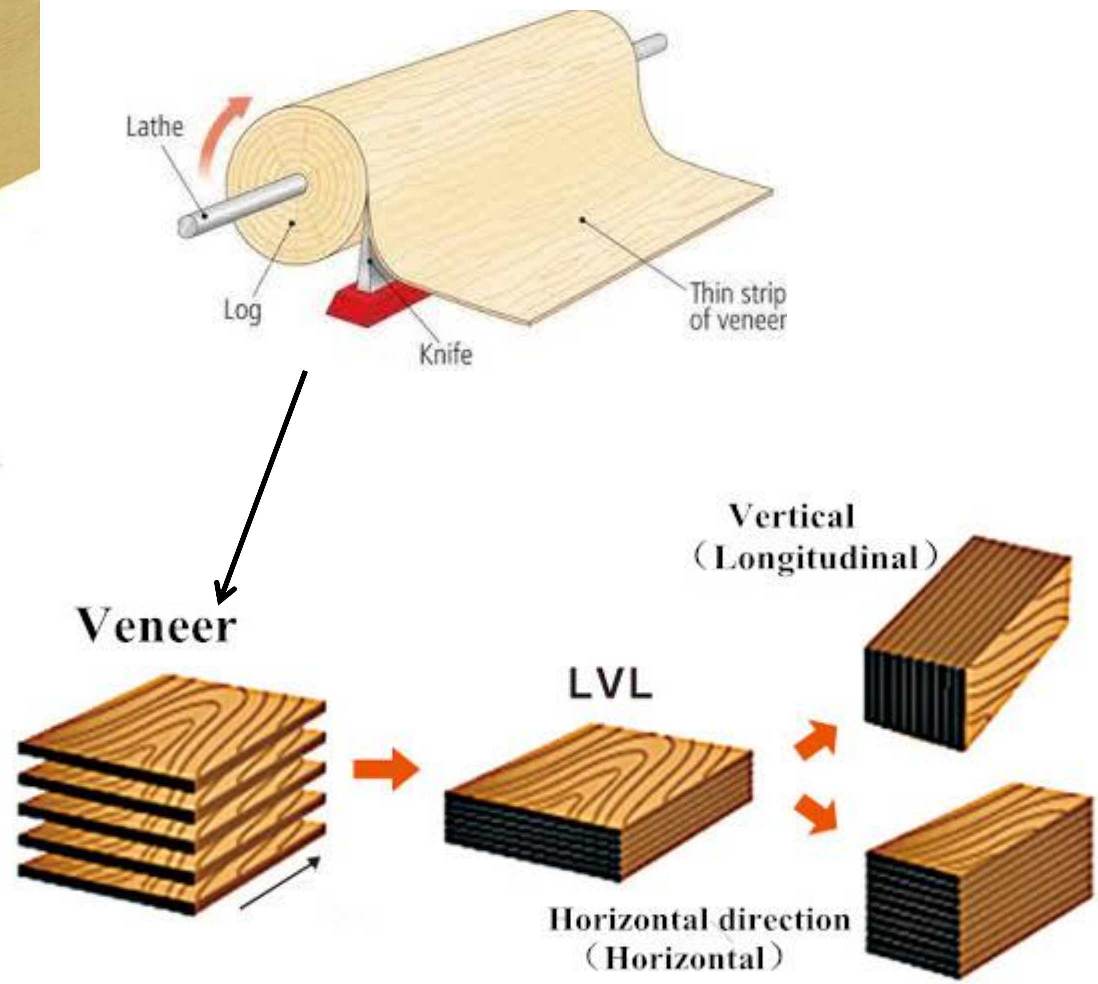
Source: Mohammad

Source: Mohammad

Structural Composite Lumber (SCL)

- Made by bonding smaller wood components to produce large panels using durable adhesive
  - Laminated Veneer Lumber (LVL) } Veneer
  - Parallel Strand Lumber (PSL) } Veneer → strand
  - Laminated Strand Lumber (LSL)
  - Oriented Strand Lumber (OSL) } Flakes
- Panel size can be up to 3m x 20m
- Thickness can be up to 175mm for PSL or 75mm for other SCL
- Commonly ripped into one-dimensional members for use as beams and columns

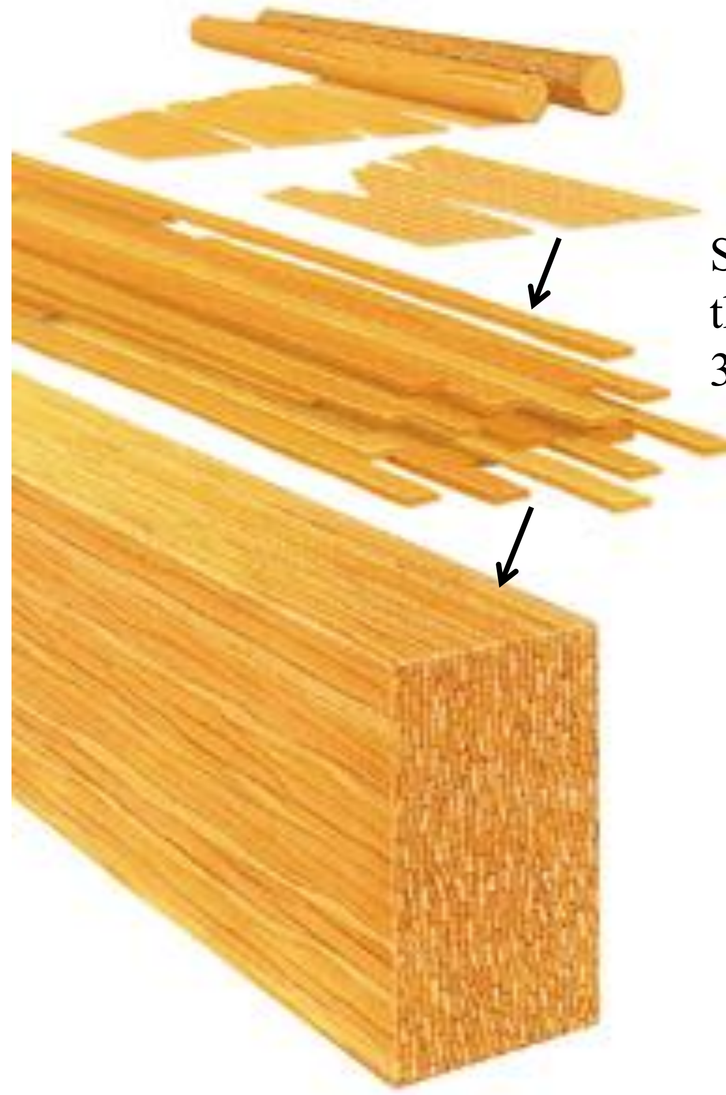
Laminated Veneer Lumber (LVL)



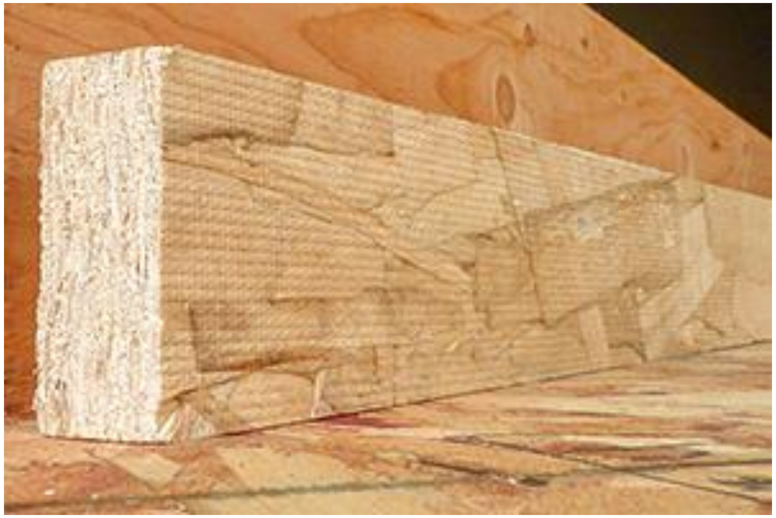
- Moderate strength and modulus
- Tendency to split which may lead to weak connections

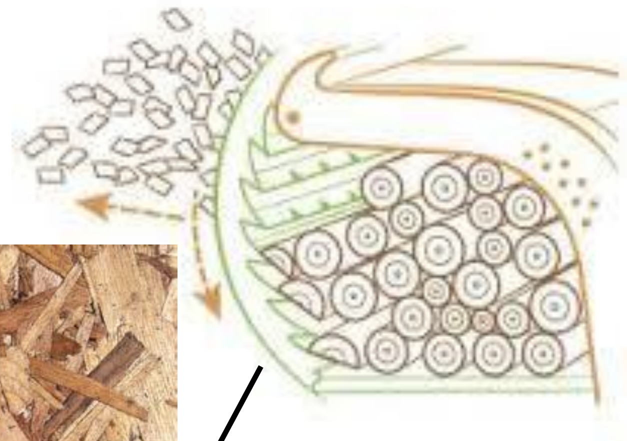
Parallel Strand Lumber (PSL)

- Material with strength higher wood of the same species
- Low connection strength due to voids in structure



Laminated Strand Lumber (LSL) & Oriented Strand Lumber (OSL)

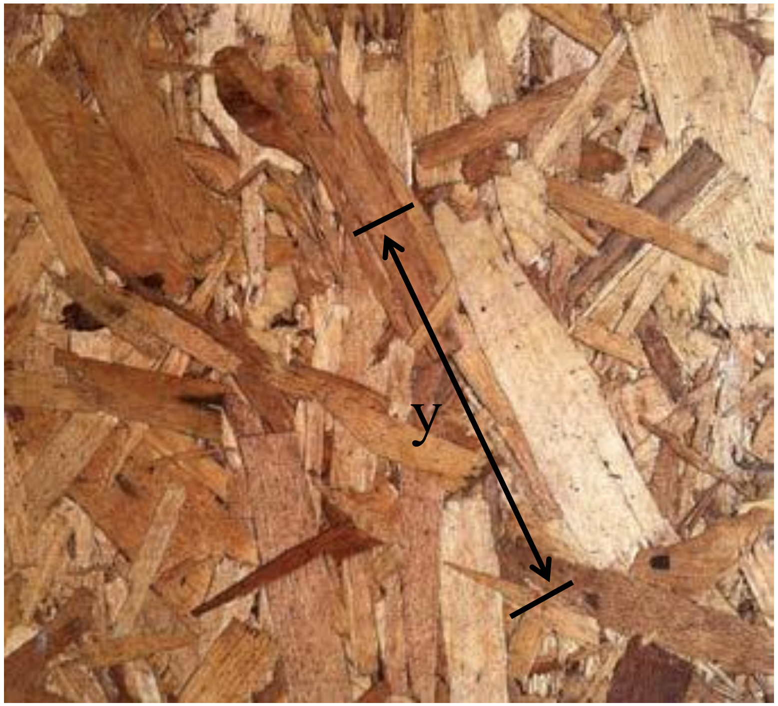


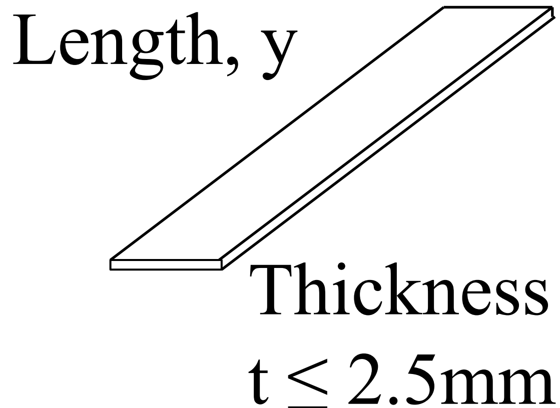


- Material with high in-plane strength but relatively low modulus
- High connection strength due to cross grain and high density

Process is similar to OSB but strands are longer

Laminated Strand Lumber (LSL) & Oriented Strand Lumber (OSL)



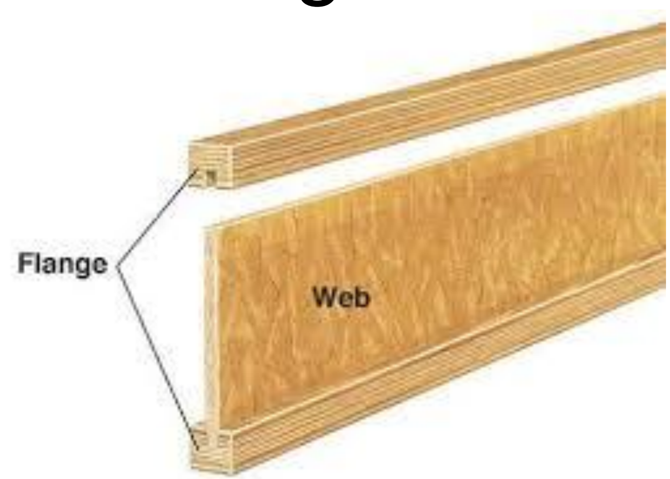


LSL – strand aspect ratio y/t ≥ 150

OSL – strand aspect ratio y/t ≥ 75

Applications of SCL and glulam

- Beams and columns in residential and commercial buildings
- LVL and LSL are used as flange material for wood I-joists

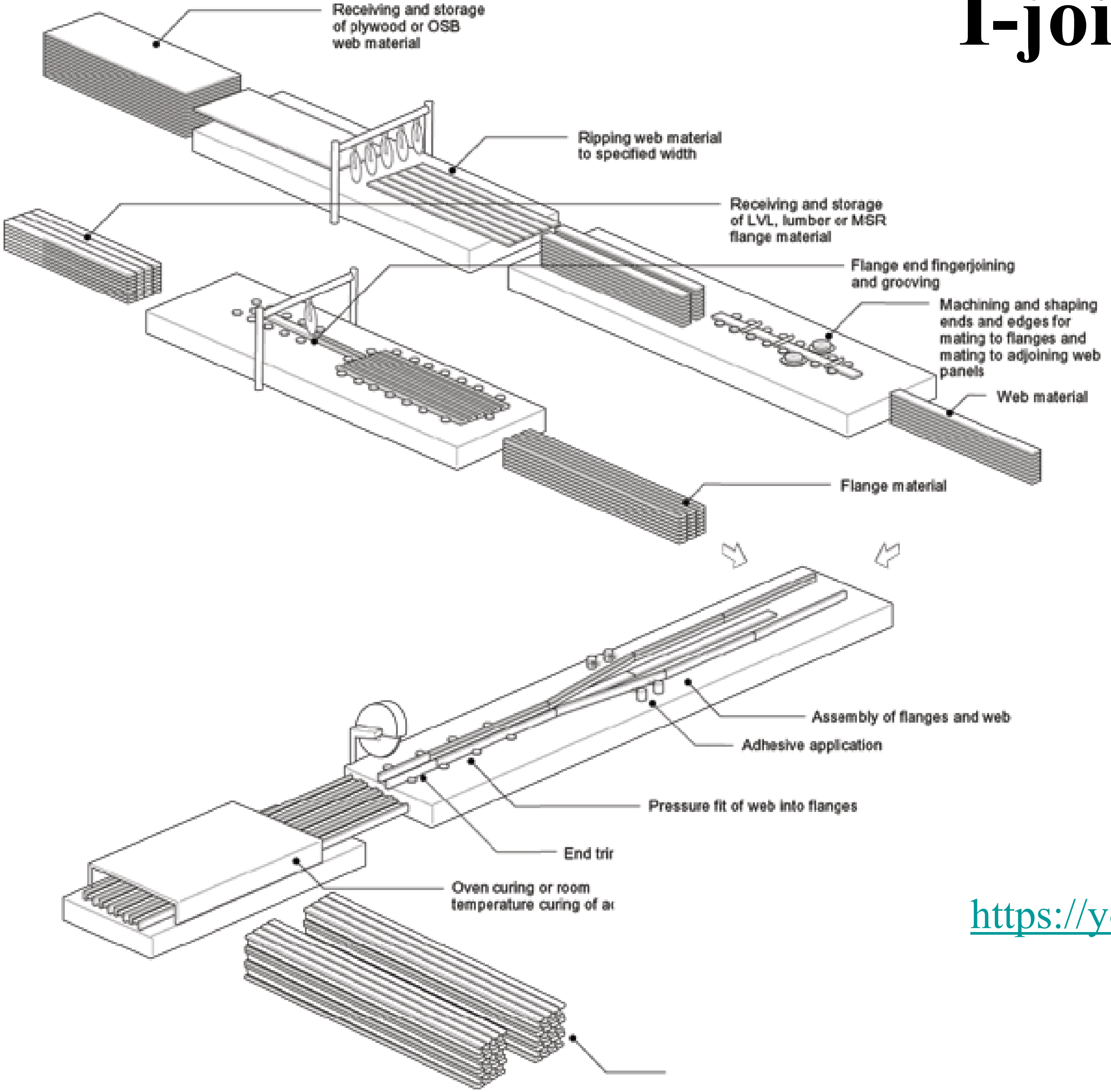


- New applications for SCL as mass timber panels (similar to CLT)

Wood I-joists

- Flanges made of lumber or SCL
- Web is either OSB or plywood
- Gradually replacing lumber joists in floor construction (60% new floors in North America)
- Available depths : 240mm to 610mm
- Light weight and available in length up to 16m

I-joist



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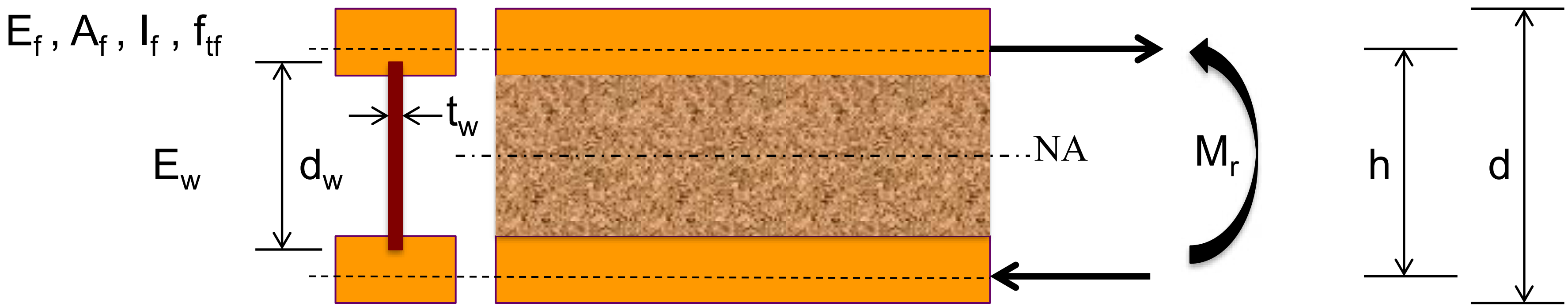
Bending property determination for wood I-joist



Moment capacity, $$M_r = F_{tf}\, A_f\, h$$

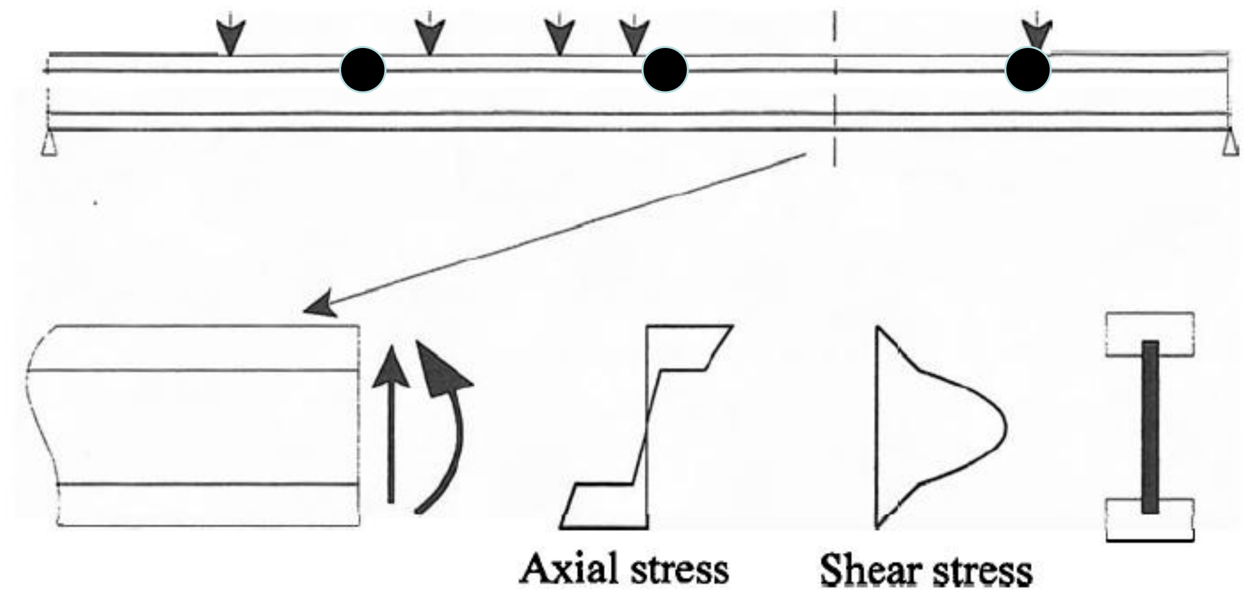
Bending stiffness, $$EI = \underbrace{2\,E_f(I_f + A_f\left(\frac{h}{2}\right)^2)}_{\text{Flange}} + \underbrace{E_w\left(\frac{t_w\, d_w^3}{12}\right)}_{\text{Web}}$$

Notes

1. F_{tf} is specified tensile strength of flange material (modified by size factor)
2. I_f, A_f and h should account for the rout in flange to connect to the web

Structural performance of wood I-joist

- Flanges resist bending moment
- Web resists shear stress
- Deflection caused by transverse loading should account for contribution of shear deformation of the web
- Presence of web opening reduces shear capacity

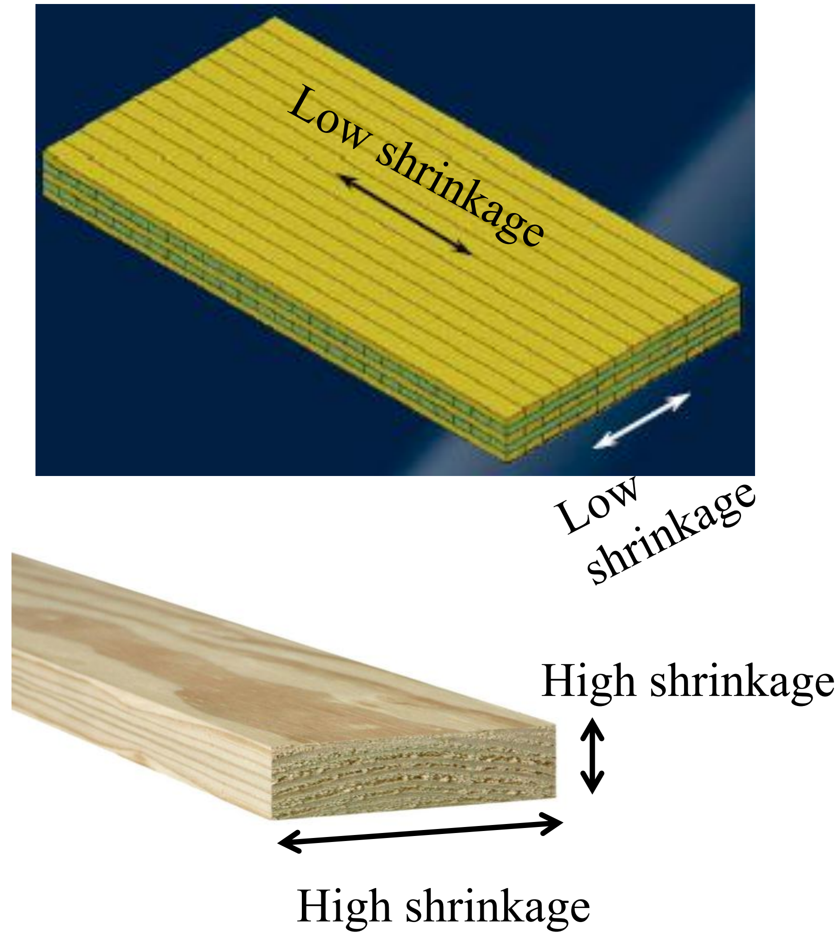


Application of Wood I-Joist

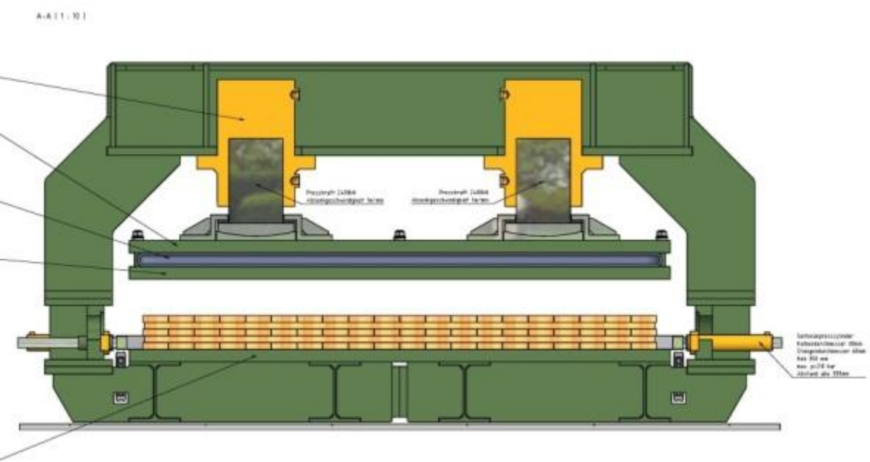
Floor and
Roof Joists

Cross Laminated Timber (CLT)

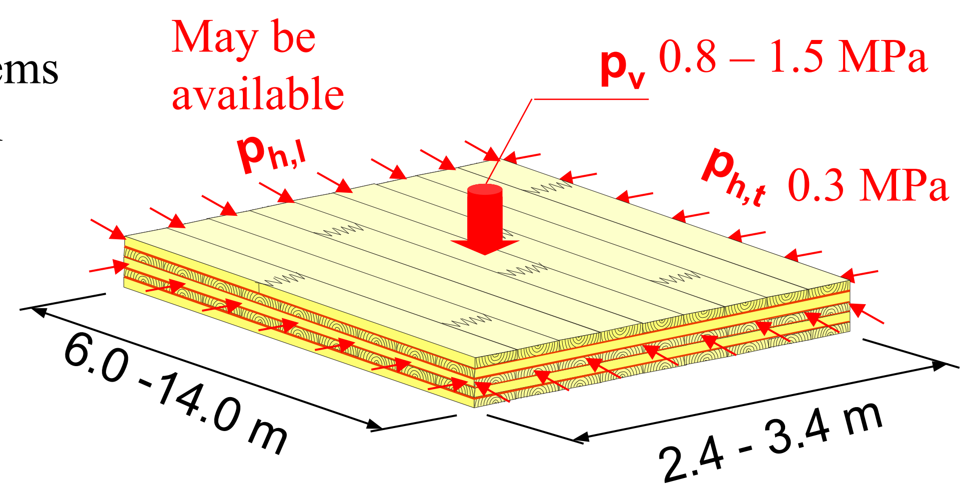
- New generation of engineered wood product – developed in Europe about 20 years ago
- Lumber planks stacked cross-wise and bonded with a glue
- Cross grain effect:
  - High in-plane shear strength
  - Dimensionally stable
- Product thickness : 50 to 300 mm
- Product plane dimensions: 3m x 14m



Hydraulic press systems



Most commercial systems can press up to 300mm thick panel



Source : Schickhofer

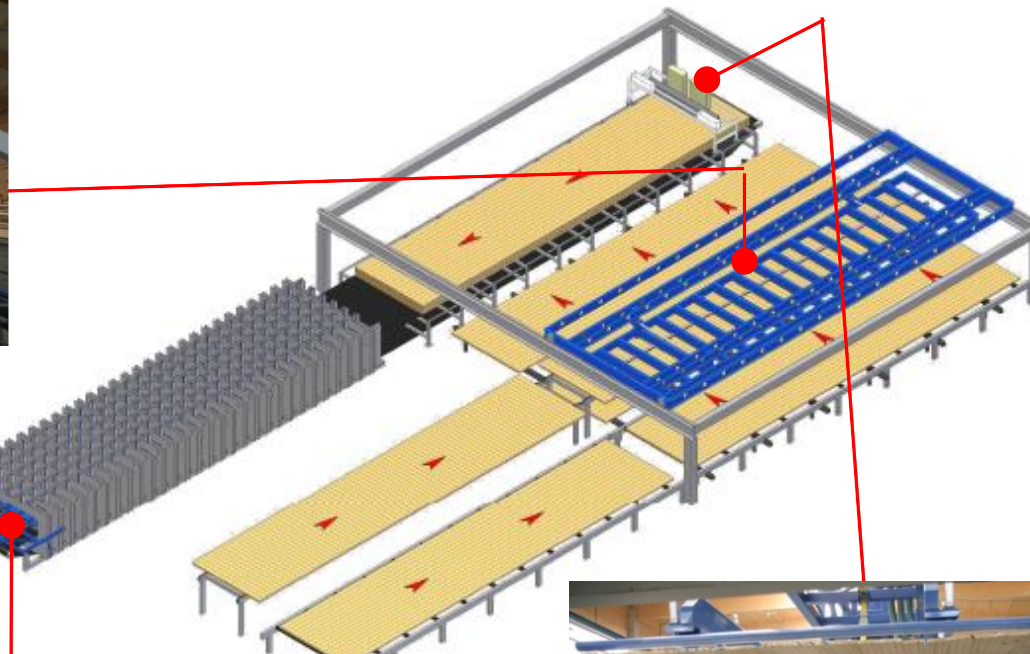
Processing line - MINDA

https://youtu.be/jokkqSTtM74

Vacuum station

40 min. per cycle

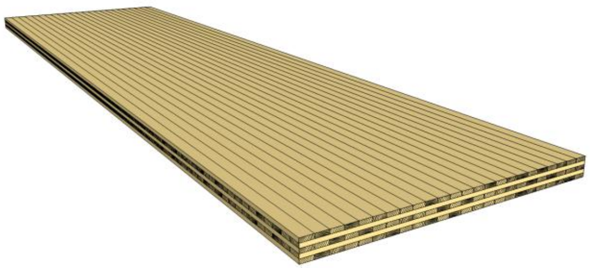
20,000 m³/shift/yr



Press station

Glue station

Cutting and machining by CNC machine



Ready-to-Assemble building system

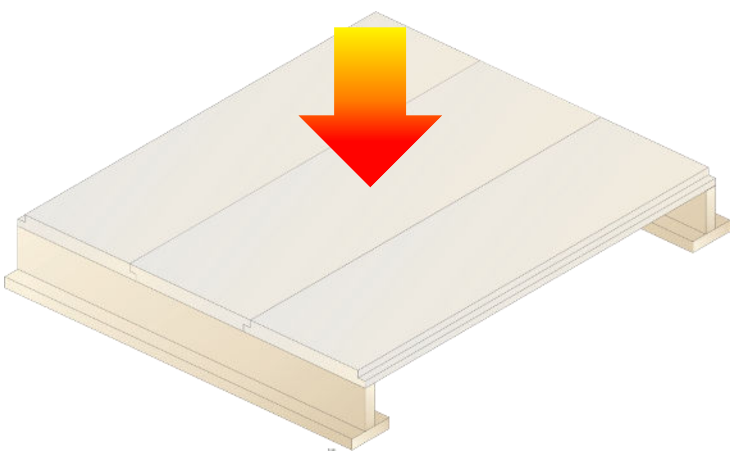
CNC machine to cut to size, make opening, fastener hole, etc

Evaluation of CLT product properties

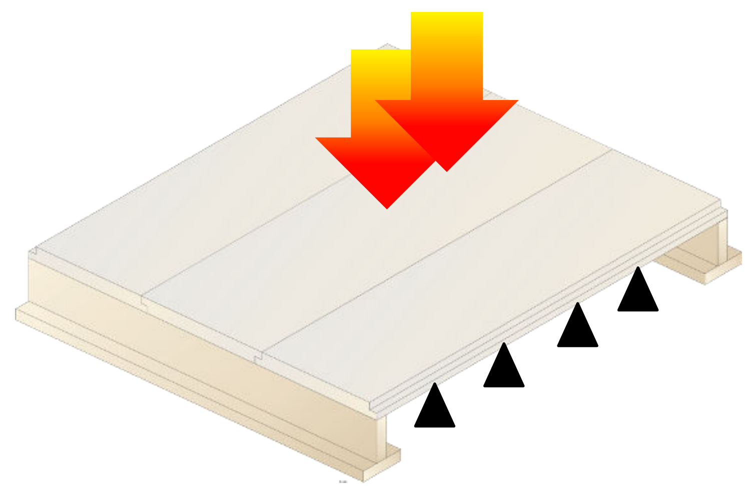
- Some properties in CLT can be calculated using properties of laminates (e.g. bending)
- Some properties are difficult to calculate or even measure (e.g. rolling shear)

Bending properties – floor and roof panels

- Designs generally treat CLT as one-way beam and not two-way plate



One-dimensional beam
- Simple formula but conservative



Two-way plate
- More complex analysis, but accounts for real behaviour

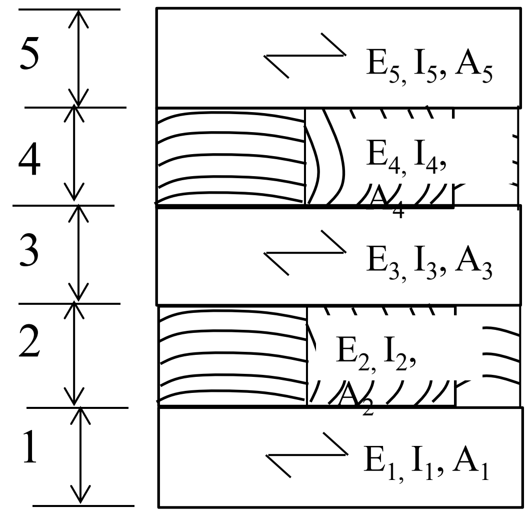
Calculation of bending properties

Effective bending stiffness:

$$(EI)_{eff} = \sum_{i=1}^{n} (E_i I_i + E_i A_i a_i^2)$$

where
E_i = modulus of elasticity of layer i
I_i = second moment of area of layer i
A_i = cross sectional area of layer i
a_i = distance of centroid of layer i to centroid of cross section

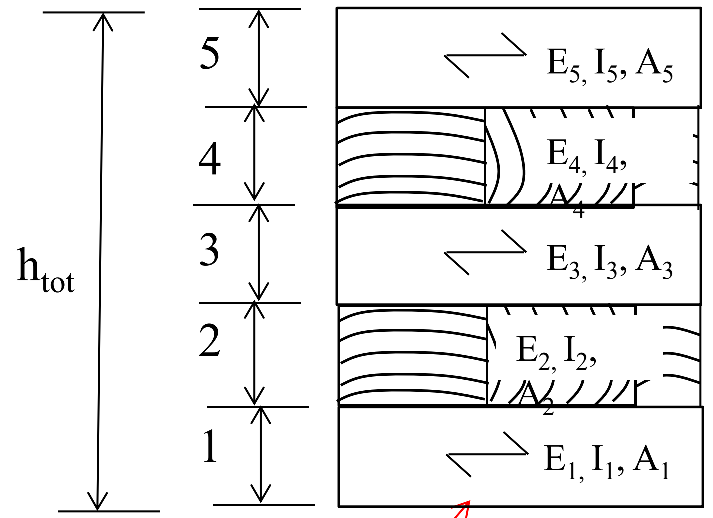
Layer, i=1…n



Calculation of bending properties

Bending strength (moment) capacity:

$$M_r = f_{b,1} \cdot \frac{(EI)_{eff}}{E_1} \cdot \frac{1}{0.5h_{tot}}$$



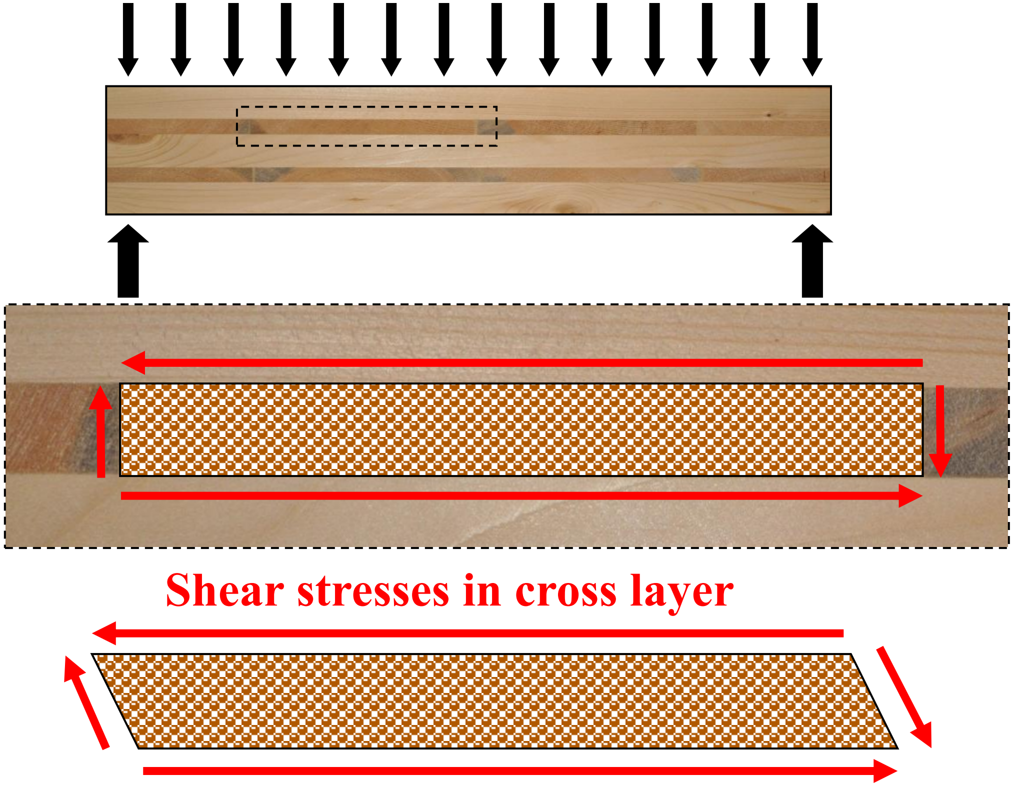
For symmetric section

$$M_r = f_{b,1} \cdot \frac{I_{eff}}{0.5h_{tot}}$$

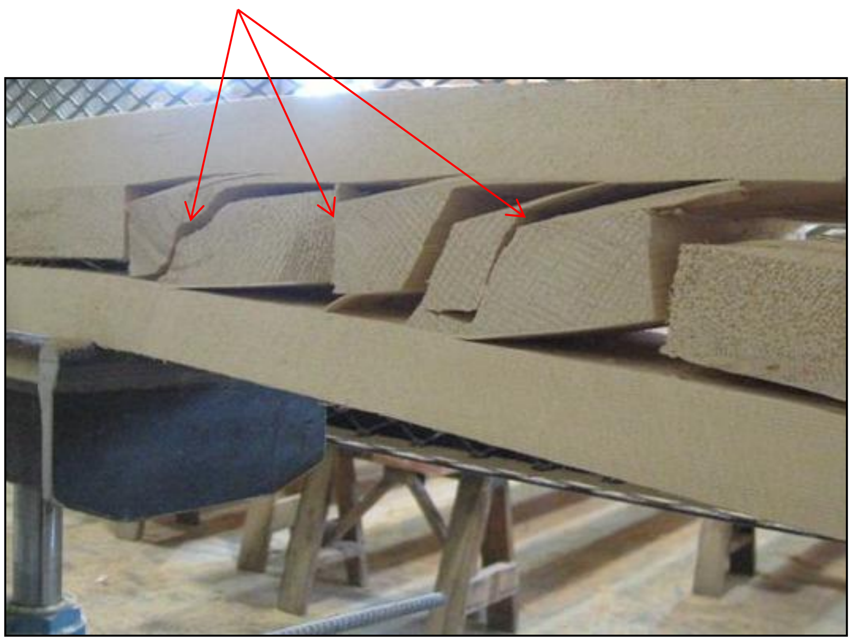
$f_{b,1}$ = bending strength of laminate in layer 1

Rolling shear strength & modulus

- Under bending, failure could be rolling shear in a cross layer

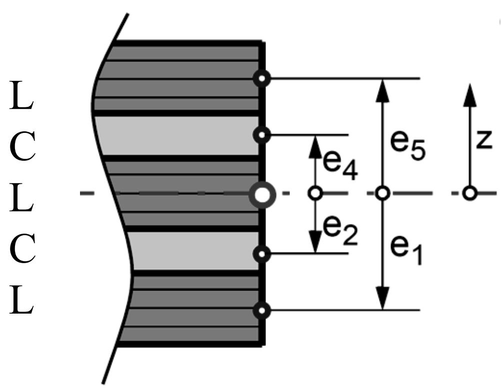


Rolling Shear failure

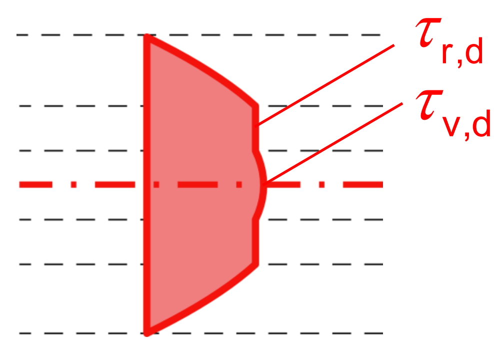


Calculation of shear stresses under bending

- Shear stresses in various layers can be calculated
- Horizontal shear in longitudinal layers
- Rolling shear in cross layers



Shear stress distribution



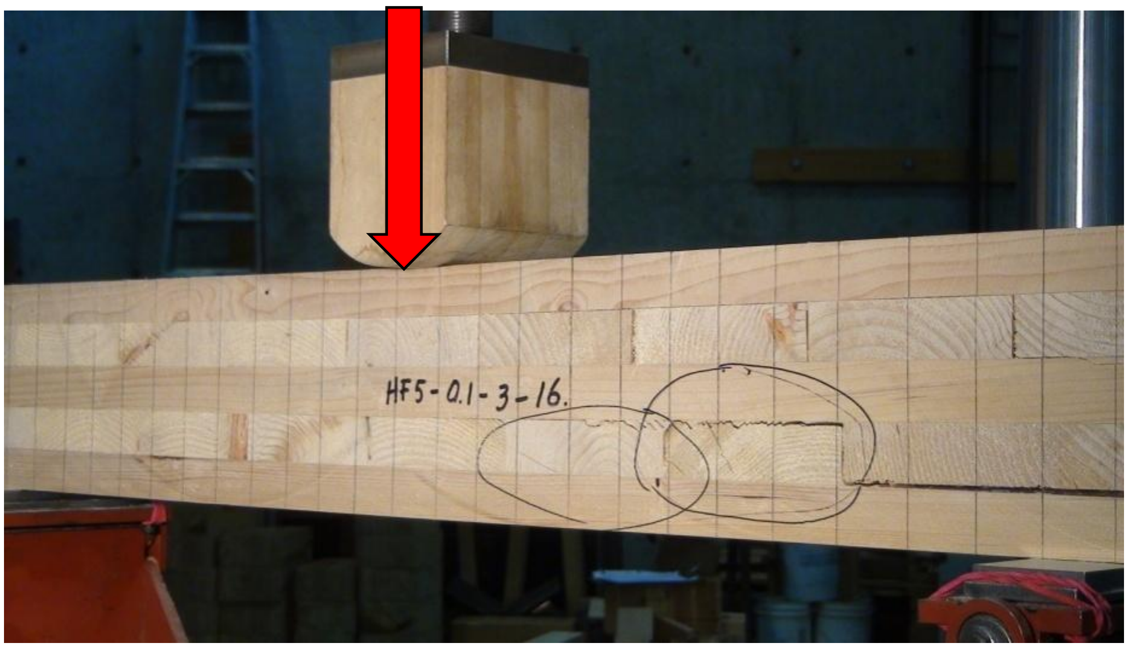
Source : Schickhofer

$\tau_{v,d}$ **(longitudinal) and** $\tau_{r,d}$ **(rolling)**

Measurement of rolling shear properties of CLT

- Two methods
  - Bending
  - Two-plate shear

Steel plates



Bending – North America

Two-plate shear

CLT structures

Single-family houses

Under construction

Finished structure

Source: KLH

Low-rise residential buildings

Under construction

Finished structure

Source: KLH

Commercial - gymnasium

Under construction

Finished structure

Source: KLH

Commercial – Office building

Under construction

Finished structure

Source: KLH

Height progression of CLT buildings

??

2017

Vancouver, Canada

2015

Bergen, Norway

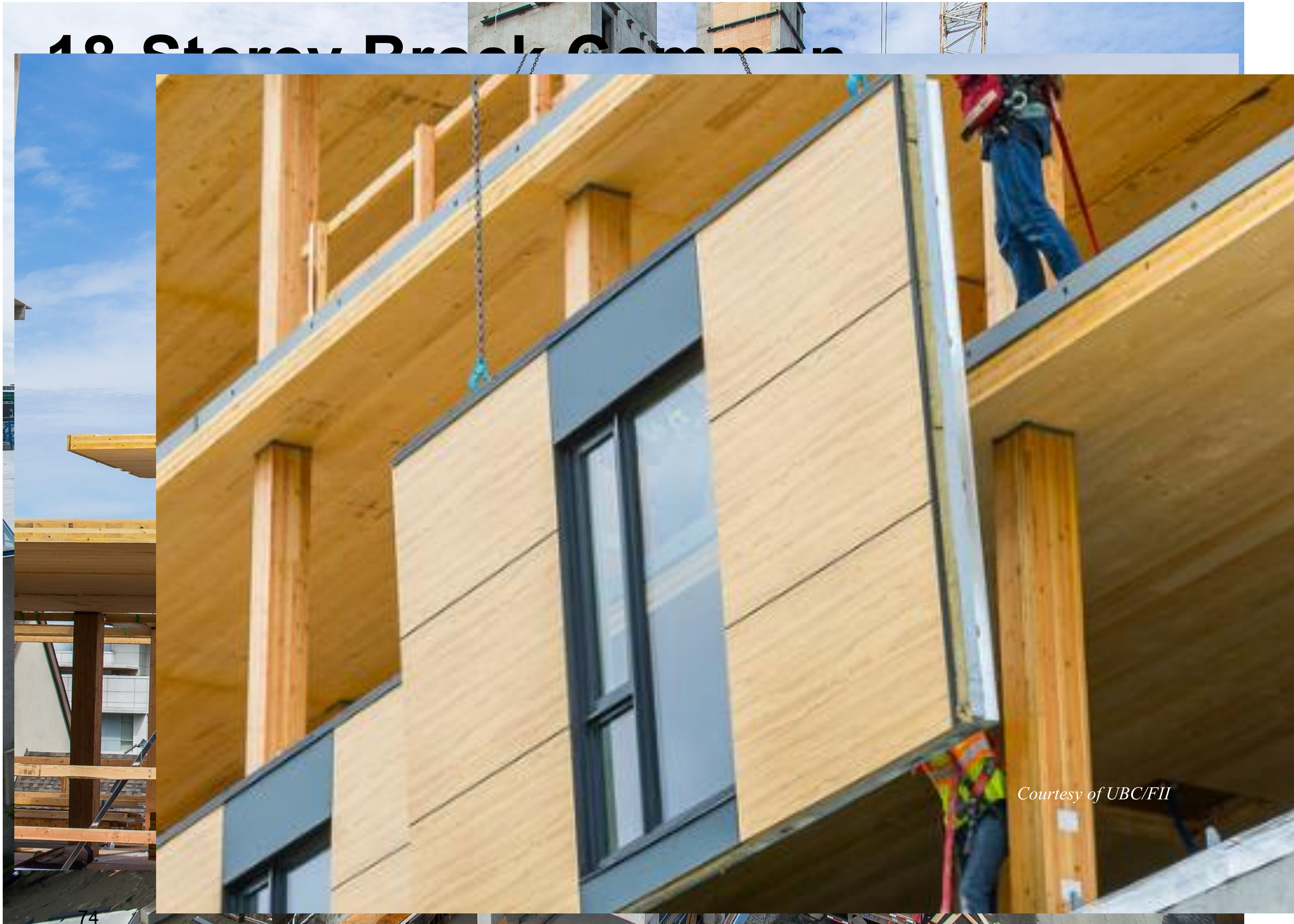
2012

Melbourne, Australia

2008

Växjö, Sweden

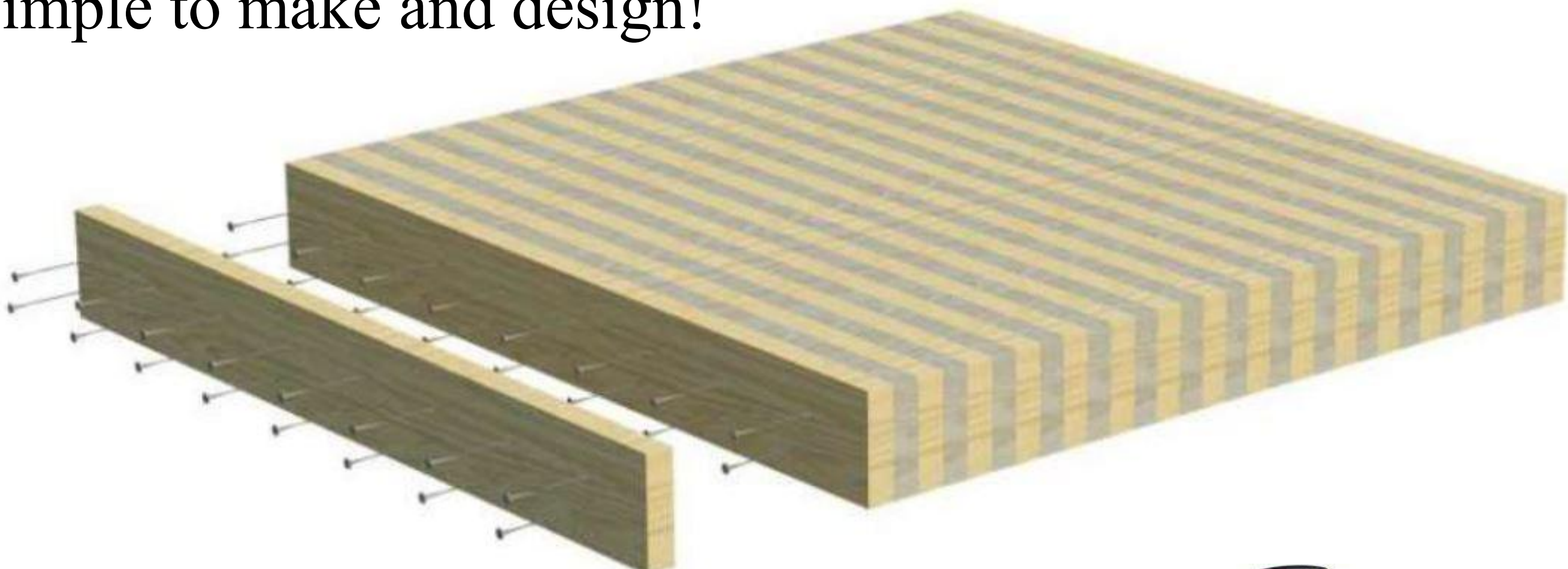
18 Storey Brock Common



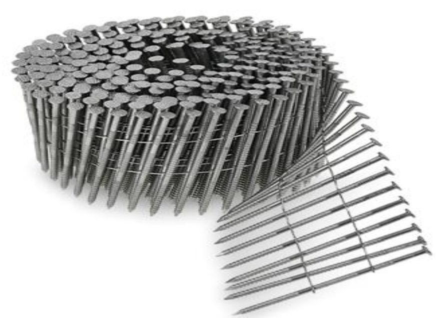
Courtesy of UBC/FII

Nail laminated timber (NLT)

Simple to make and design!



Width : up to 4m
Length : up to 20m
Lumber : 2 × 4 – 2 × 12

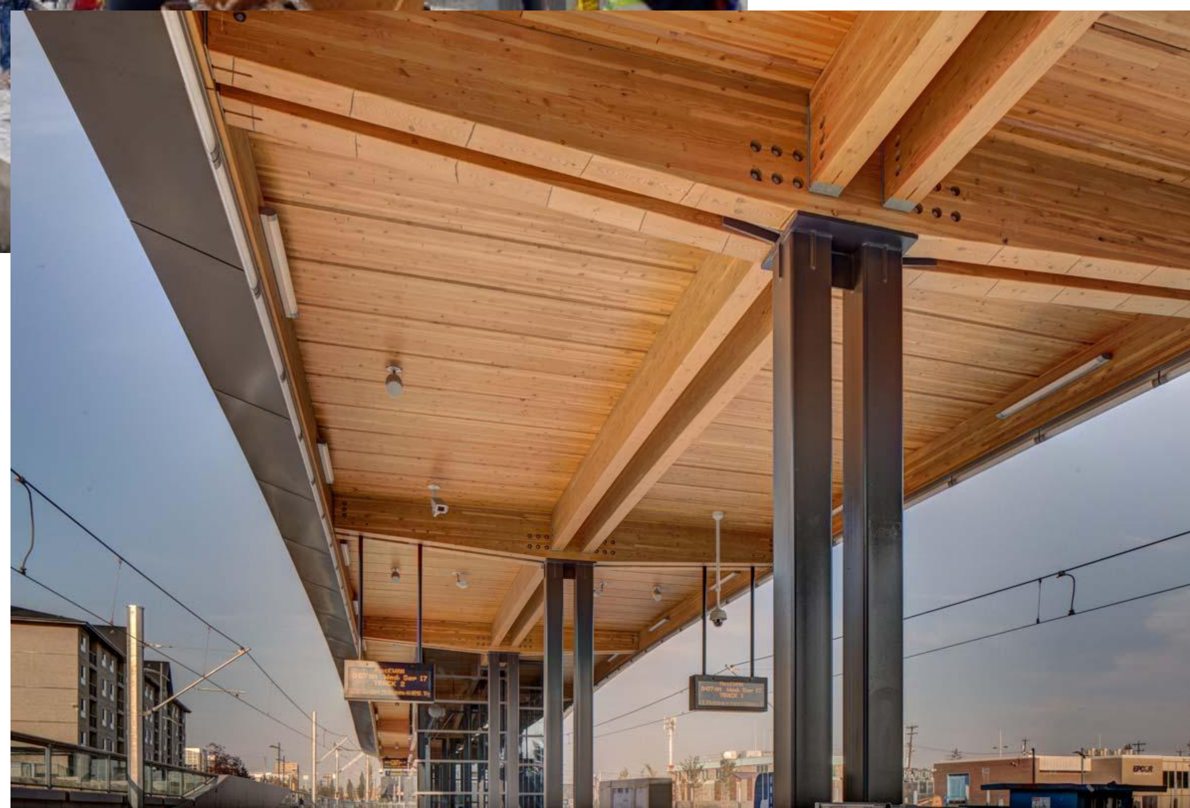


Design and fabrication of NLT

- CSA O86 provides construction details in Clause 6.5.11.3.
- Design assumes beam formula and using bending strength and stiffness of lumber
- Unlike CLT, special product approval is necessary (similar to trusses) – engineer seal is sufficient

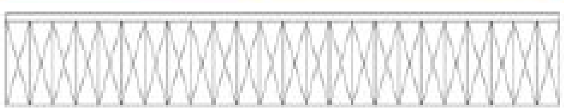
Glue laminated timber (GLT)

- Similar to NLT but with glue instead of nails

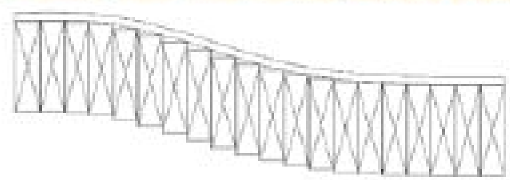


Pictures : Western Archrib, Edmonton

NLT and GLT profiles



Flat

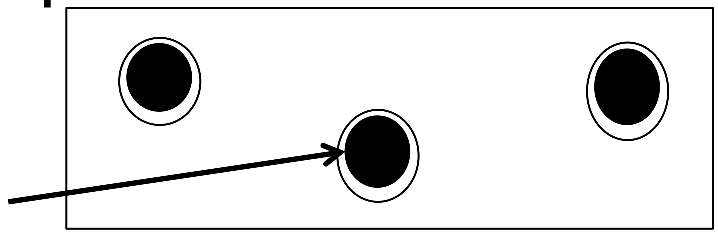


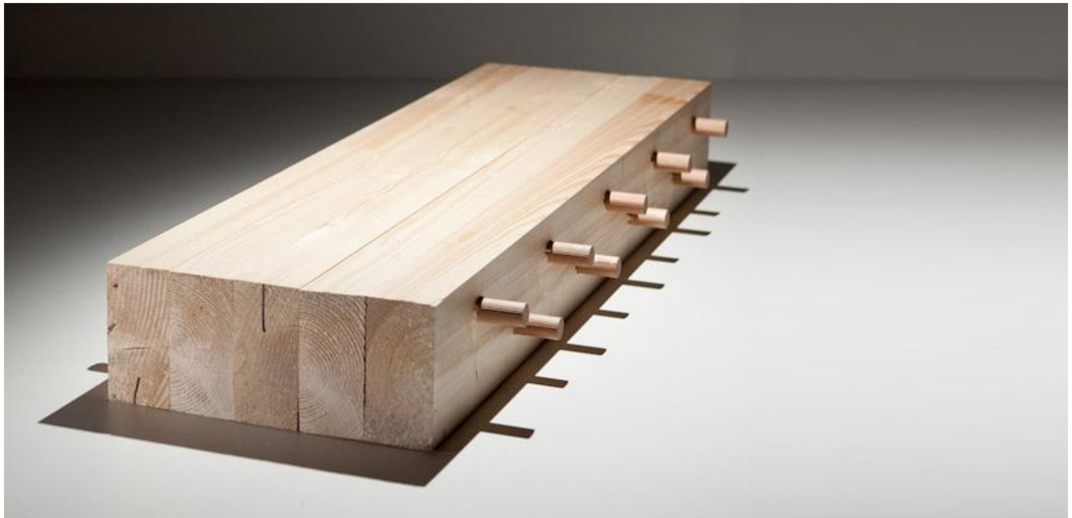
Curved

Fluted

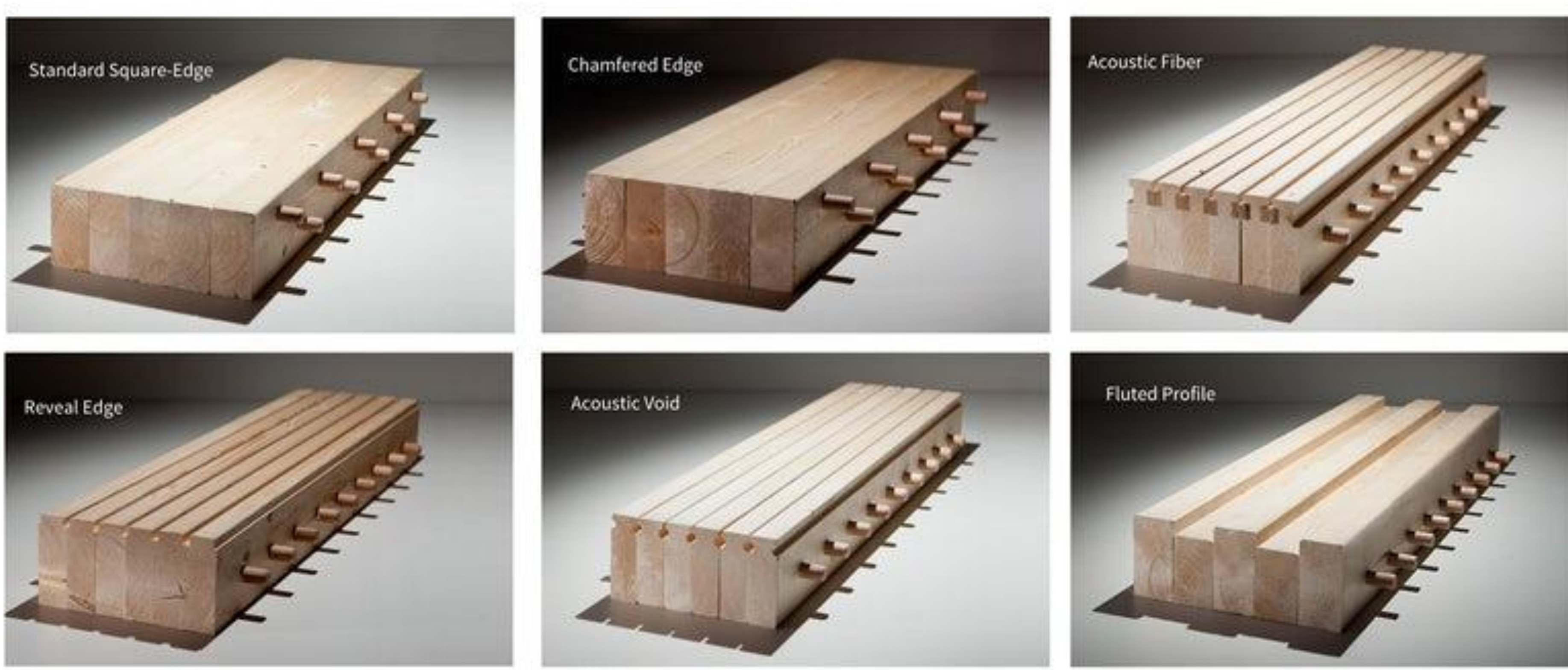
Dowel Laminated Timber (DLT)

- Developed in early 1990’s in Europe
- 100% wood-based – no glue, no nails
- Dry hardwood dowels – swelling of dowel provides tight-fitting
- Faster process than NLT and GLT
- Similar sizes to NLT but stiffer





Dowel Laminated Timber



Panel profiles

Dowel Laminated Timber

Wall panels

Generic vs Proprietary EWP

- Generic
  - Standardized products according to published product standard e.g. CSA, ASTM
  - Design properties are published in design standards
  - Company X’s product has same design properties as Company Y’s for the same grade
- Proprietary
  - Usually no product standard
  - Design properties are unique to the producer and approved by a third-party code approval agency

Where to find design properties for proprietary EWP?

15 Proprietary structural wood products — Design

15.1 Scope

Clause 15 specifies design requirements for proprietary structural wood products used in specific applications. The design procedures specified in Clause 15 are provided for the project engineer or building designer. The manufacturer's design values are usually generated by the manufacturer's engineer in accordance with Clause 16. Unless otherwise specified by the product manufacturer, proprietary products shall be used only under dry service conditions.

Note: *In general, proprietary design values are published by the product manufacturer (i.e., proprietary design literature and Product Evaluation Reports in the CCMC* Registry of Product Evaluations*) with appropriate factors for specific applications. For applications where adjustments to design values are possibly warranted, the designer should seek guidance from the product manufacturer. For additional information on proprietary structural wood products in general, and prefabricated wood I-joists and structural composite lumber products in particular, see the CWC* Commentary on CSA O86.

Where to find design properties for proprietary EWP?

15.3 Structural composite lumber products

15.3.1 General

Structural composite lumber products for use in accordance with Clause 15.3, including products subjected to secondary processing operations, shall meet the applicable requirements of Clauses 16.3.1 to 16.3.6.

Note: *Evidence of compliance is typically a marking of a certification organization (CO).*

15.3.3.1 Bending moment resistance

The factored bending moment resistance, M_r, of structural composite lumber products shall be taken as follows:

$$M_r = \phi F_b S K_{Zb} K_L$$

where

ϕ = 0.90

$F_b = f_b (K_D K_H K_{Sb} K_T)$

where

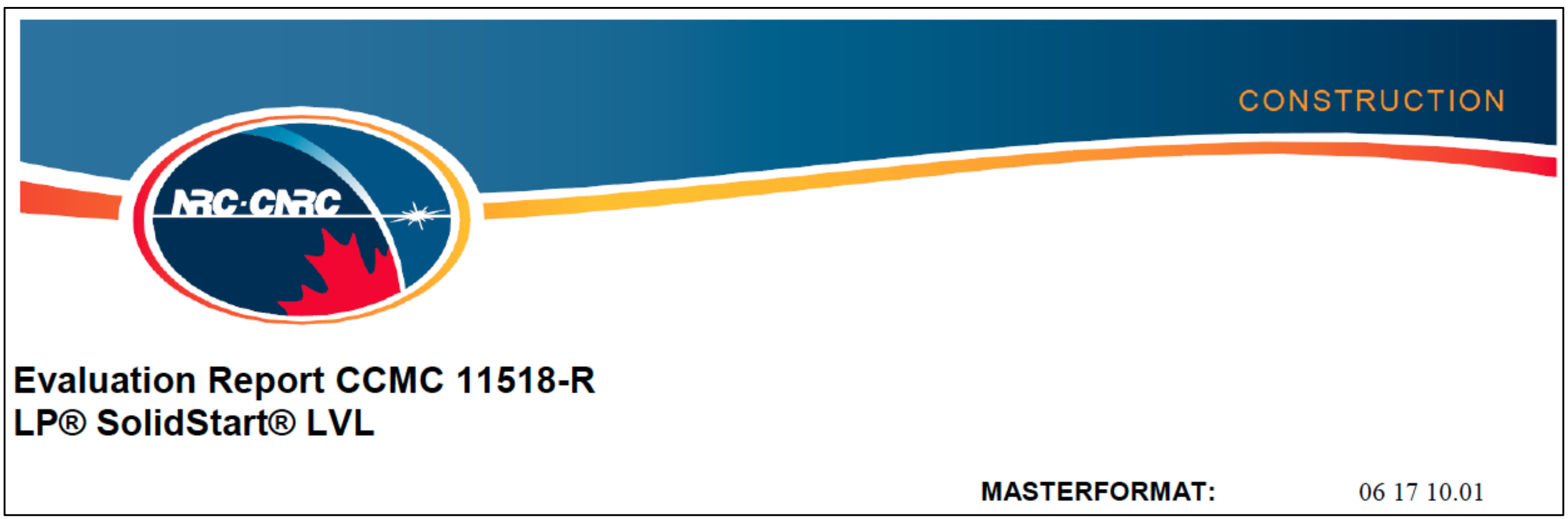
f_b = specified bending strength, MPa, determined in accordance with the manufacturer's product evaluation report

K_{Zb} = size factor in bending (Clause 15.3.2.5)

K_L = lateral stability factor (Clause 15.3.2.7)

Where to find design properties for proprietary EWP?

- Design properties are developed according to procedures specified by product approval agency – NRC Canadian Construction Material Centre (CCMC)


CONSTRUCTION

NRC·CNRC

Evaluation Report CCMC 11518-R
LP® SolidStart® LVL

MASTERFORMAT: 06 17 10.01

Part II - Structural Wood Systems

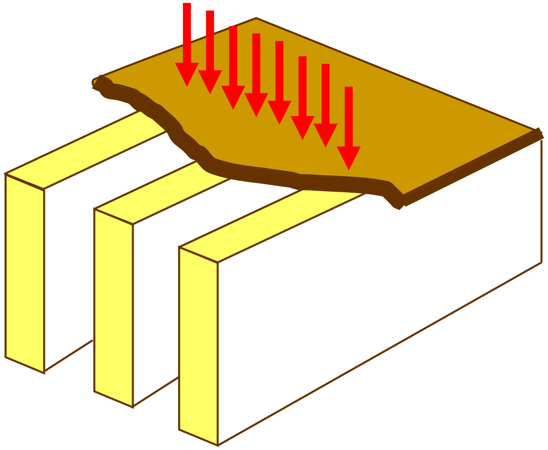
- Light wood frame construction
  - Platform framing
  - Balloon framing
- Heavy timber
  - Post-and-beam
  - Mass timber panel
- Hybrid
  - Combination of above or different materials

Factors in selection of construction type

- **Cost**
- Schedule
- Function
  - Clear span, clear height, open space, etc.
- Code requirements
  - Structural capacity, fire protection, sound transmission, durability
- Appearance
  - Aesthetic considerations
- Environmental issues
  - Energy efficiency, thermal insulation, disposal or recycle at end of life cycle

Light wood frame construction

- Primarily lumber members spaced closely together in a load-sharing arrangement
- Structural resistance
  - Main structural members: lumber
  - Secondary structural component: sheathing
  - Connected by light fasteners, e.g. nails
- Advantages
  - High strength-to-weight ratio
  - Economical
  - Ease of panelization
  - Load-sharing in design

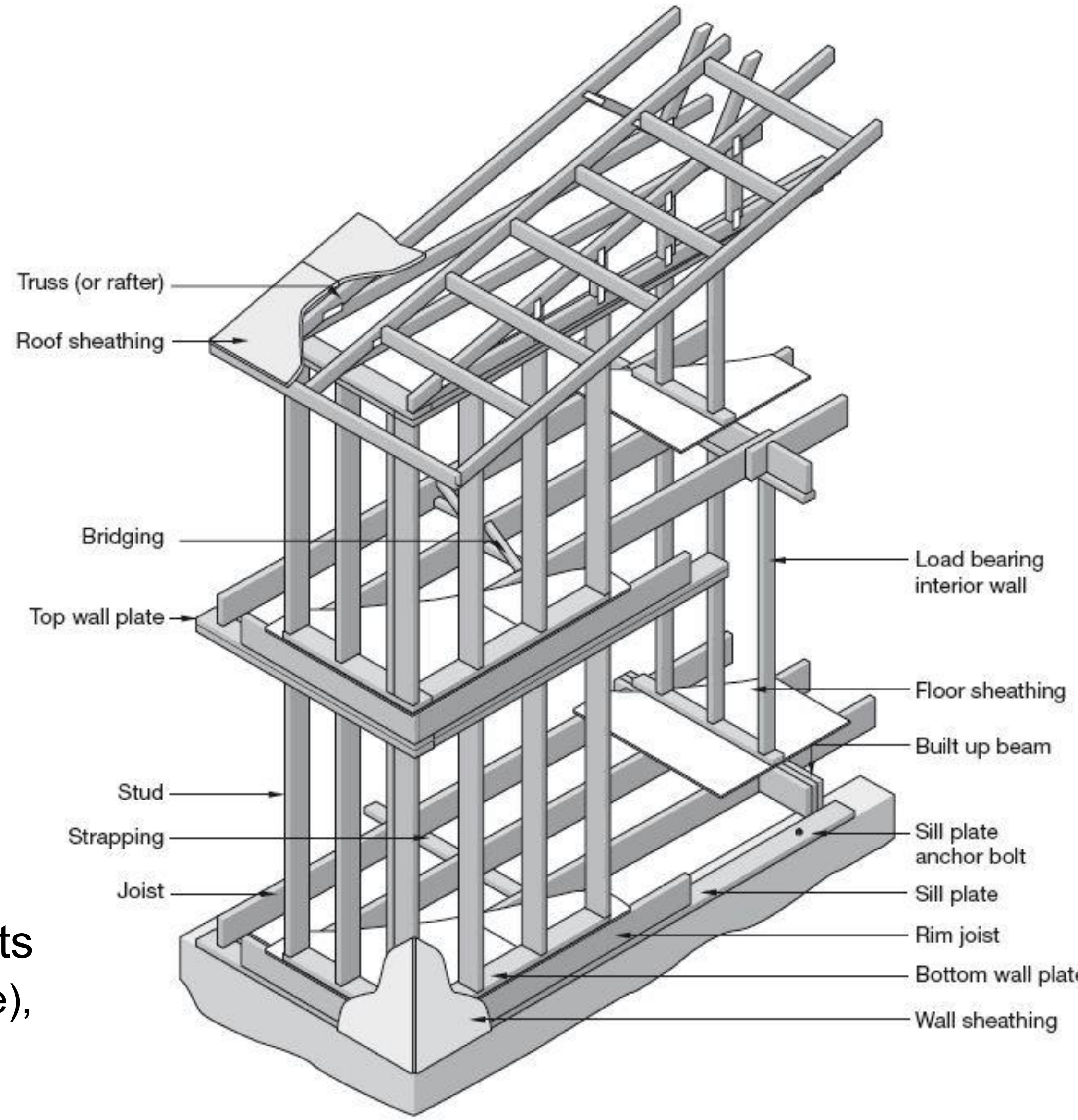


Light wood frame construction

- Framing Types
  - Platform framing
    - Floor assembly is built separately from the wall, and therefore is a working surface for next floor up
    - All walls are one storey high
  - Balloon framing
    - The studs for the exterior walls are continuous from the foundation sill plate to the top plate below the roof framing

Platform frame construction

- Roof assembly
  - Framing: truss or rafter
  - Roof sheathing
- Floor assembly
  - Framing: joist
  - Floor sheathing
  - Rim joists
- Wall assembly
  - Framing: stud
  - Sheathing: wood-based panels/GWB
  - One storey high & consists of top plate (double or single), studs, and bottom plate

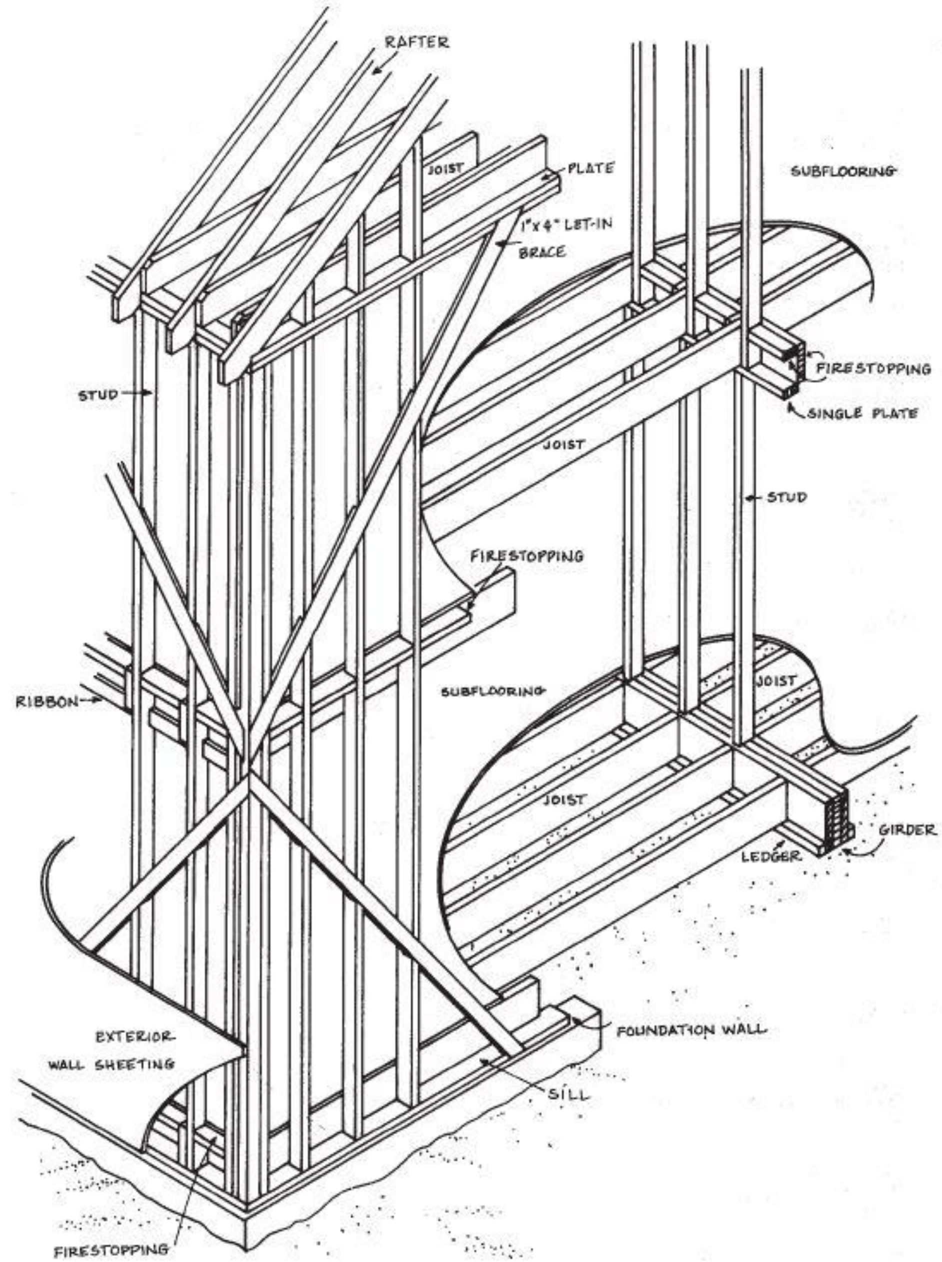


https://youtu.be/OMvKHw4F7MU

Balloon frame construction

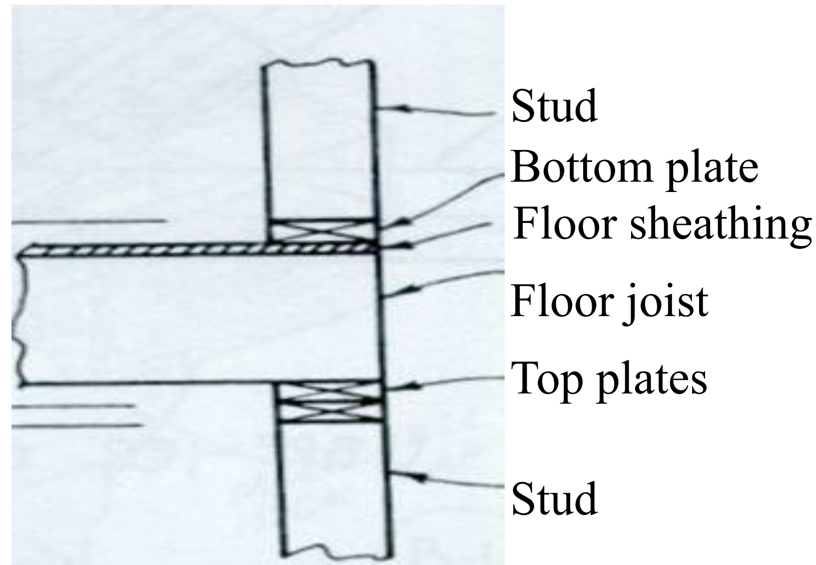
- Wall studs are continuous between floors below the roof framing
  - First-floor joists bear on the sill plate
  - Second-floor joists bear on ribbon strip

https://youtu.be/Q1ZPw2cbxtc



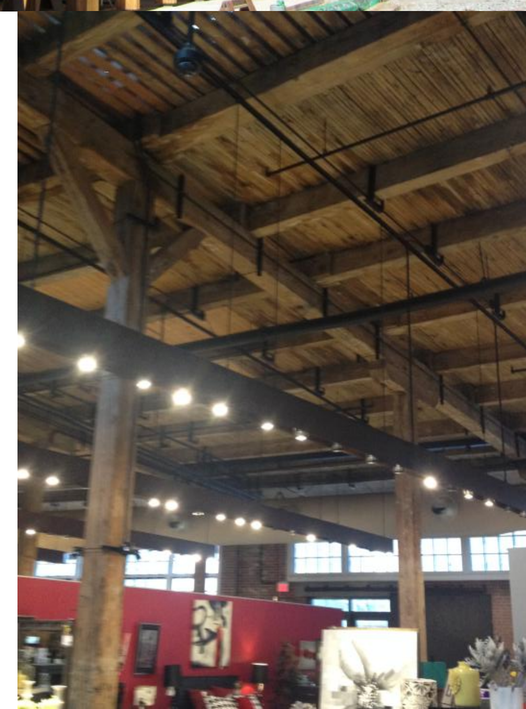
Platform vs Balloon Construction

- Platform frame construction
  - Advantages:
    - Simplicity and ease of erection
  - Disadvantages:
    - More settlement due to shrinkage and compression deformation
- Balloon frame construction
  - Advantages:
    - Less in total shrinkage
    - Reduces variation in settlement of framing and the masonry veneer
  - Disadvantages:
    - Requirement for longer studs
    - Difficulty in accommodating erection practices and fire-stopping



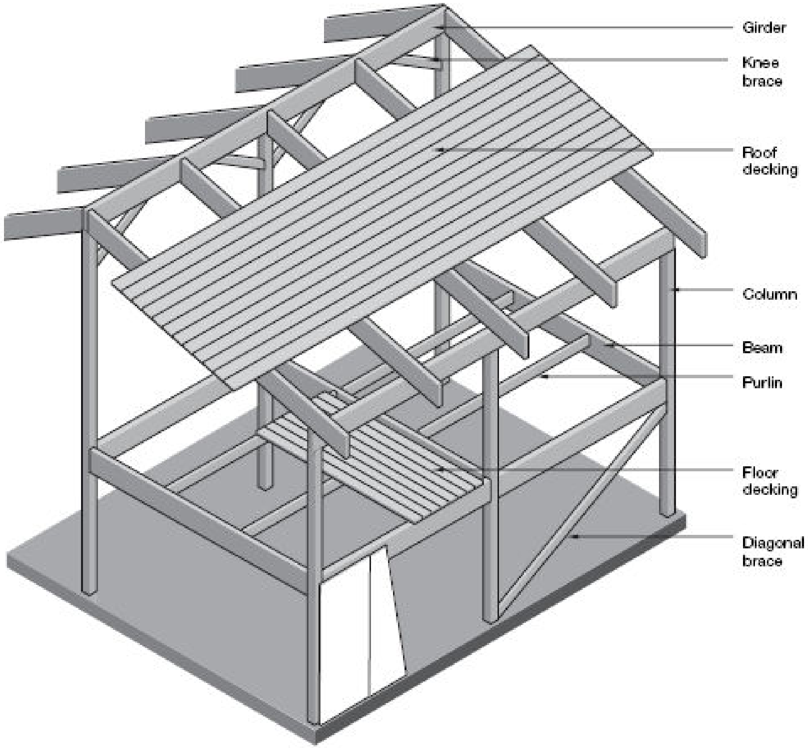
Heavy timber – Post-and-Beam

- Timber or glulam members spaced far apart in a non load-sharing arrangement
- Main members are usually connected with heavy fasteners, e.g. steel dowels, bolts and lag screws, and steel plates



Heavy timber – Post-and-beam

- Secondary members often are designed as stand-alone members e.g. purlins, floor/roof decking
- May require diagonal braces and in-fill shear wall to avoid use of moment connections



Heavy timber – Mass timber panel

- Panelized construction for floor, wall, elevator shaft and roof
- Products : CLT, NLT, GLT, DLT and SCL
- May only require light gauge fasteners e.g. screws and steel brackets
- Height limit ≈ 10 – 12 storeys

Hybrid – P&B + Mass timber panels

- Allow longer spans to be achieved compared with mass timber panels alone
- Same material used in whole building – no material incompatibility

Glulam P&B + CLT floor / roof

Brock Commons – glulam columns + CLT floor

CLT wall + glulam beam

Hybrid – Different materials

- One material can address the weaknesses of the other e.g. concrete core for lateral load and fire resistance
- In predominantly wood structures, steel and concrete members may be used in locations where load level is extremely high e.g. bottom-storey columns in multi-storey buildings
- Indeed nearly all buildings are hybrid to some extent, since foundation is typically concrete

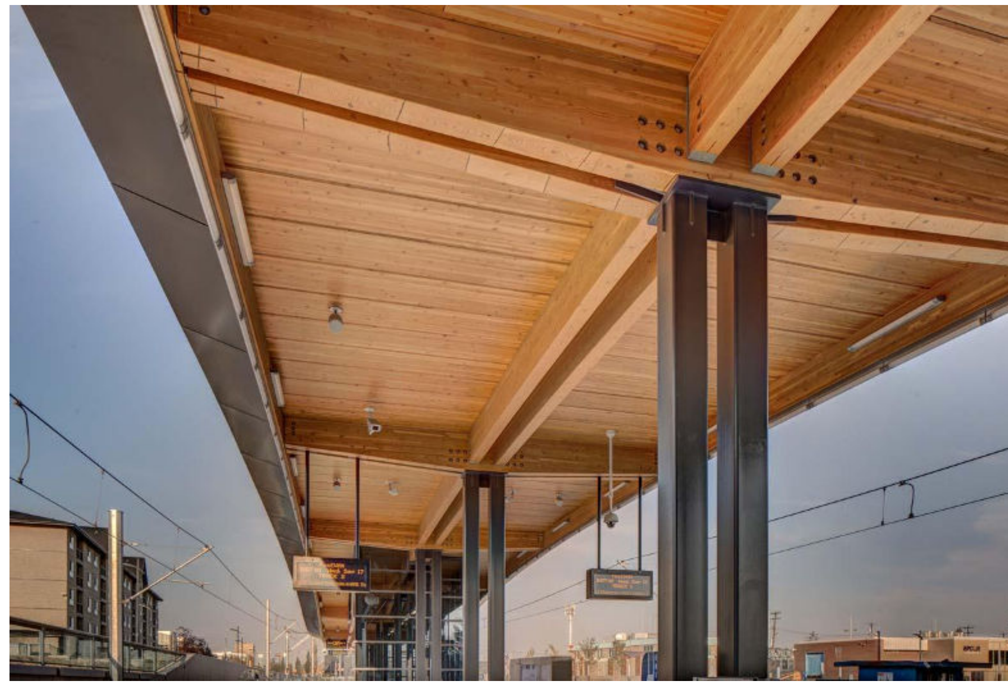
Hybrid – Steel + Wood

Steel frame structure with CLT roof panels (MEC Building, Edmonton)

Steel frame building with light wood floor and wall panels

Hybrid – Steel + Wood

Steel floor beam with timber columns and CLT floor deck



GLT deck with steel column (LRT station, Edmonton)

Hybrid – Steel + Wood

6-storey CLT building with a steel LLRS, Portland, Oregon

Hybrid – Concrete + Wood

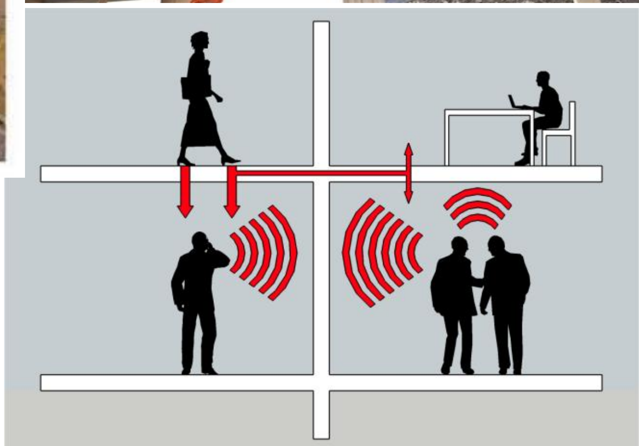
- Often rely on structural systems built with other materials to resist lateral load to avoid the need to use large connections

6-storey glulam

Hybrid – Concrete + Wood

- Timber-concrete composite floor
- Light-weight system (c.f. concrete)

Thermal

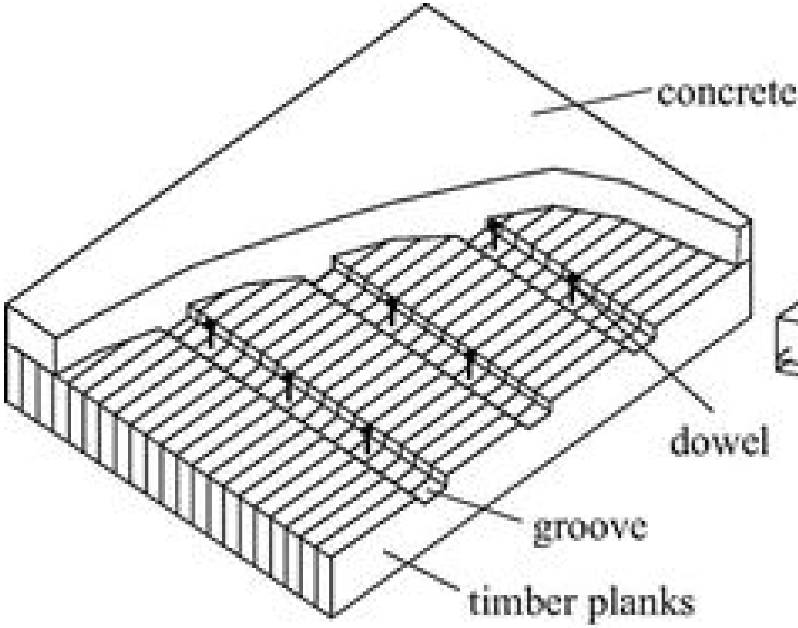


Acoustics

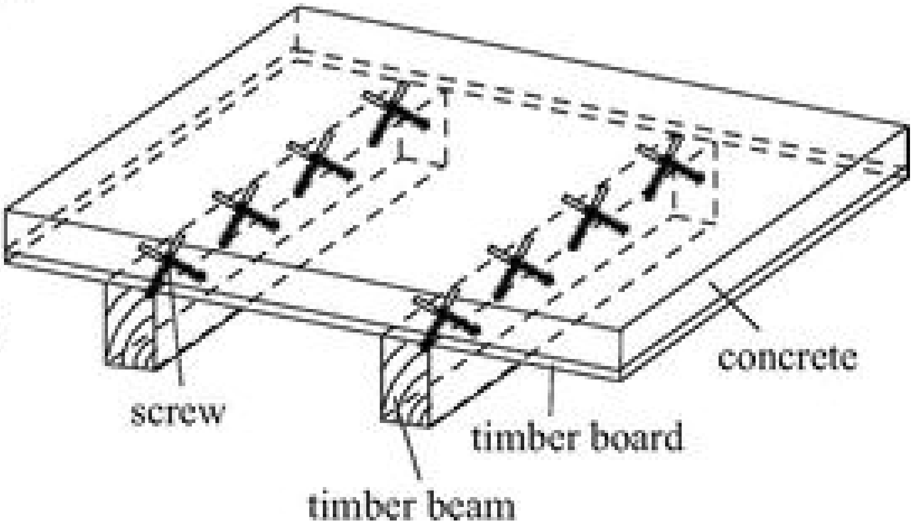
Fire

Hybrid – Concrete + Wood

- Two main construction forms
- Mechanical connectors, groove/notch and glue
- Acoustics mat placed between concrete and wood



Mass timber panel – concrete slab



Timber beams – concrete slab

CLT – Concrete floor

https://youtu.be/_RB5k77V89w

End
Lecture #2