IPROMO

Summer School IPROMO 2017 – Pieve Tesino

FOREST BIOECONOMY: FOREST AND MOUNTAIN PRODUCTS, BIOENERGY

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Outline:

- **Introduction**: use of wood in construction
- **Sustainability and wood**
- **Advantages and disadvantages of wood as structural material**
- **Wood-based products**
- **Timber construction systems**
- **Use of timber and straw**
- The **short supply chain of timber**

Use of wood in construction:

- Structural material
- Finishing (flooring, cladding)

Use of wood in construction:

- Thermal and acoustic insulation
- Doors and windows
- Furniture
- etc.

Sustainability

Sustainability

"Meeting the needs of the present generation without compromising the ability of future generations to meet their needs."

Brundtland (1987)

Ecological footprint

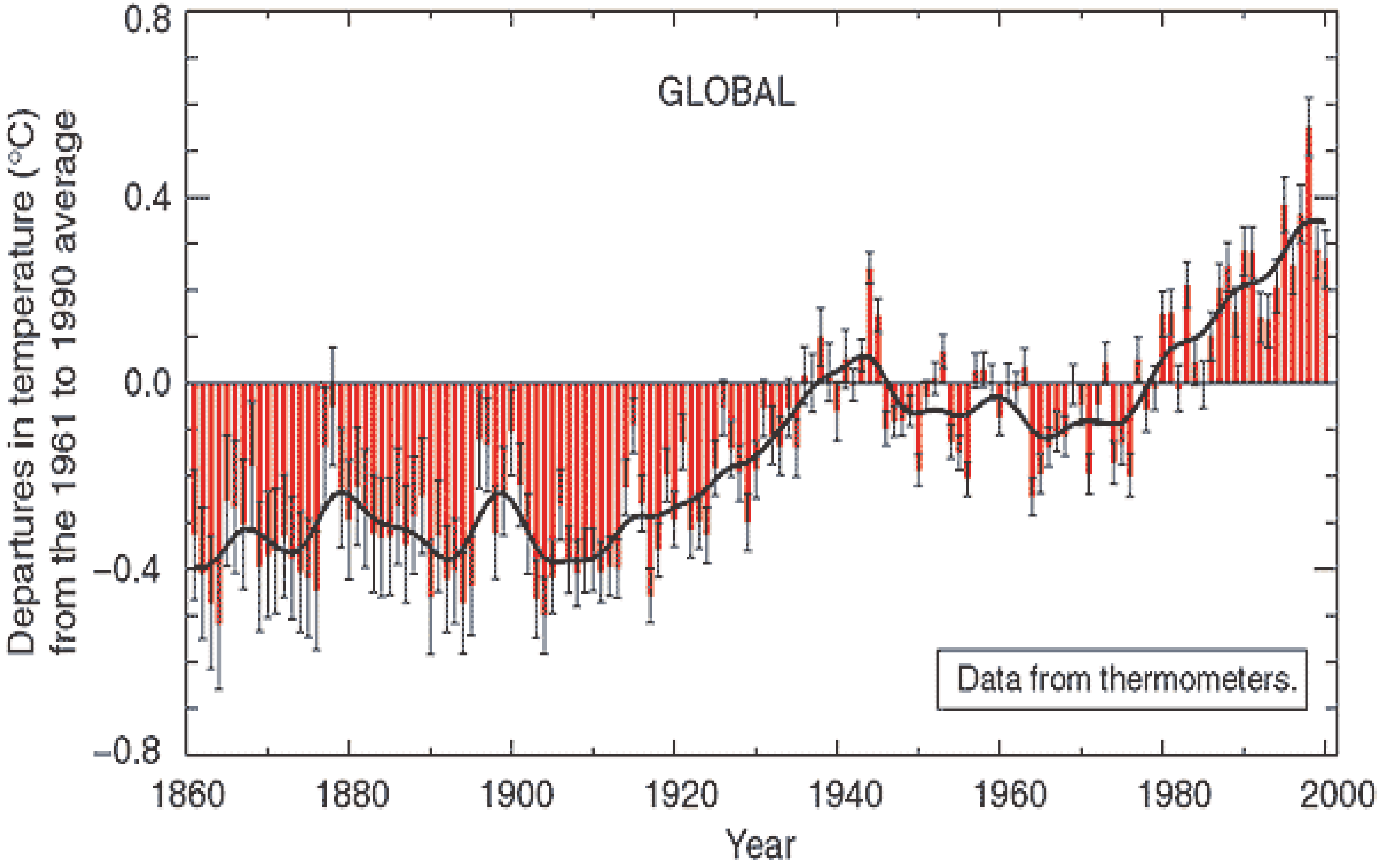
"The amount of ecologically productive land area required to support the resource demands and absorb the wastes of a given population or specific activities"

Global warming:

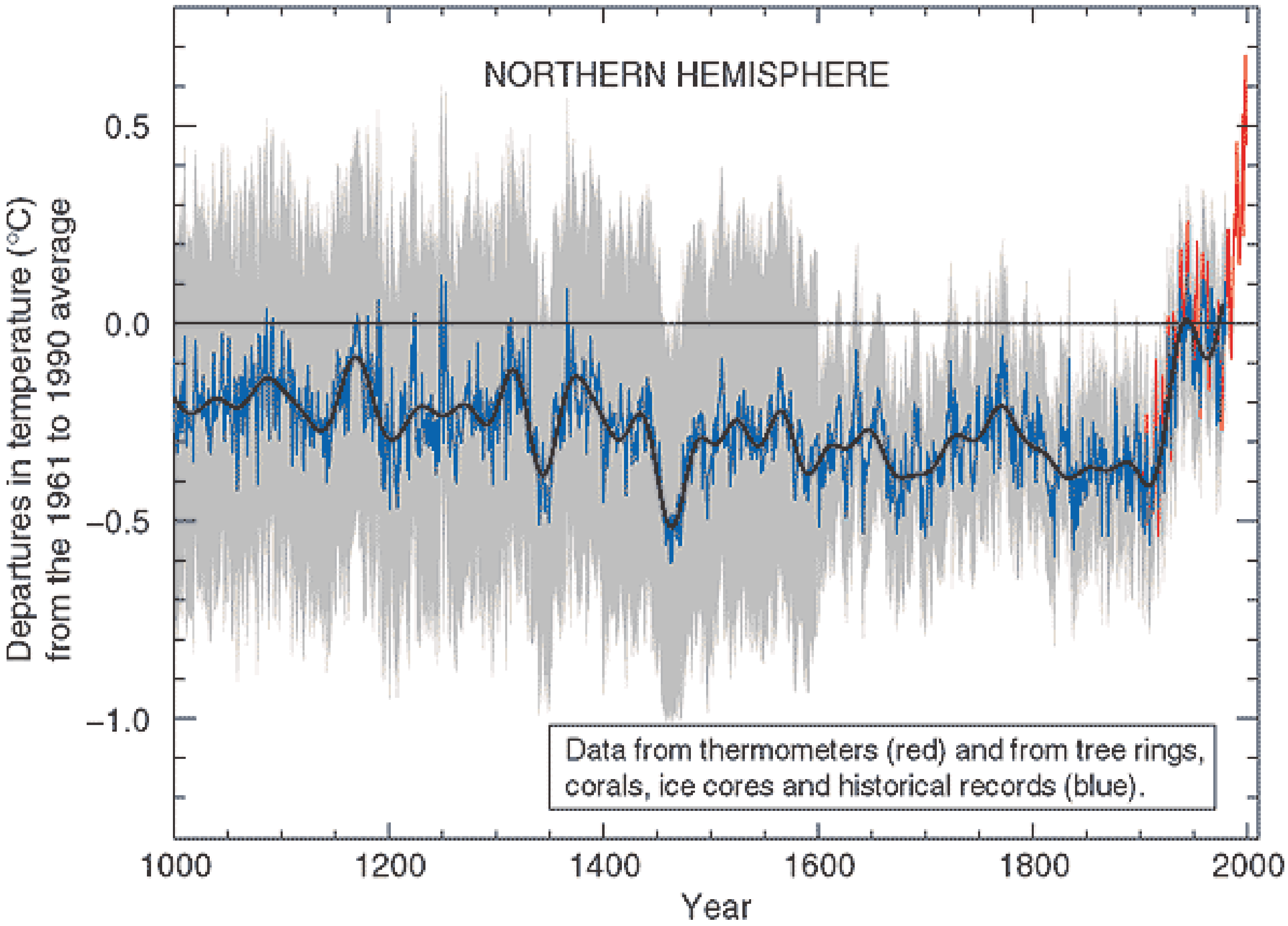
a Huge problem for our planet!

Variations of the Earth's surface temperature for:

(a) the past 140 years



(b) the past 1,000 years

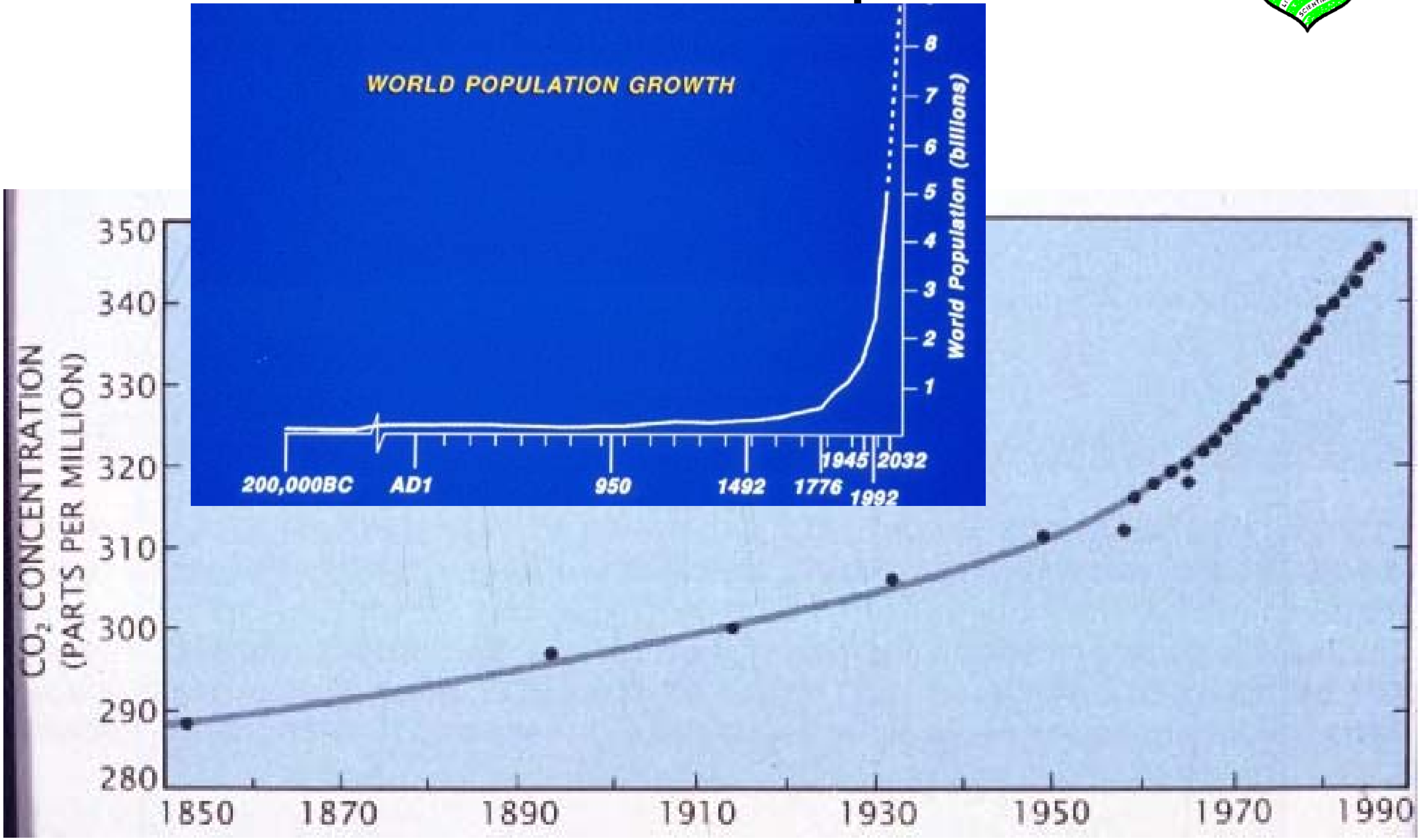


Global warming

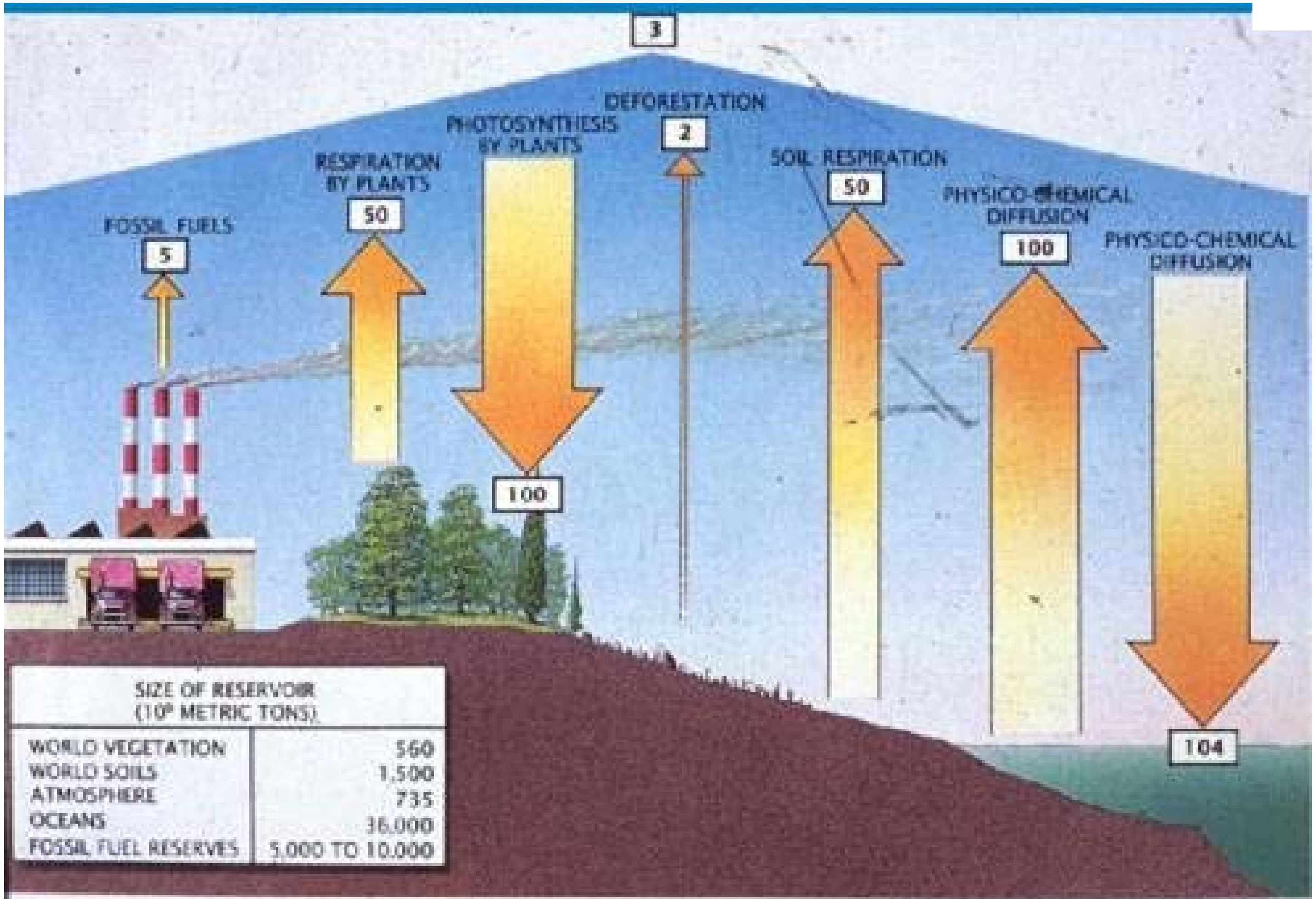
Possible consequences of global warming:

- **De-icing of the mountain, artic and Antarctic glaciers with increase of the sea and ocean levels;**
- **More extreme weather events (hurricanes, heat waves, etc.);**
- **Loss of biodiversity with extinction of animals and plant species;**
- **Etc.**

CO_2 in atmosphere



Global carbon cycle



NNUAL CARBON FLUXES are shown in units of one billion 0⁹) metric tons. Photosynthesis on land removes about 100 illion tons of carbon from the atmosphere annually in the rm of carbon dioxide. Plant and soil respiration each return bout 50 billion tons. Fossil-fuel burning and deforestation release into the atmosphere respectively about five and two billion tons. Physicochemical processes at the sea surface release about 100 billion tons into the atmosphere and absorb about 104. The net atmospheric gain is about three billion tons annually. The table lists the world's major carbon reservoirs.

Global carbon cycle

How to reduce the volume of CO_2 in the atmosphere?

- **By reducing the** CO_2 emissions due to anthropogenic activities (use of fossil fuels);
- **By reducing deforestation and increasing the forested land** (photosynthesis - CO_2 is stored in the trees);
- **By using more wood in construction (buildings, bridges, etc.)**, since CO_2 is stored in wood.

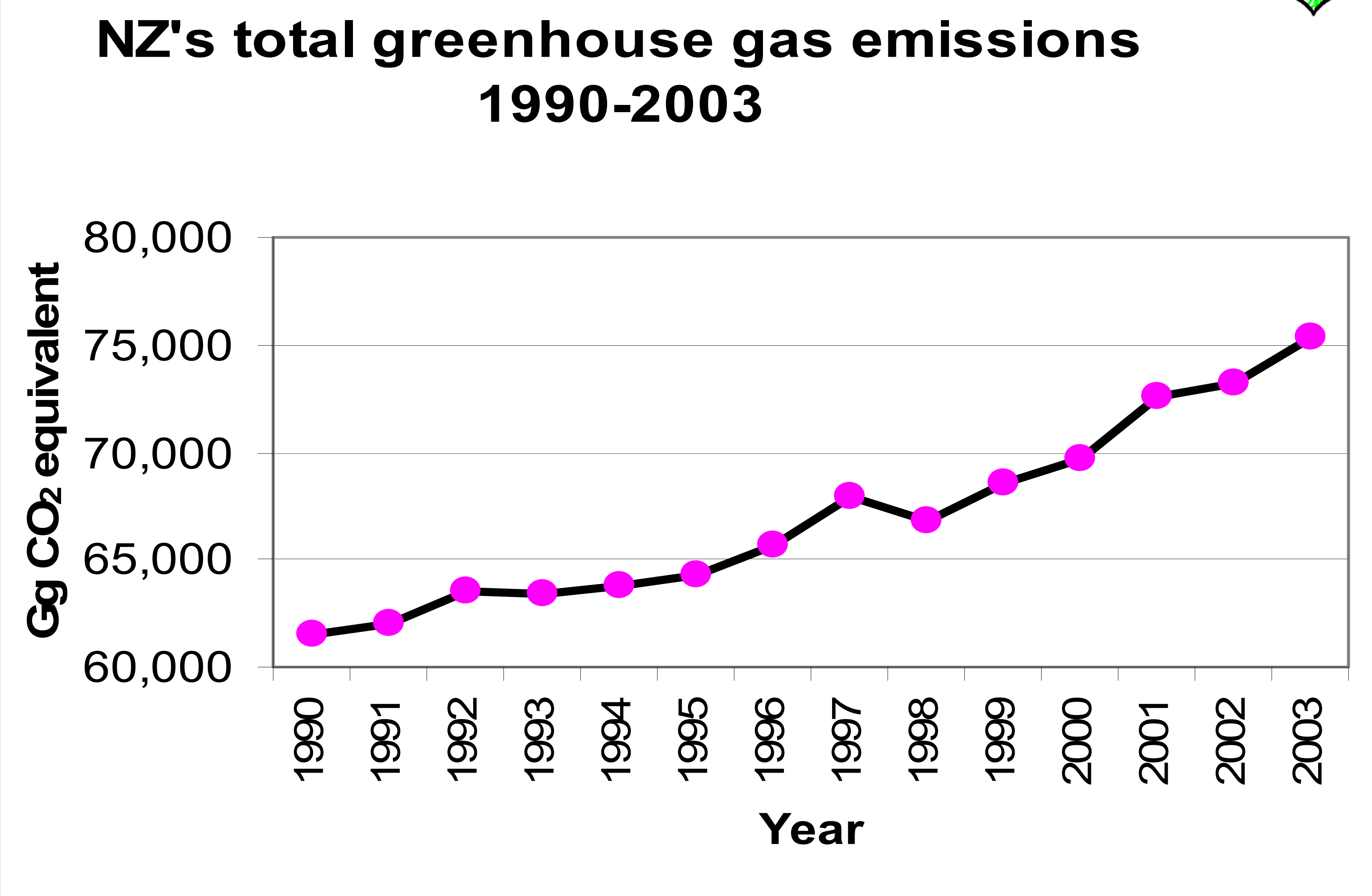
Kyoto Protocol

What were the requirements of Kyoto ?

- Reduce emissions relative to 1990 levels
  - carbon dioxide CO_2
  - methane CH_4

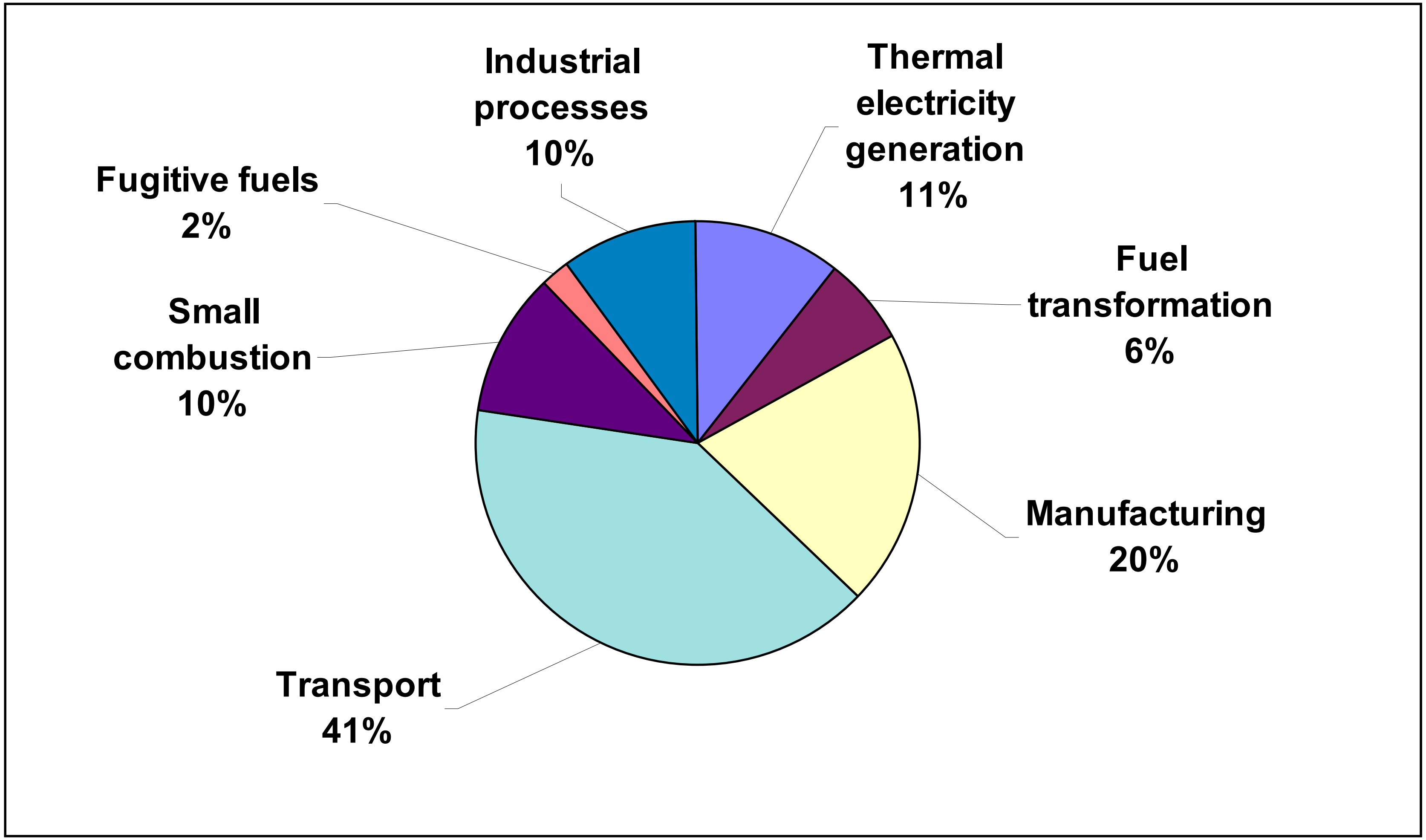
- First commitment period was 2008-2012
- Kyoto allowed carbon in forests to offset CO_2 emissions from other sources

NZ’s GHG Emissions

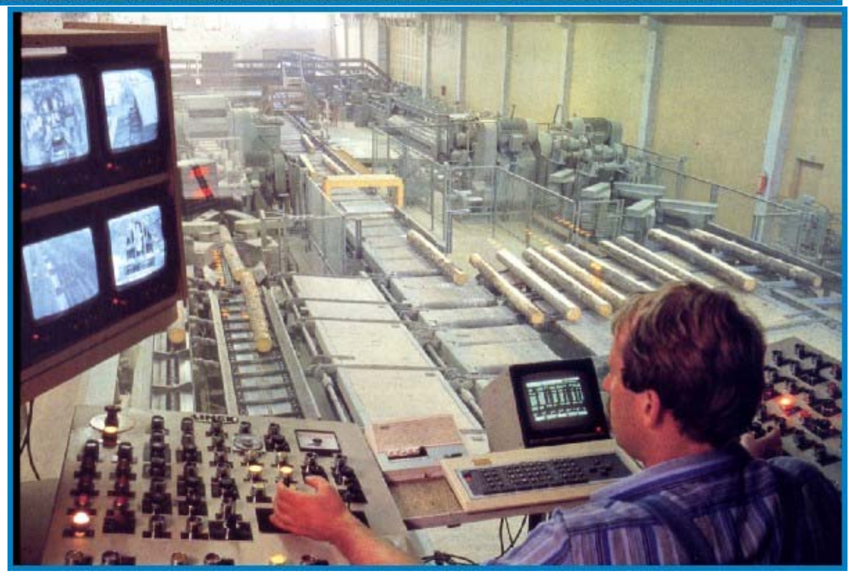


CO_2 Emissions

New Zealand's emissions in 2003 were 37% higher than in 1990



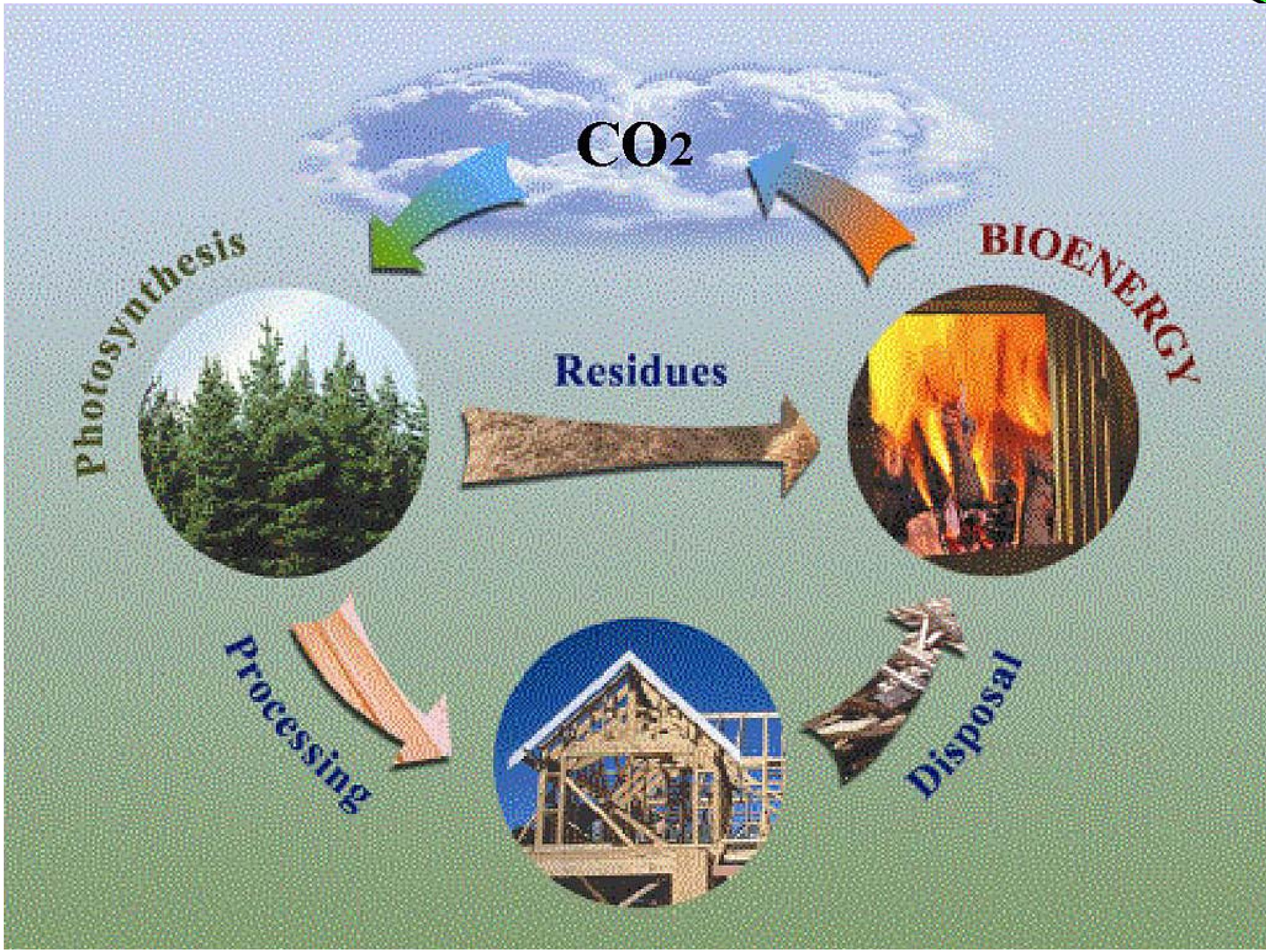
Forestry can help



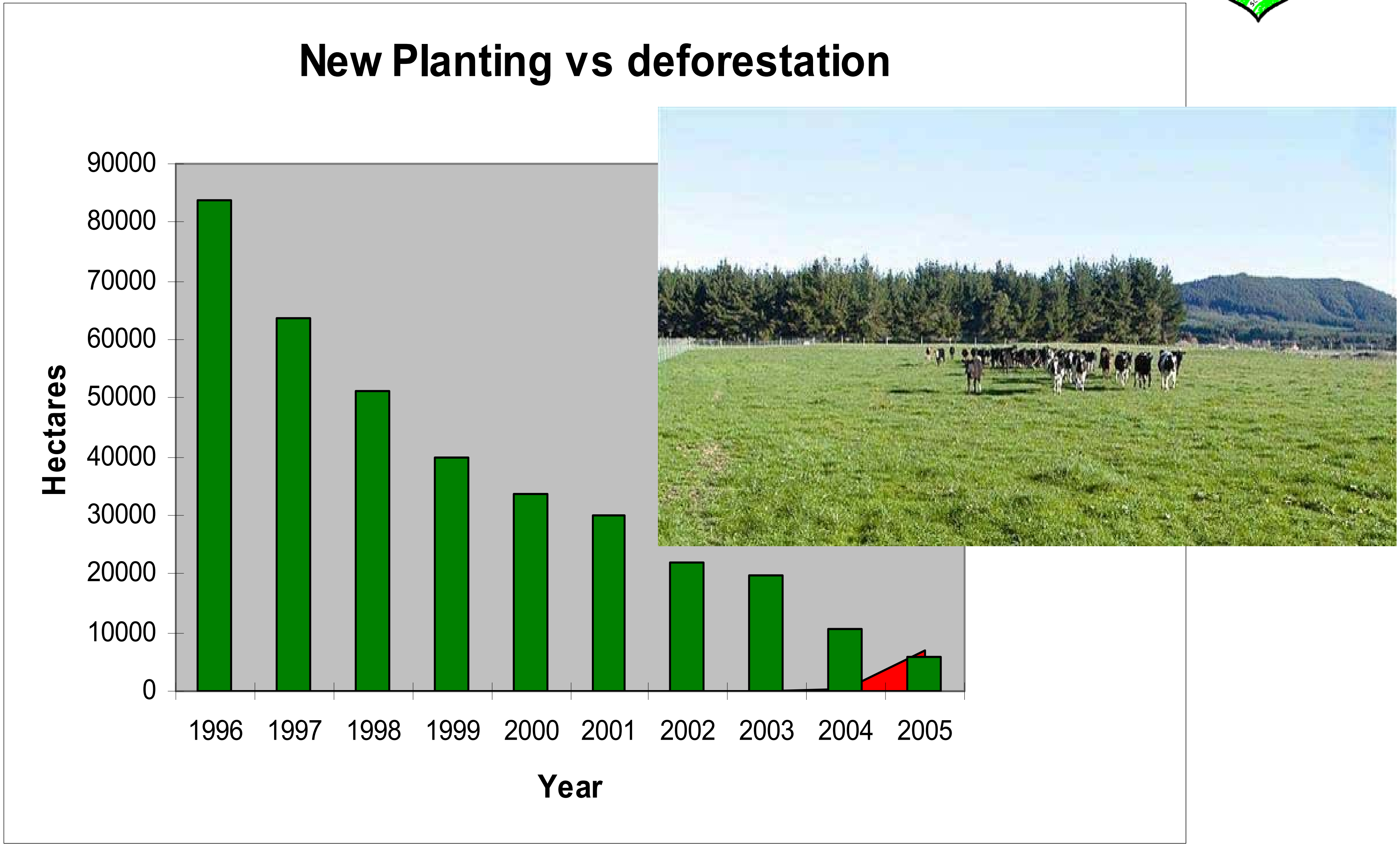
Wood – a renewable resource

Planted forests are manufactured by the sun, and managed sustainably for production of renewable building materials.

Global carbon cycle



An example: forestry in New New Zealand



Planting trees is not enough

To optimize forestry for offsetting fossil fuel emissions, it is necessary to:

1. Plant new forests on non-forested land
2. Maintain planted forests in perpetuity
3. Manage the forests for wood production
4. Use wood as a building material
5. Extract solar energy from the wood waste

Buildings

The structural skeleton of a building can be made of different construction materials:

Buildings

- **in reinforced concrete**
- **in masonry**
- **in steel**
- **in timber**

Energy in buildings

1. Construction

Embodied energy in materials

2. Operation

Energy for heating, cooling etc

(Thermal envelope, passive solar, natural lighting etc)

Fossil fuel energy is directly related to CO_2 emissions

Energy and CO_2 benefits of more wood in buildings

1. Reduced fossil fuel for heating and cooling, over life of building (wood is an insulating material)

2. Increased pool of carbon in wood and wood products (due to photosynthesis)

3. Less fossil fuel for making wood rather than steel, concrete, aluminium (reduced embodied energy)

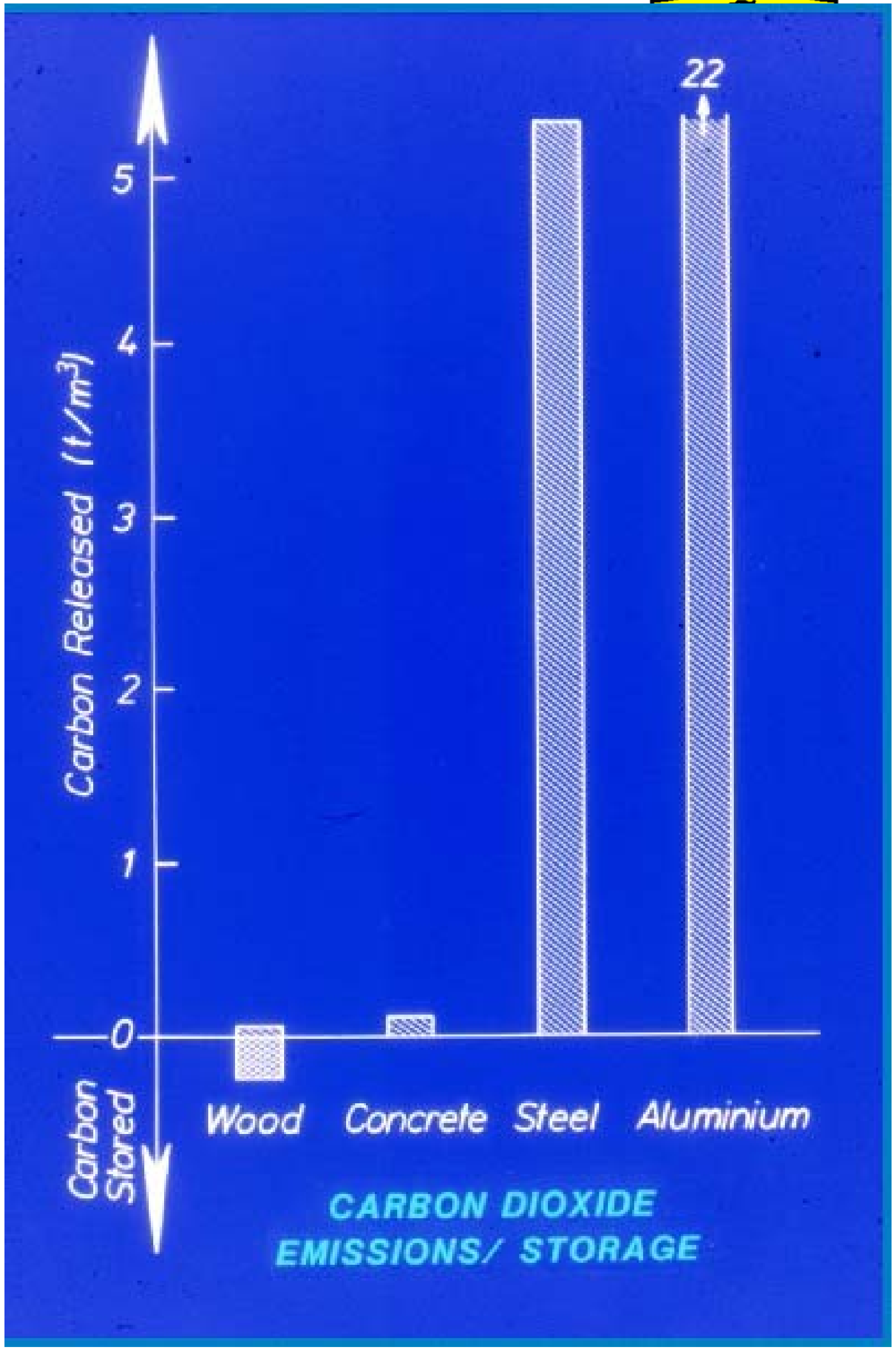
4. Displacement of fossil fuel by burning wood waste materials

Carbon stored in timber buildings

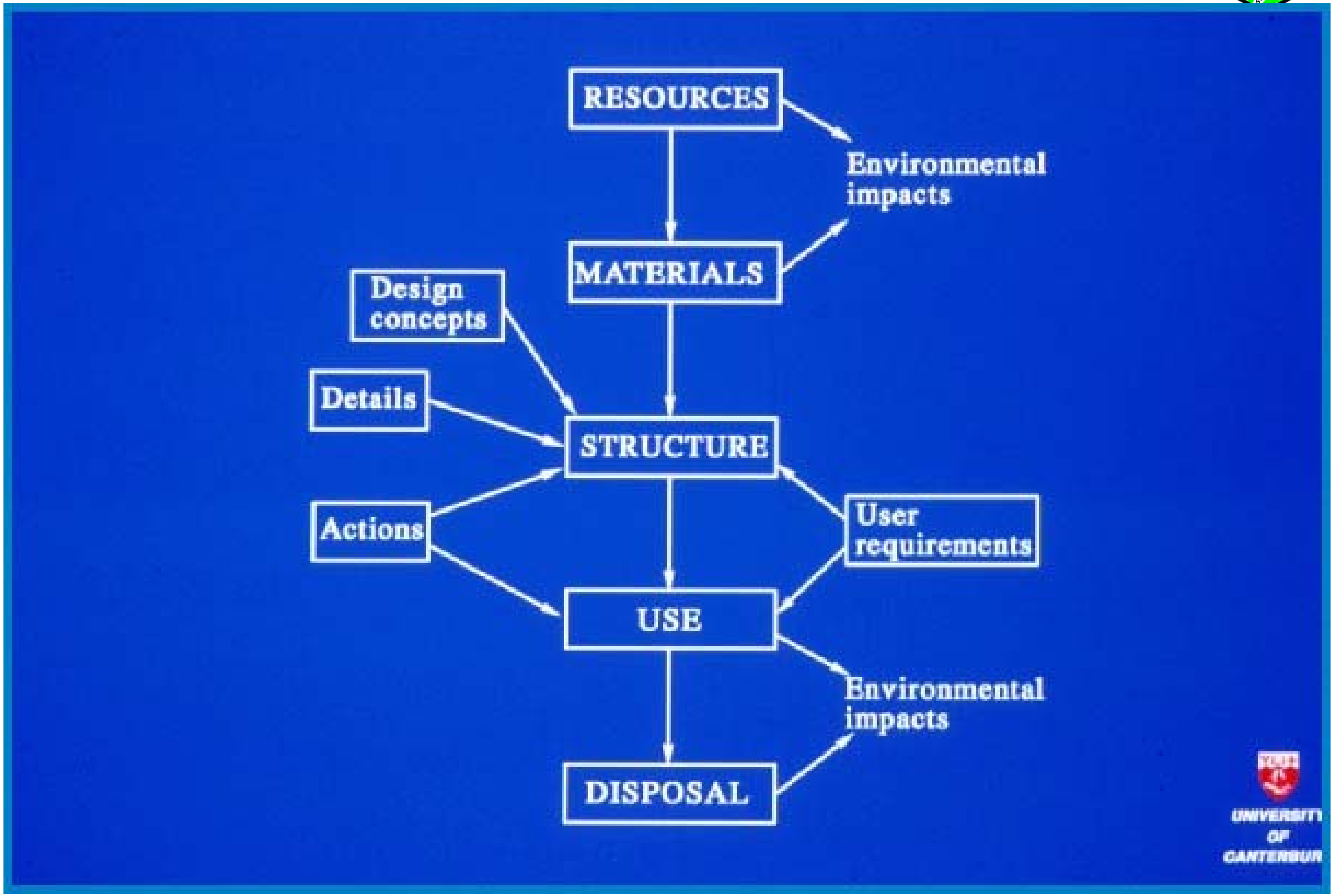
Carbon is only stored for life of building

CO_2 in materials

- Burning fossil fuel to make materials
- Less if energy comes from renewables
- CO_2 released making cement
- Only wood can store carbon



Flow of resources for buildings



Life Cycle Assessment (LCA)

- Lifetime environmental merits of products or processes
  - Extracting & processing raw materials
  - Manufacturing
  - Transportation, distribution & construction
  - Use & maintenance
  - Recycling or final disposal

- ISO 14000

Embodied energy:

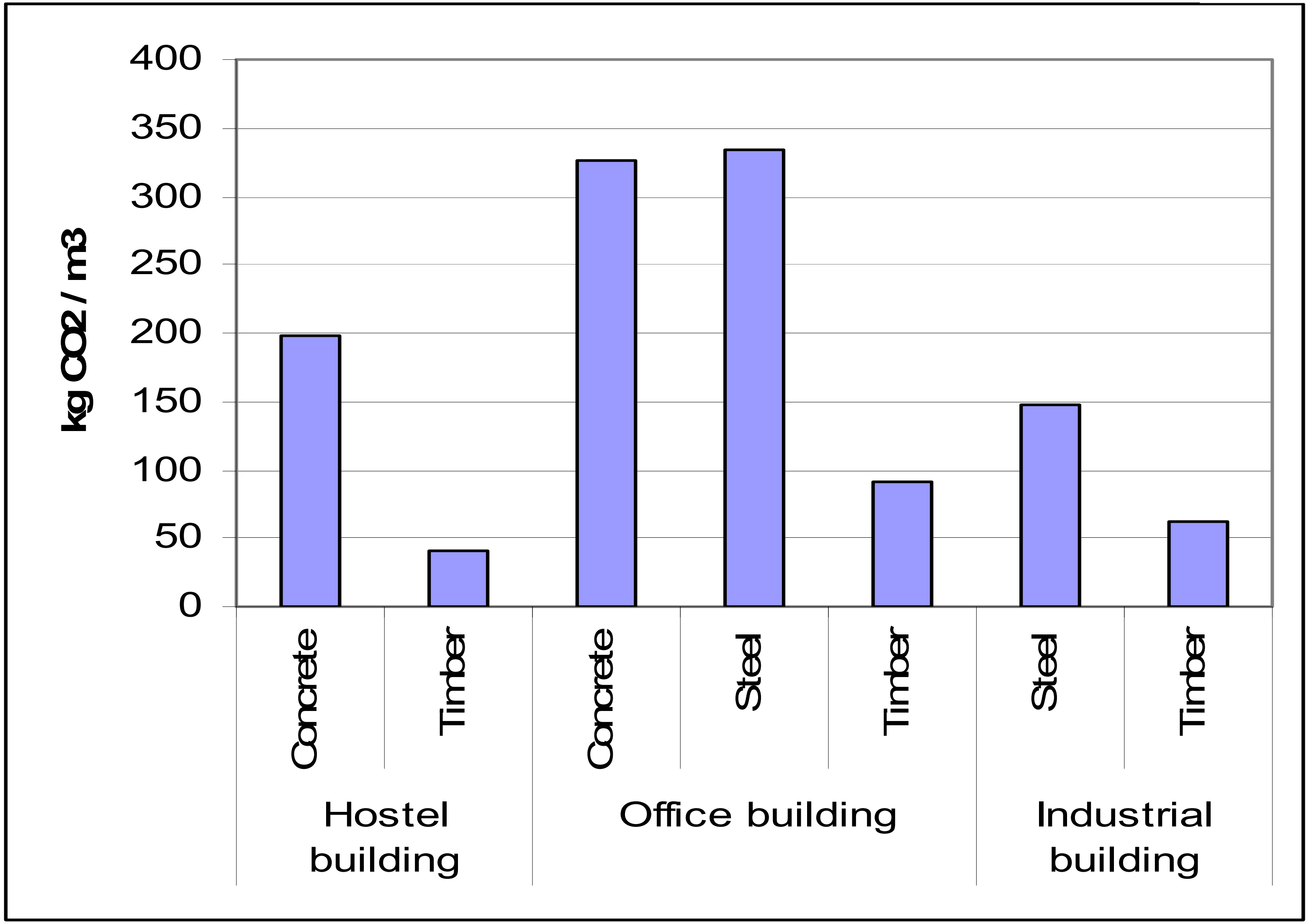
Energy consumed in the acquisition of raw materials, processing, manufacturing, transport to site & construction, and disposal

Embodied effects summary: *(Canadian Wood Council)*

Environmental effect	Timber	Steel	Concrete
Embodied energy	1	1.26	1.57
GHG emissions	1	1.34	1.81
Air pollution	1	1.24	1.47
Water pollution	1	4.00	3.50
Resource consumption	1	1.11	1.81
Solid waste production	1	1.08	1.23

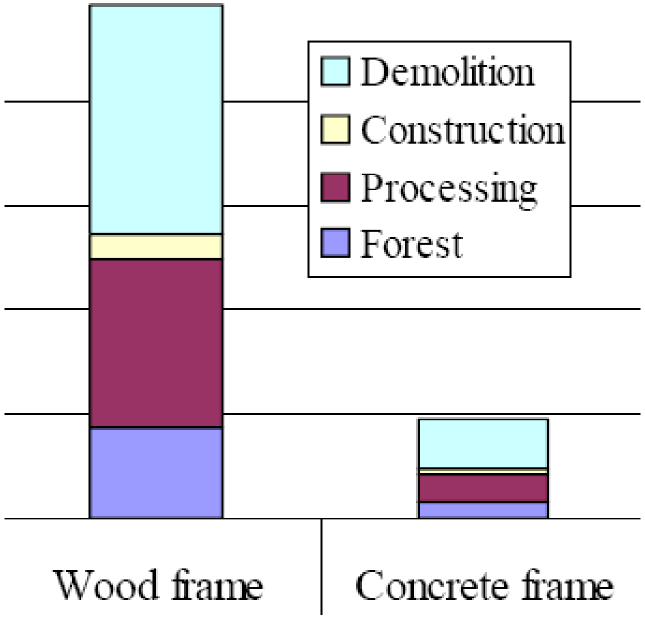
Embodied energy

CO_2 emissions

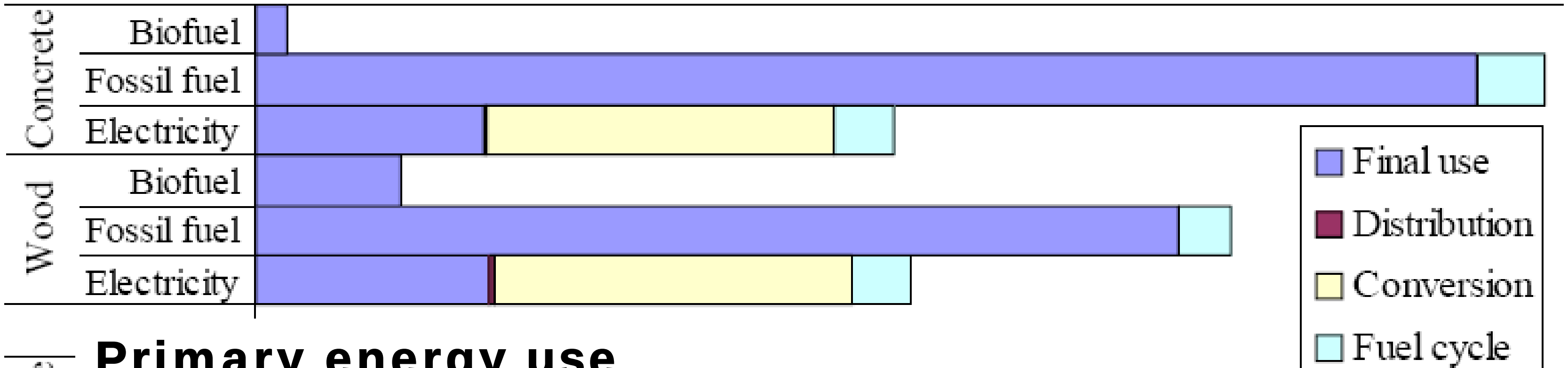


Energy from wood waste

Building in Finland



Biofuel production



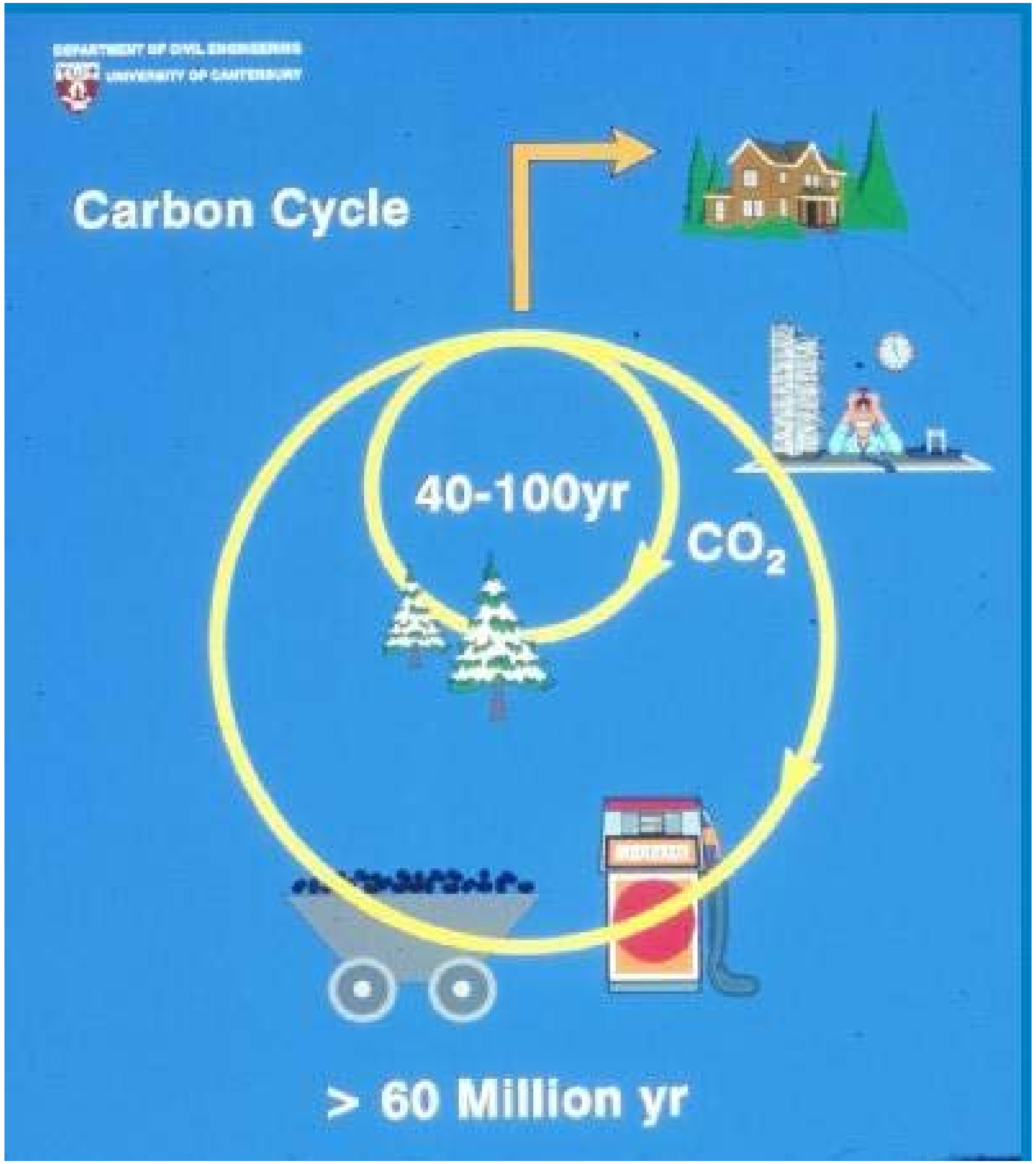
Primary energy use

Wood as biofuel

- Burning wood is "carbon neutral"
- Scandinavian countries get 20% of energy from wood

- Exciting potential - requires investment
  - Clean burning wood pellets
  - Wood-fired power stations
  - Co-generation of heat and electricity
  - Gas and other biofuels

Global carbon cycle



Wood is a renewable material - cycles of 25 to 50 years are needed to create a tree ready for harvesting from the sidling compared to the millions years needed to create coal and oil

Some advantages of wood over other materials:

- Aesthetical appearance and pleasant smell
- Sustainability
- Hygroscopicity
- Thermal insulation
- Tensile, compression and bending strength
- High strength-to-weight ratio
- Speed of erection
- Excellent seismic resistance

Aesthetical appearance and pleasant smell:

- **Often preferred by architects and clients to decorate a flat/house**
- **The wood is pleasing to smell**

Sustainability:

- **Material regeneration over 25 to 50 years rotation cycles**
- **Reduced CO_2 emissions**
- **Reduced embodied energy**

Hygroscopicity:

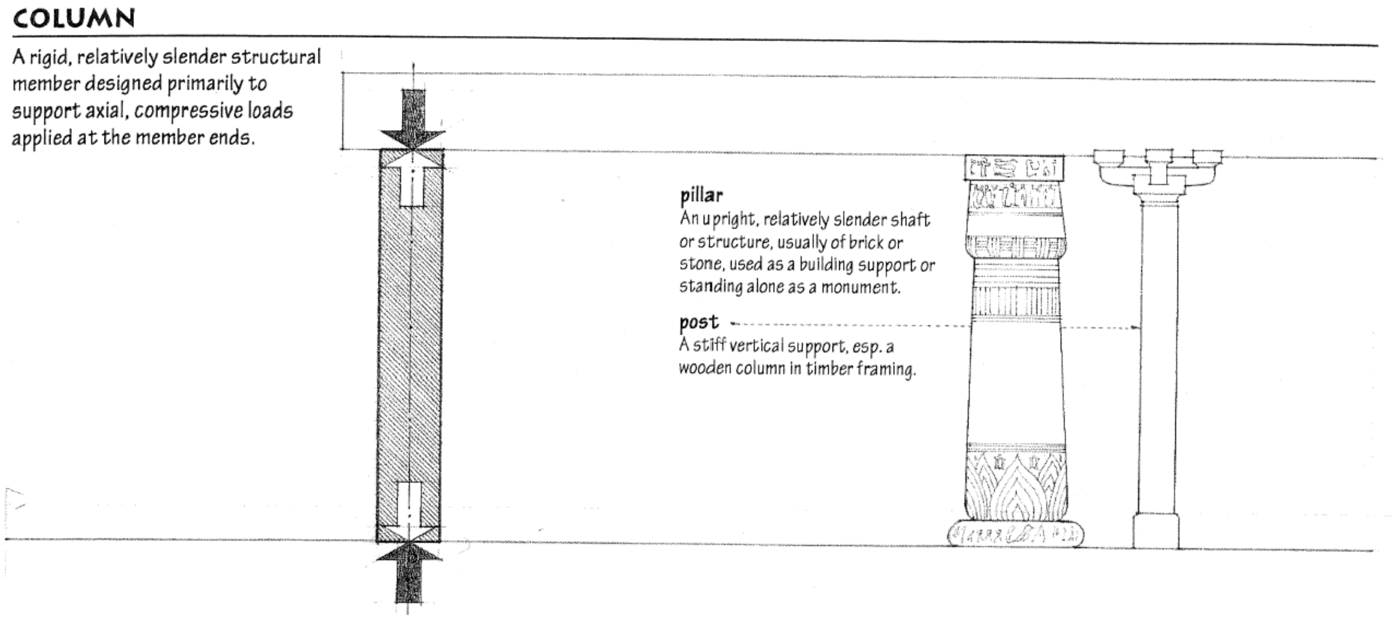
- Wood breaths, meaning that it can absorb excessive air humidity and return it later to the environment, acting as a sort of reservoir to reduce the humidity fluctuations and ensure a dry environment
- This effect is very important to ensure a healthy indoor condition (no mould, etc.) and the well being in a timber building

Thermal insulation:

- Wood has an excellent thermal insulation, which contributes to reduce the primary energy consumption of the building
- Due to this properties, wood appears as a dry and warm material when touching it
- Appropriate thermal mass can be obtained in massive timber structures (e.g. Xlam system), which is important to reduce the environmental thermal variations in summer and wintertime

TENSILE AND COMPRESSION STRENGTH:

- **Due to the high tensile and compression strength, unlike other materials such as concrete and masonry, timber can be used for beams, columns, truss systems without the need of coupling it with other materials**

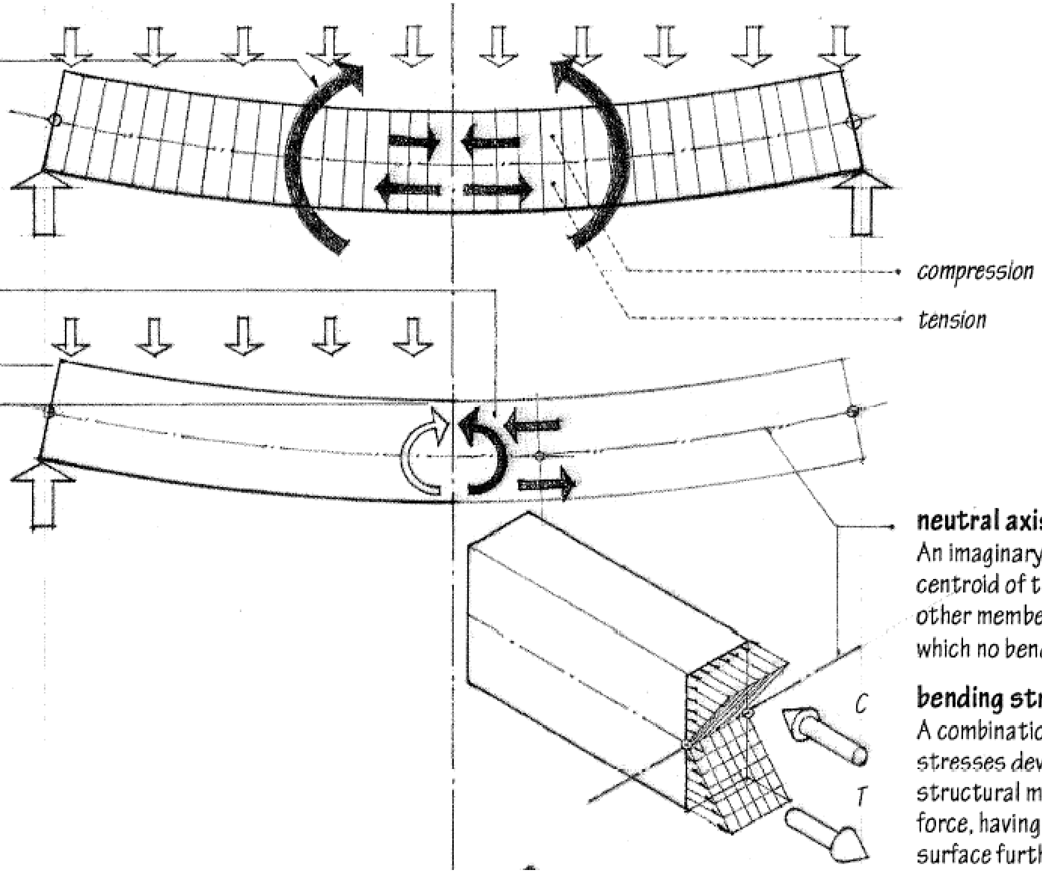


BEAMS:

bending moment
An external moment tending to cause part of a structure to rotate or bend, equal to the algebraic sum of the moments about the neutral axis of the section under consideration.

resisting moment
An internal moment equal and opposite to a bending moment, generated by a force couple to maintain equilibrium of the section being considered.

deflection
The perpendicular distance a spanning member deviates from a true course under transverse loading, increasing with load and span, and decreasing with an increase in the moment of inertia of the section or the modulus of elasticity of the material.



neutral axis
An imaginary line passing through the centroid of the cross section of a beam or other member subject to bending, along which no bending stresses occur.

bending stress
A combination of compressive and tension stresses developed at a cross section of a structural member to resist a transverse force, having a maximum value at the surface furthest from the neutral axis.

HIGH STRENGTH-TO-WEIGHT RATIO:

PROPERTY	TIMBER	STEEL	CONCRETE
Permissible stress (compr.) σ_{adm} [MPa]	10	160	10
Unit weight γ_m [daN/m^3]	500	7850	2400
Ratio γ_m / σ_{adm}	50	50	240
Elastic modulus [GPa]	10	210	30
Tensile strength	Yes	Yes	No
Ductility	No	Yes	No
Time dependent behaviour	Yes	No	Yes
Hygroscopic behaviour	Yes	No	No
Isotropy	No	Yes	Yes
Omogeneity	No	Yes	Yes
Combustibility	Yes	No	No

HIGH STRENGTH-TO-WEIGHT RATIO:

REMARK: Suppose we want to design a column subjected to a vertical load P=1000 kN.

	Formula	Unit	Timber	Steel	Concrete
Area	$A=P/\sigma_{adm}$	cm^2	**33x33=1000**	**7.9x7.9=62.5**	**33x33=1000**
Weight	$W=A\gamma_m$	**daN/m**	**50**	**49**	**240**

Timber and concrete columns have an **area 16 times larger than steel** columns (hence they are **bulkier than steel** structures).

HIGH STRENGTH-TO-WEIGHT RATIO:

But: because of the different density, **timber and steel columns weigh just 1/5th of concrete ones!!!**

Timber structures are lightweight!!!

Benefits of having a **light structure:**

- **Less load on foundations** and soil
- **Less** mass and, hence, less **seismic action**
- **Simple transportation and erection**

POSSIBLE PROBLEMS WITH LIGHT STRUCTURES:

- **Important effects due to the wind** (possible unroofing)
- **Important effects of snow (due to the high Q/G ratio, there are only few safety margins in the case of an increase in Q with respect to the design value)!**

SPEED OF ERECTION:

- ‘Dry’ construction without the need of waiting for curing and hardening of concrete
- No formworks and props

Construction time: 28 days

Construction time: few hours

SPEED OF ERECTION:

- **Ease of handling thanks to the light weight**
- **Possibility of prefabrication off-site by reducing the work on the building site to a minimum (connections among structural members)**



Excellent seismic resistance:

- **Excellent seismic performance with limited residual damage at the end of the seismic event and important energy dissipation**

Shaking table test 2007, SOFIE Project, Miki –
Seismic Input : JMA Kobe 3D x,y,z 0.60, .82, 0.34 g

(Courtesy of Prof. Ceccotti)

SOME DISADVANTAGES OF TIMBER:

- **Influence of defects**
- **Anisotropy**
- **Reduced Modulus of Elasticity and creep behaviour**
- **Influence of the moisture content (dimensional variations)**
- **Reduced ductility**
- **Possible durability problems if in contact with water/humidity**
- **Combustibility**

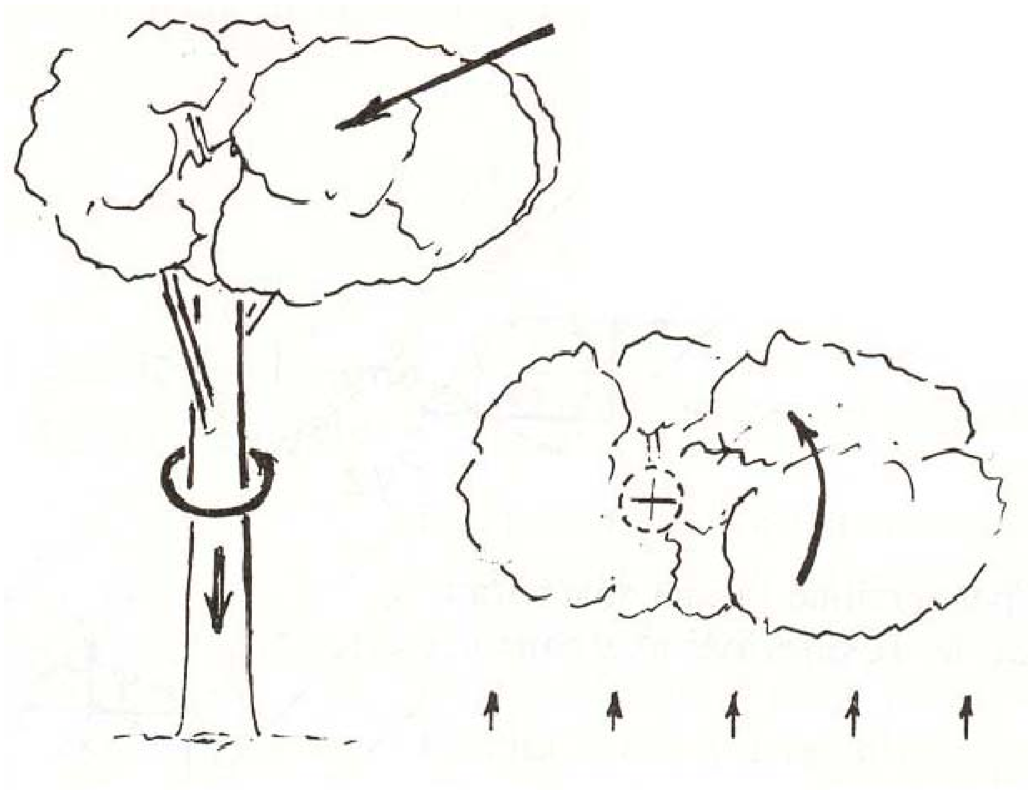
INFLUENCE OF DEFECTS:

- Wood is markedly **heterogenous**

- Wood has important **defects**, which significantly affect its mechanical properties:
  - **grain deviation**
  - **knots**

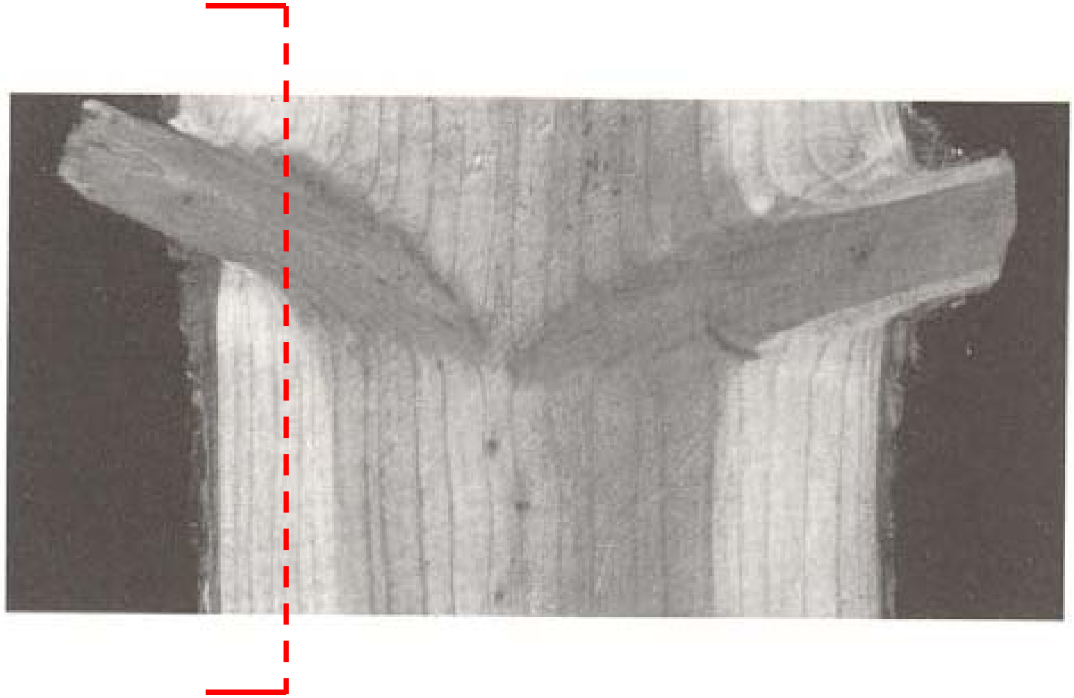
INFLUENCE OF DEFECTS:

Grain deviation: in trees that grow in a spiral



INFLUENCE OF DEFECTS:

Knots: part of the branches embedded in the main trunk of the tree

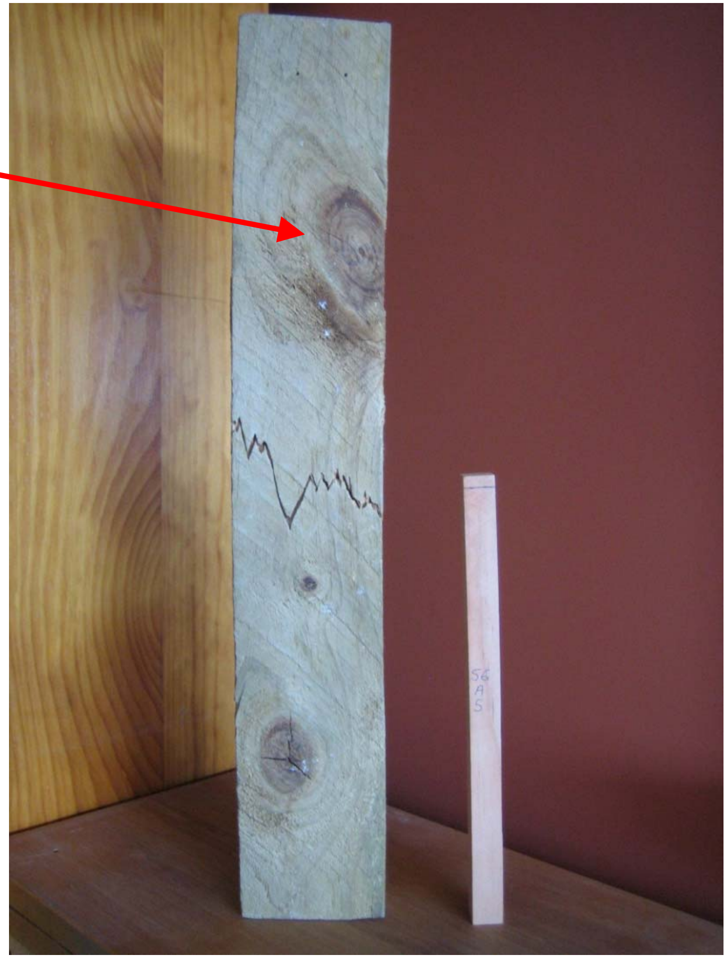


INFLUENCE OF DEFECTS:

- Knots

- Grain deviations

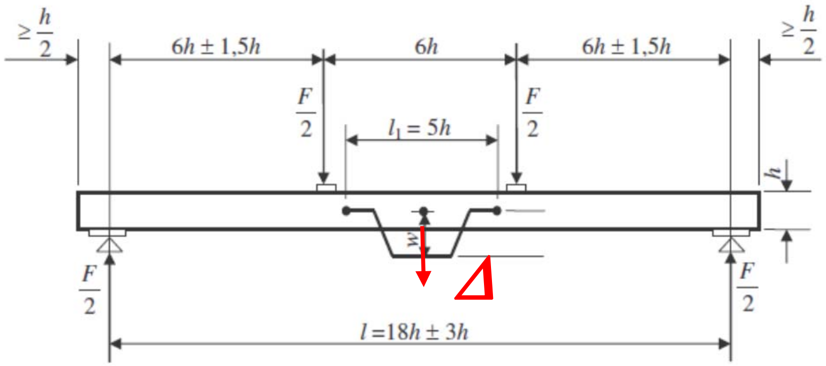
Defects reduce strength and increase the scatter of the mechanical properties

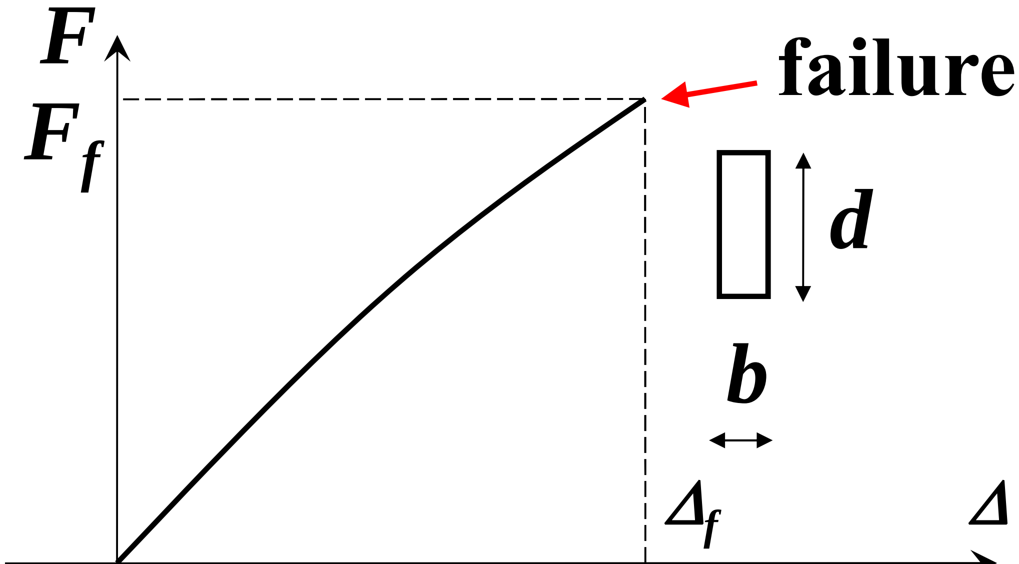


THE STRENGTH OF WOOD:

How is the strength of wood f_m measured?

By the **bending test**, carried out on beams.

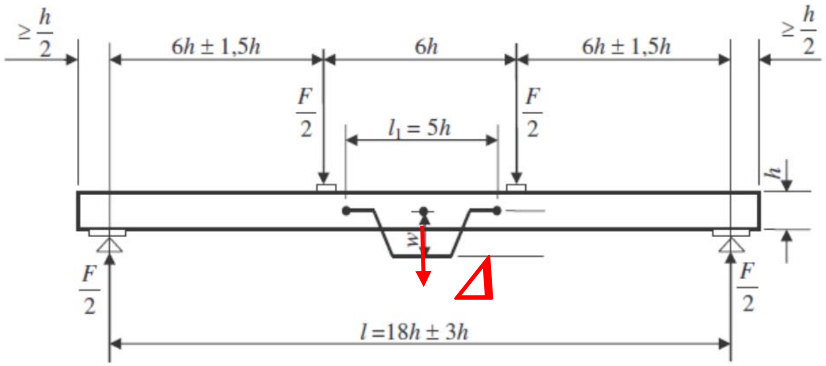


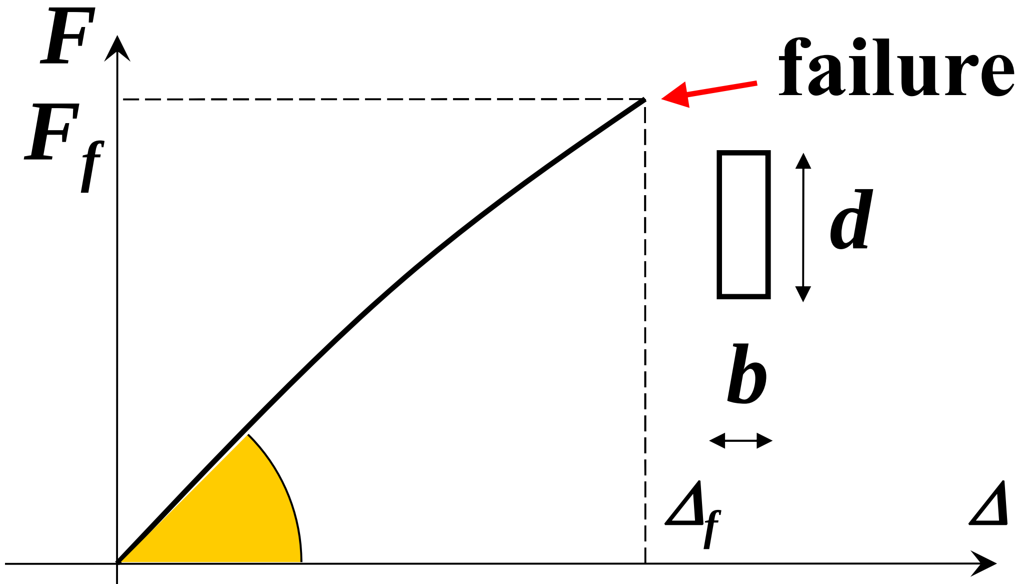


$$f_m = M_f/Z = (F_f L/6)/(bd^2/6)$$

MODULUS OF ELASTICITY:

Affects the deflection of a beam – measures the slope of the F-Δ curve:





$$MOE = \frac{23}{1296} \cdot \frac{FL^3}{\Delta} \cdot \frac{12}{bd^3}$$

THE STRENGTH OF WOOD:

How much does the strength and MOE vary within a species and grade due to the defects?

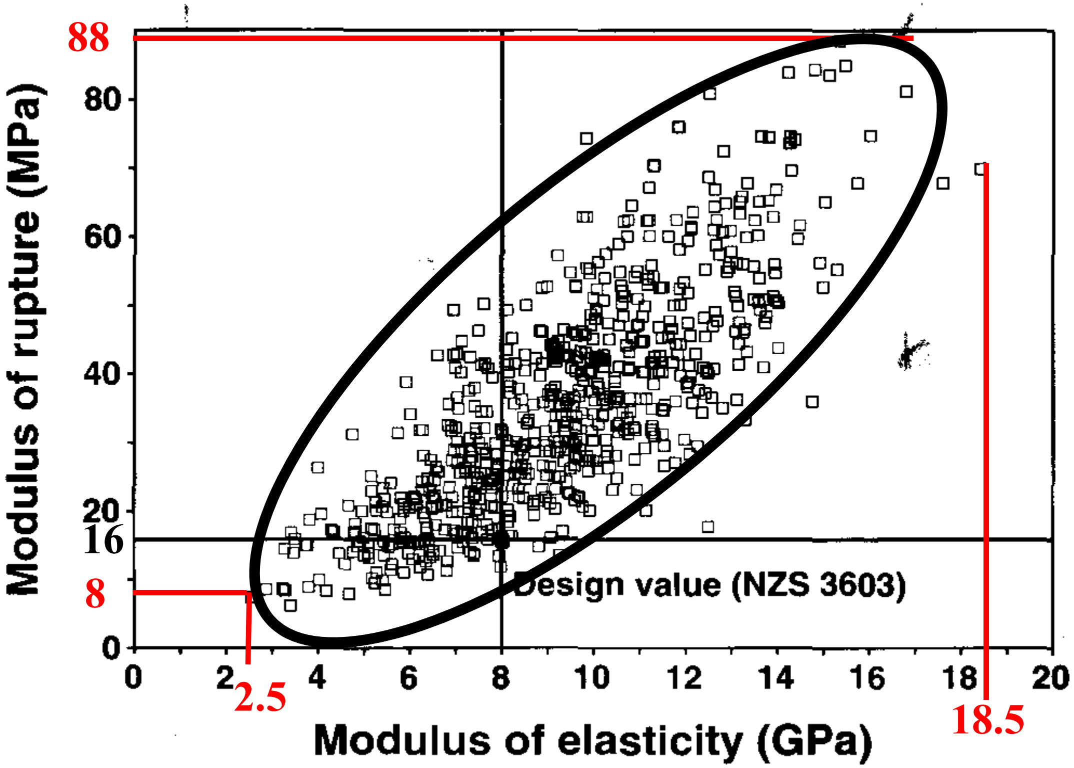
More significantly than for steel and concrete due to the influence of defects (**drawback** which discourage the use of wood): the strongest pieces may be 5 or more times the strength of the weakest pieces

Need to grade the timber (otherwise: the characteristic value would be too low due to the large scatter of experimental results).

THE STRENGTH OF WOOD:

Example of scatter of experimental strength and MOE of New Zealand radiata pine:

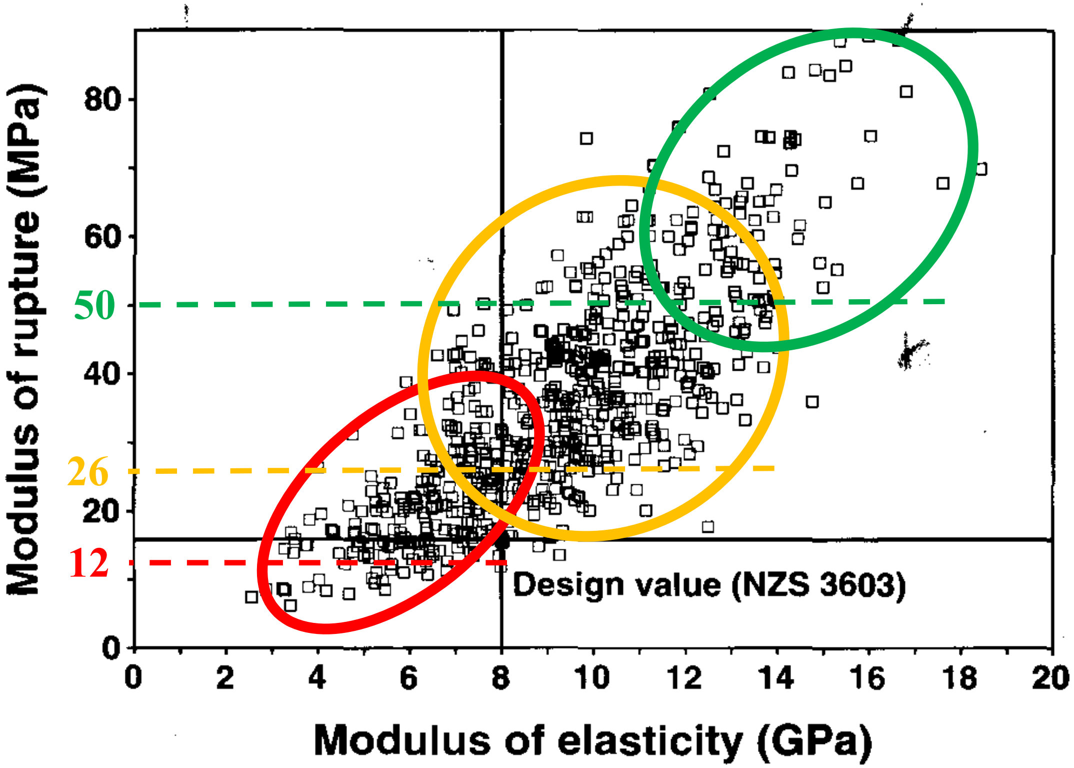
With only one strength class (without grading) the characteristic strength would be 16 MPa for all the timber



THE STRENGTH OF WOOD:

Example of scatter of experimental strength and MOE of New Zealand radiata pine:

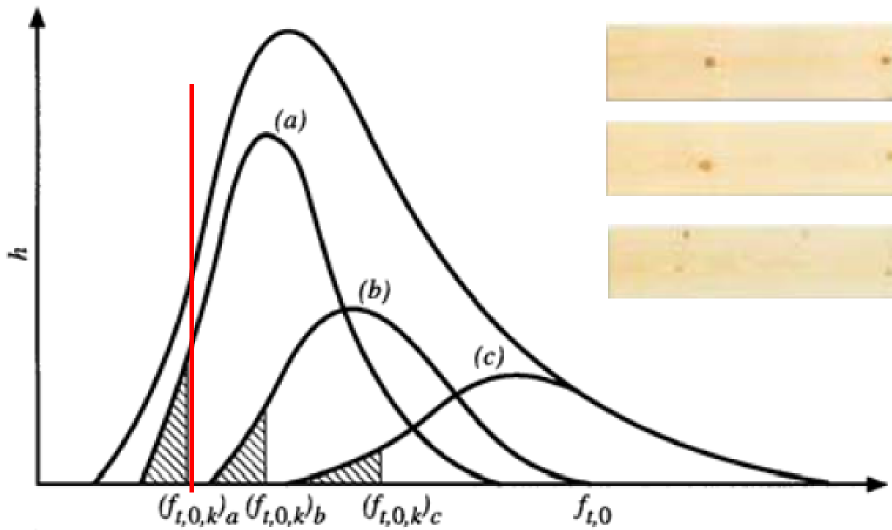
By grading the wood in three classes: three different values of characteristic strength can be obtained: 12 (<16), 26 e 50 MPa



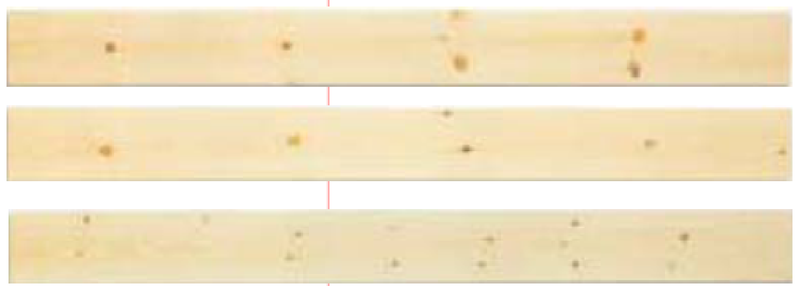
GRADING:

Strength grading

Strength grading is a quality control method by which structural timber is graded in strength groups. All sawn timber for structural purpose is graded



Scheme of tensile strength distribution of structural timber assigned to three grades a, b, c according to Diebold and Glos (1994).



(a)

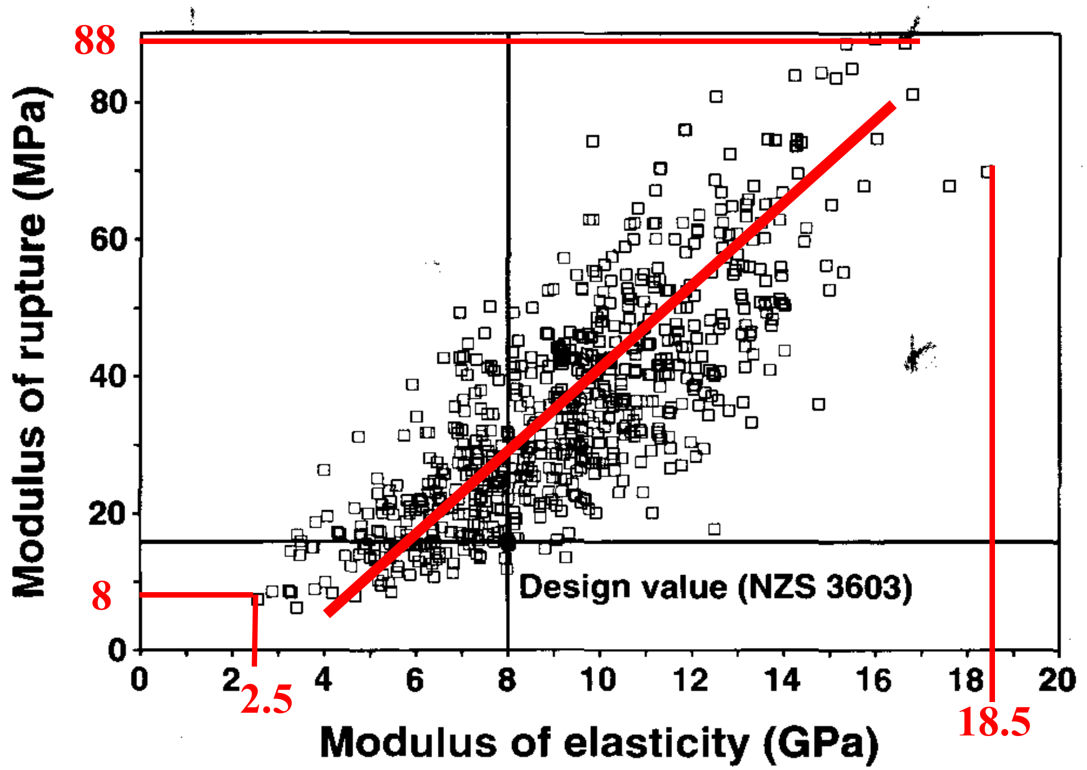
(b)

(c)

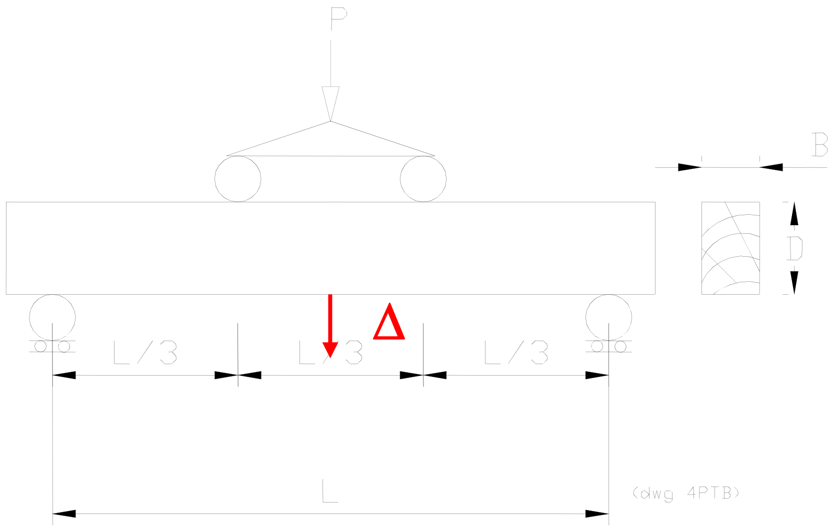
THE STRENGTH OF WOOD:

Relationship between Bending Strength and Modulus of Elasticity for Radiata Pine (NZ Standard):

By measuring the MOE with a non destructive test, it is possible to have an indirect measure of the strength and assign the board to a certain strength class (strength grading)



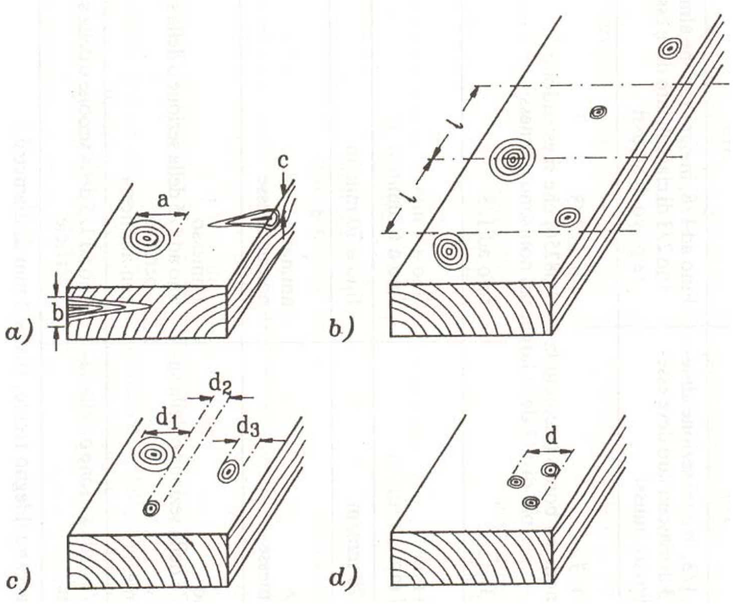
MACHINE GRADING:

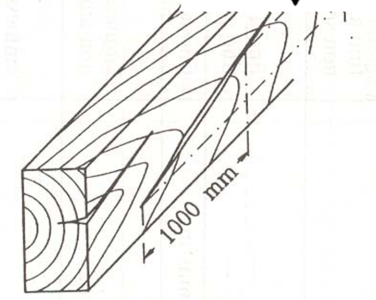


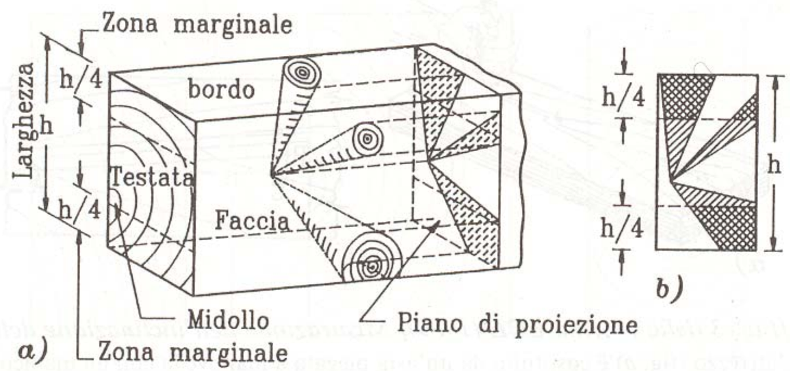
$$MOE = \frac{23}{1296} \cdot \frac{PL^3}{\Delta} \cdot \frac{12}{BD^3}$$

Based on the value of MOE calculated via deflection measurement Δ due to the applied load P in non-destructive bending tests

VISUAL GRADING:







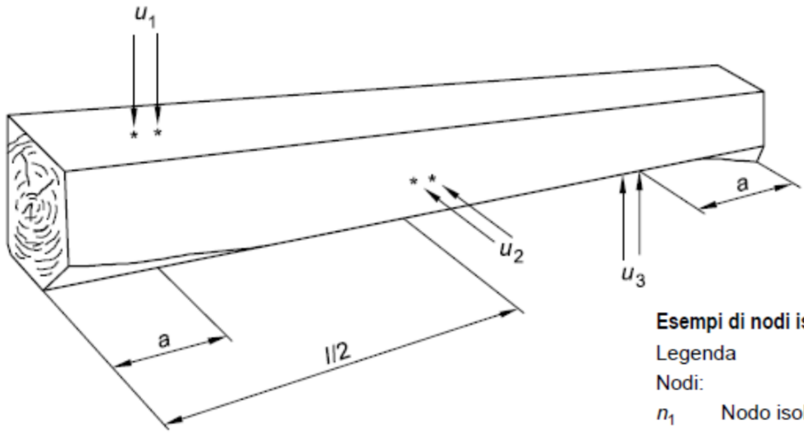
Based on size and number of defects (knots, grain deviation) on the surface of the timber structural element.

VISUAL GRADING – UNI 11035-1:

Determinazione dell'umidità media: $u_{media} = (u_1 + u_2 + u_3)/3$

Legenda

a Distanza dei punti laterali di misura dell'umidità u_1 e u_3 dalle testate dell'elemento, uguale a 1 m

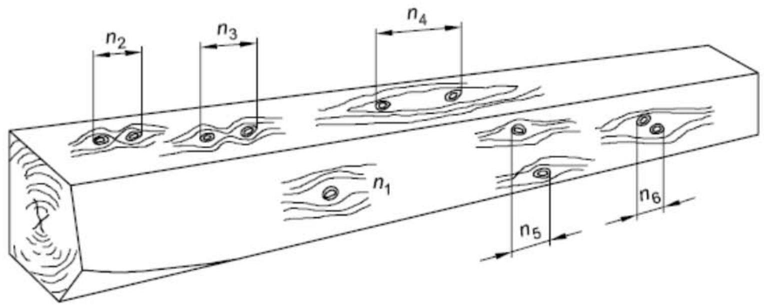


Esempi di nodi isolati e raggruppati

Legenda

Nodi:

- n_1 Nodo isolato
- n_2 Gruppo di nodi, in quanto nodi allineati a meno di 150 mm di distanza
- n_3 Nodi isolati, in quanto allineati a più di 150 mm di distanza
- n_4 Gruppo di nodi, in quanto anche se a più di 150 mm di distanza la fibratura non recupera la direzione originale fra i nodi
- n_5 Nodi isolati, in quanto anche se insistenti su un tratto minore di 150 mm di lunghezza non sono allineati e la fibratura fra di essi recupera la direzione originale
- n_6 Gruppo di nodi, in quanto presentano la fibratura che non recupera la direzione originale



VISUAL GRADING – UNI 11035-1:

4.3.2 **Inclinazione della fibratura**

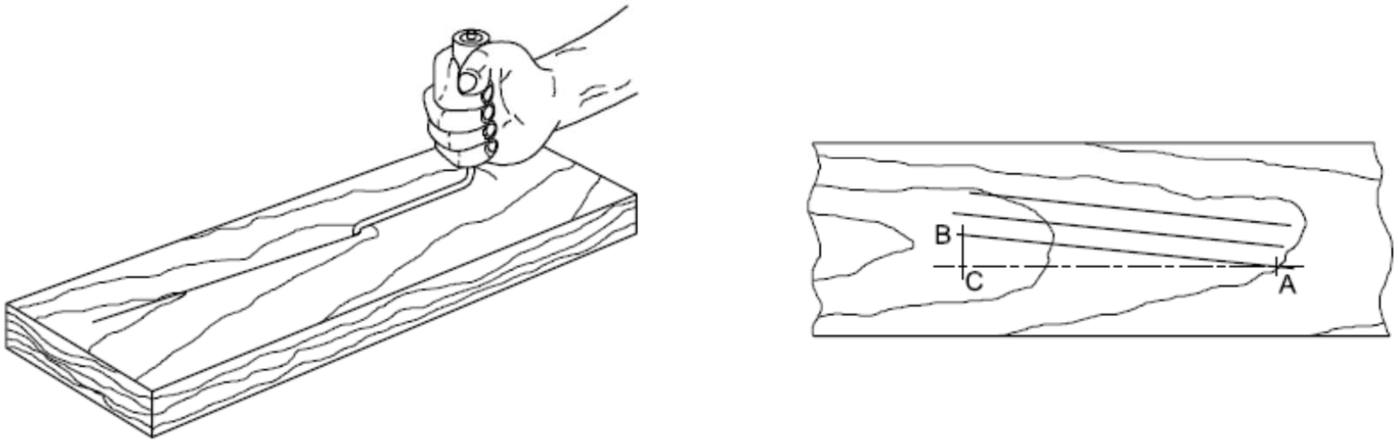
La direzione generale della fibratura viene determinata su una base di misura avente lunghezza minima pari a un metro. Essa può essere determinata sulla base delle fessurazioni da ritiro eventualmente visibili, oppure mediante l’appropriato uso del graffietto (vedere figura 3).

I limiti di ammissibilità per i diversi tipi di legname sono riportati nella UNI 11035-2.

figura 3 **Determinazione dell’inclinazione della fibratura mediante graffietto**

Legenda

AB	Direzione della fibratura, determinata mediante il graffietto
AC	Asse geometrico del segato
BC/AC	Inclinazione della fibratura, espressa come rapporto



VISUAL GRADING – UNI 11035-1:

La rapidità di accrescimento ω, laddove richiesta, dovrà essere misurata su una testata del segato; essa è assunta uguale alla larghezza media, espressa in millimetri, degli anelli di accrescimento. La misurazione si effettua sulla linea più lunga e il più perpendicolare possibile agli anelli di accrescimento e cominciando a y = 25 mm dal midollo quando questo è presente (vedere figura 4). Essa è data da:

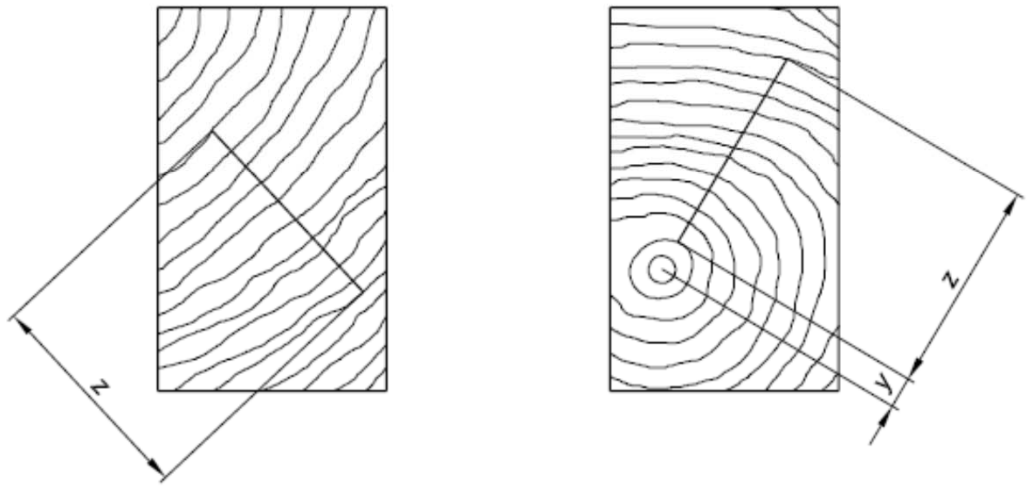
$$\omega = \frac{z}{N} \text{ mm}$$

dove:

z è almeno 75 mm (quando possibile);

N è il numero di anelli compreso in z.

figura 4 **Determinazione della rapidità di accrescimento**

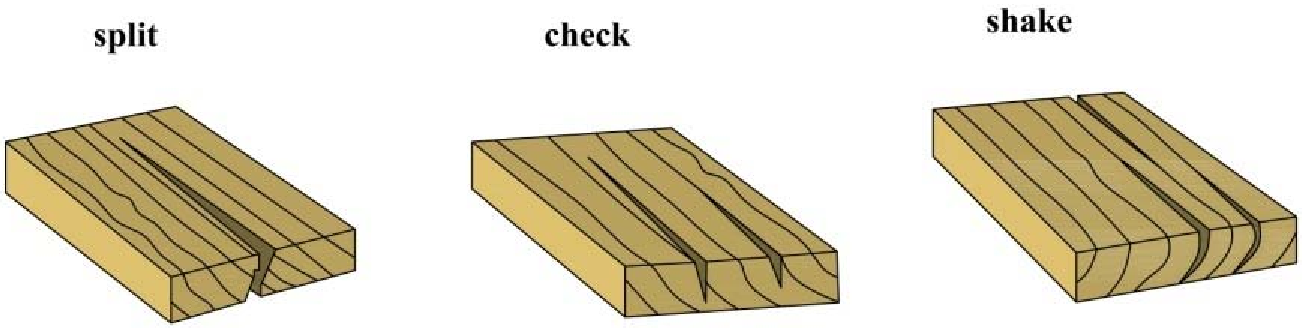


VISUAL GRADING – UNI 11035-1:

4.3.4 Fessurazioni longitudinali da ritiro

La lunghezza delle fessurazioni da ritiro è legata all'umidità, pertanto i limiti assegnati per i diversi tipi di legname nelle regole di classificazione sono di norma applicabili solo per legno equilibrato a umidità del 20% o minore.

I limiti di ammissibilità per i diversi tipi di legname sono riportati nella UNI 11035-2.



4.3.5 Cipollatura

Non sono ammissibili cipollature affioranti su una qualsiasi faccia dell'elemento.

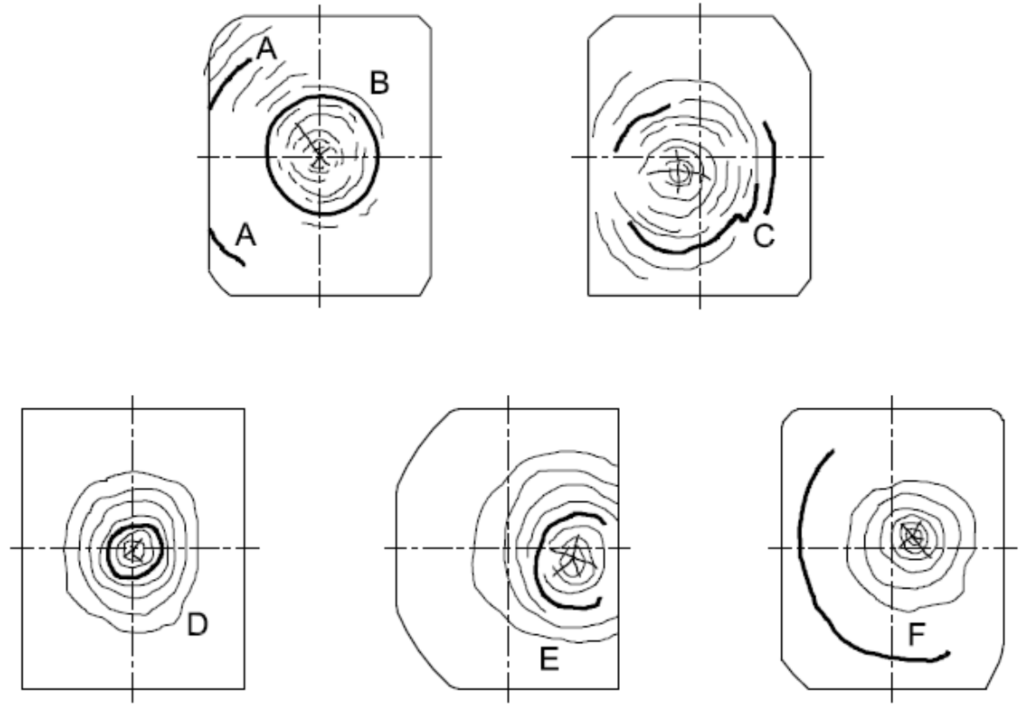
Singole cipollature non affioranti sono ammissibili solo se si aprono su una sola testata dell'elemento e se rispondono ai requisiti di diametro massimo e di eccentricità precisati per i diversi tipi di legname nella UNI 11035-2.

VISUAL GRADING – UNI 11035-1:

figura 5 **Esempi di cipollatura**

Legenda

A Cipollatura affiorante
B Cipollatura completa e inclusa
C Cipollatura multipla
D Cipollatura ammissibile
E Cipollatura inammissibile per eccessiva eccentricità
F Cipollatura inammissibile per eccessivo diametro

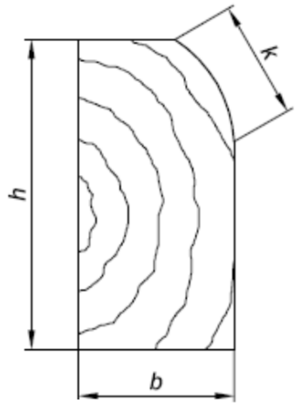


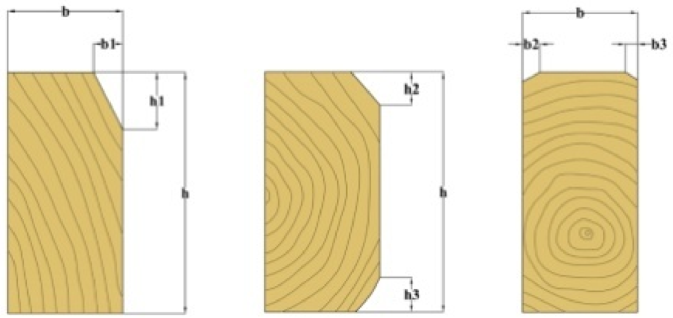
VISUAL GRADING – UNI 11035-1:

figura 6 **Metodo di misurazione dello smusso**

Legenda

- *s* = *k*/*h* Ampiezza dello smusso
- *k* Larghezza della zona smussata, misurata obliquamente
- *h* Lato maggiore della sezione
- *b* Lato minore della sezione





$$w_f = \frac{h1}{h} \qquad w_e = \frac{b1}{b}$$

$$w_f = \frac{h2+h3}{h}$$

$$w_e = \frac{b2+b3}{b}$$

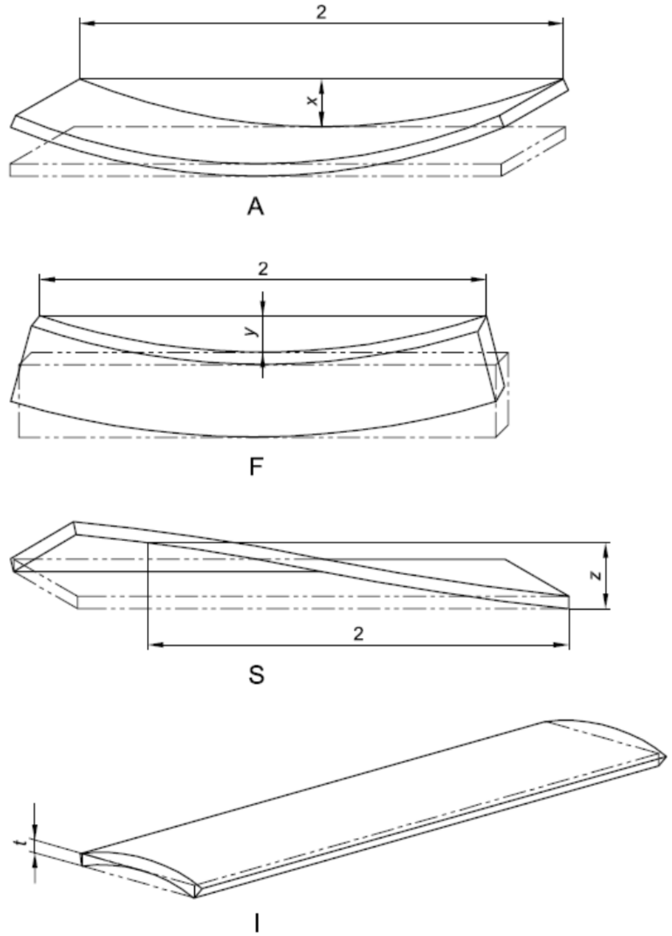
UNI 11035-1

figura 7 **Metodi di misurazione delle deformazioni: base di misura 2 m**

Legenda

- A Arcuatura
- F Falcatura
- S Svergolamento
- I Imbarcamento

Dimensioni in m



VISUAL GRADING – UNI 11035-2:

5 REGOLE DI CLASSIFICAZIONE E VALORI CARATTERISTICI

5.1 Modalità di esecuzione della classificazione a vista

La classificazione visuale deve essere condotta con le modalità seguenti:

a) esame a vista di tutte le facce e delle testate di ciascun segato;

b) applicazione a tutte le sezioni del segato di tutti i criteri di classificazione previsti dal prospetto;

c) assegnazione del segato alla categoria peggiore fra quelle ottenute in b);

d) se il segato non rientra nella categoria minima anche per uno soltanto dei criteri di classificazione, deve essere scartato in quanto "non classificabile".

5.2 Scelta delle regole di classificazione e dei profili di valori caratteristici appropriati

La classificazione di segati di una delle combinazioni specie/provenienza deve essere condotta adottando la regola di classificazione prevista nel prospetto 1.

Tale prospetto indica:

- la combinazione specie/provenienza;
- la sigla di identificazione del materiale;
- la regola di classificazione appropriata (sono previste due distinte regole per le Conifere e una sola regola riservata alle Latifoglie, da individuare fra quelle riportate nei prospetti da 2 a 4);
- la categoria cui ciascun segato, una volta classificato, può essere assegnato; il numero delle categorie varia a seconda della maggiore o minore efficienza con cui le regole possono classificare le diverse combinazioni specie / provenienza;
- il relativo profilo resistente riportato nel prospetto 5, dal quale si possono desumere i valori caratteristici di resistenza, rigidezza e massa volumica per ciascun tipo di legname; questi valori sono ricavati conformemente alla UNI EN 384.

5.3 Prospetti relativi alle regole di classificazione a vista secondo la resistenza meccanica e ai valori caratteristici per tipi di legname italiani

prospetto 1 **Regole di classificazione da adottare per i diversi tipi di legname italiani di Conifera e di Latifoglia**

Specie/Provenienza	Sigla	Regola di classificazione da adottare	Categoria
Conifere			
Abete[1] / Nord[9]	A/N	"Conifere 1"	S1
			S2
			S3
Abete[1] / Centro Sud[10]	A/C	"Conifere 1"	S1
			S2
			S3
Larice[4] / Nord[9]	L/N	"Conifere 1"	S1
			S2
			S3
Douglasia[2] / Italia	D/I	"Conifere 2"	S1
			S2/S3
Altre conifere[7] / Italia	CON/I	"Conifere 1"	S1
			S2
			S3
Latifoglie			
Castagno[3] / Italia	C/I	"Latifoglie"	S
Querce caducifoglie[5] / Italia	Q/I	"Latifoglie"	S
Pioppo e Ontano[6] / Italia	P/I	"Latifoglie"	S
Altre latifoglie[8] / Italia	LAT/I	"Latifoglie"	S

1) Comprende, senza distinzione, l'A. bianco (*Abies alba* Mill.) e l'A. rosso (*Picea abies* Karst.).
2) Varietà coltivate in Italia di *Pseudotsuga menziesii* (Mirb.) Franco.
3) Varietà da legno, governate a ceduo o ad alto fusto, di *Castanea sativa* Mill.
4) *Larix decidua* Mill.
5) Comprende, senza distinzione, la Rovere (*Quercus petraea* Liebl.), la Farnia (*Q. robur* L.), la Roverella (*Q. pubescens* Willd.) e il Cerro (*Q. cerris* L.).
6) Comprende il Pioppo bianco (sinonimo: Gattice) (*Populus alba* L.) e l'Ontano (*Alnus incana* Willd. e *A. glutinosa* Gaertn.). Non include i vari cloni di Pioppo ibrido (*Populus x euramericana* (Dode) Guinier).
7) Segati di conifere italiane appartenenti ad altre combinazioni specie/provenienza. Si applica principalmente ai segati di Pino silvestre (*Pinus sylvestris* L.), P. silano (*P. laricio* Poir.), P. nero (*P. nigra* Arn.), P. marittimo (*P. pinaster* Sol.), P. domestico (*P. pinea* L.), P. strobo (*P. strobus* L.), nonché ai segati di Cipresso (*Cupressus sempervirens* L.) e di Cedro (*Cedrus* spp.) di provenienza italiana.
8) Comprende il Faggio (*Fagus sylvatica* L.), la Robinia (*Robinia pseudoacacia* L.), il Frassino (*Fraxinus excelsior* L.) e l'Olmo (*Ulmus campestris* L.).
9) Comprende le regioni alpina e dolomitica.
10) Comprende la regione appenninica peninsulare e le Isole.

prospetto 2 **Regola per la classificazione a vista secondo la resistenza dei segati di Conifera corrispondenti alla definizione "Conifere 1" del prospetto 1**

"Conifere 1"			
Criteri per la classificazione	Categorie		
	S1	S2	S3
Smussi[1]	$s \leq 1/8$ e comunque ciascun lato della sezione, per almeno 2/3, non deve essere interessato da smussi	$s \leq 1/3$ e comunque ciascun lato della sezione, per almeno 1/3, non deve essere interessato da smussi	$s \leq 1/2$ e comunque ciascun lato della sezione, per almeno 1/4, non deve essere interessato da smussi
Nodi singoli[2] Nodi raggruppati[3]	$A \leq 1/5$ e comunque $d < 50$ mm $A_g \leq 2/5$	$A \leq 2/5$ e comunque $d < 70$ mm $A_g \leq 2/3$	$A \leq 3/5$ $A_g \leq 3/4$
Ampiezza anelli	≤6 mm	nessuna limitazione	
Inclinazione fibratura	≤1:14	≤1:8	≤1:6
Fessurazioni: - da ritiro - cipollatura - da fulmine, gelo, lesioni	 ammesse, se non passanti non ammessa non ammesse	 ammesse senza limitazioni ammessa con limitazioni[4] non ammesse	
Degrado da funghi: - azzurramento - carie bruna e bianca	 ammesso non ammesse		
Legno di compressione	fino a 1/5 della superficie o della sezione	fino a 2/5 della superficie o della sezione	fino a 3/5 della superficie o della sezione
Attacchi di insetti	non ammessi	ammessi con limitazioni[5]	
Vischio	non ammesso		
Deformazioni: - Arcuatura - Falcatura - Svergolamento - Imbarcamento	 10 mm ogni 2 m di lunghezza 8 mm ogni 2 m di lunghezza 1 mm ogni 25 mm di larghezza nessuna restrizione		 20 mm ogni 2 m di lunghezza 12 mm ogni 2 m di lunghezza 2 mm ogni 25 mm di larghezza nessuna restrizione

1) s è il rapporto fra la dimensione obliqua dello smusso e il lato maggiore della sezione.
2) Si considera il nodo più grande del segato, e il rapporto A fra il suo diametro minimo d e la larghezza della faccia su cui tale diametro viene misurato.
3) Non considerare questo criterio per Abete/Nord e Larice/Nord. Per le altre combinazioni specie/provenienza considerare il rapporto A_g fra la somma dei diametri minimi dei nodi compresi in un tratto di 150 mm e la larghezza della faccia su cui compaiono.
4) Generalmente non ammessa; soltanto per Larice/Nord e Abete/Centro Sud la cipollatura è ammessa se $r_{max} < b/3$ ed $\varepsilon < b/6$, dove:
r_{max} il rapporto fra il raggio massimo della cipollatura e il lato minore b della sezione;
ε l'eccentricità, cioè la distanza massima del midollo rispetto al centro geometrico della sezione.
5) Ammessi solo fori con alone nerastro, oppure fori di Anobidi (purché l'attacco sia sicuramente esaurito) per un max. di 10 fori, distribuiti uniformemente, per metro di lunghezza (somma di tutte e quattro le facce).

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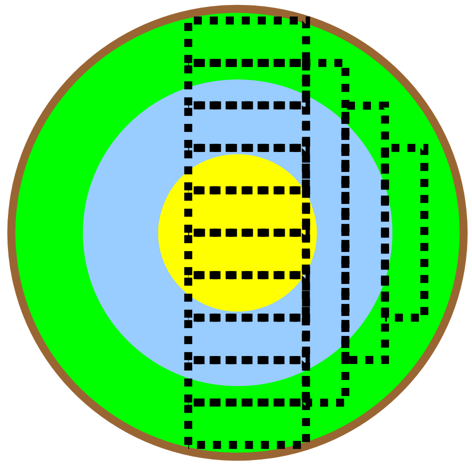
prospetto 5 **Valori caratteristici per i tipi di legname considerati nella presente norma**

Bending strength

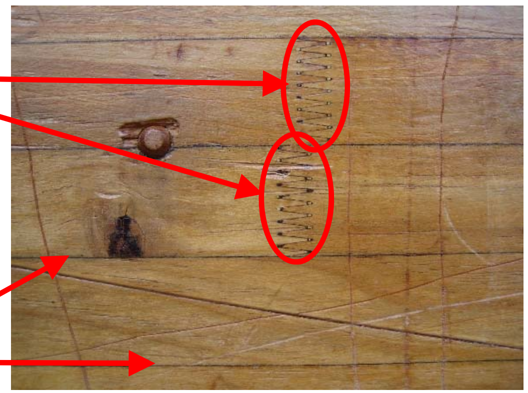
Proprietà		Abete / Nord			Abete / Centro Sud			Larice / Nord			Douglasia / Italia		Altre Conifere / Italia			Castagno / Italia	Querce caducifoglie / Italia	Pioppo e Ontano / Italia	Altre Latifoglie / Italia
		S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2/S3	S1	S2	S3	S	S	S	S
Flessione (5-percentile), MPa	$f_{m,k}$	29	23	17	32	28	21	42	32	26	40	23	33	26	22	28	42	26	27
Trazione parallela alla fibratura (5-percentile), MPa	$f_{t,0,k}$	17	14	10	19	17	13	25	19	16	24	14	20	16	13	17	25	16	16
Trazione perpendicolare alla fibratura (5-percentile), MPa	$f_{t,90,k}$	0,4	0,4	0,4	0,3	0,3	0,3	0,6	0,6	0,6	0,4	0,4	0,5	0,5	0,5	0,5	0,8	0,4	0,5
Compressione parallela alla fibratura (5-percentile), MPa	$f_{c,0,k}$	23	20	18	24	22	20	27	24	22	26	20	24	22	20	22	27	22	22
Compressione perpendi-colare alla fibratura (5-percentile), MPa	$f_{c,90,k}$	2,9	2,9	2,9	2,1	2,1	2,1	4,0	4,0	4,0	2,6	2,6	4,0	4,0	4,0	3,8	5,7	3,2	3,9
Taglio (5-percentile), MPa	$f_{v,k}$	3,0	2,5	1,9	3,2	2,9	2,3	4,0	3,2	2,7	4,0	3,4	3,3	2,7	2,4	2,0	4,0	2,7	2,0
Modulo di elasticità parallelo alla fibratura (medio), MPa	$E_{0,mean}$	12 000	10 500	9 500	11 000	10 000	9 500	13 000	12 000	11 500	14 000	12 500	12 300	11 400	10 500	11 000	12 000	8 000	11 500
Modulo di elasticità parallelo alla fibratura (5-percentile), MPa	$E_{0,05}$	8 000	7 000	6 400	7 400	6 700	6 400	8 700	8 000	7 700	9 400	8 400	8 200	7 600	7 000	8 000	10 100	6 700	8 400
Modulo di elasticità perpen-dicolare alla fibratura (medio), MPa	$E_{90,mean}$	400	350	320	370	330	320	430	400	380	470	420	410	380	350	730	800	530	770
Modulo di taglio (medio), MPa	G_{mean}	750	660	590	690	630	590	810	750	720	880	780	770	710	660	950	750	500	720
Massa volumica (5-percentile), kg/m^3	ρ_k	380	380	380	280	280	280	550	550	550	400	420	530	530	530	465	760	420	515
Massa volumica (media), kg/m^3	ρ_{mean}	415	415	415	305	305	305	600	600	600	435	455	575	575	575	550	825	460	560

HOW TO REDUCE THE INFLUENCE OF DEFECTS?

One possibility is to:



• **cut** some **planks** (50 mm thick, 1500 to 5000 mm long) from a tree;



• **join** them **lengthwise** (finger joints);

• **glue** the **laminations** together.

GLUE-LAMINATED TIMBER

Glue-laminated timber (glulam) is a solid wood member manufactured by gluing smaller pieces (planks) together.

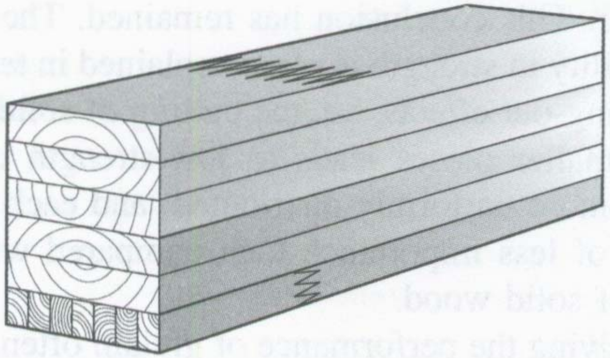
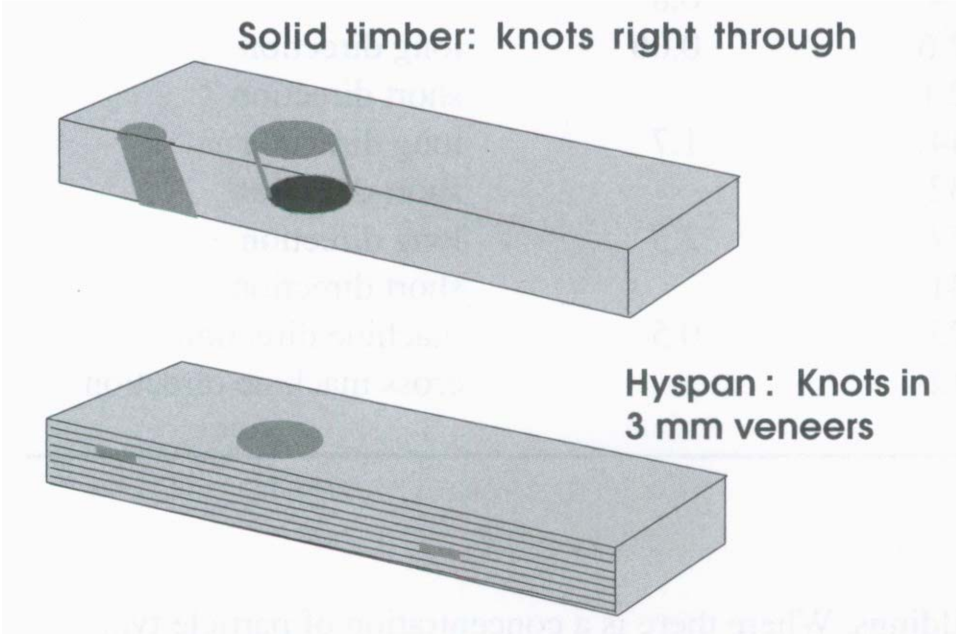


Figure 5.1 Using a glulam beam with laminated, outermost lamination, takes advantage of the laminating effect

GLUE-LAMINATED TIMBER

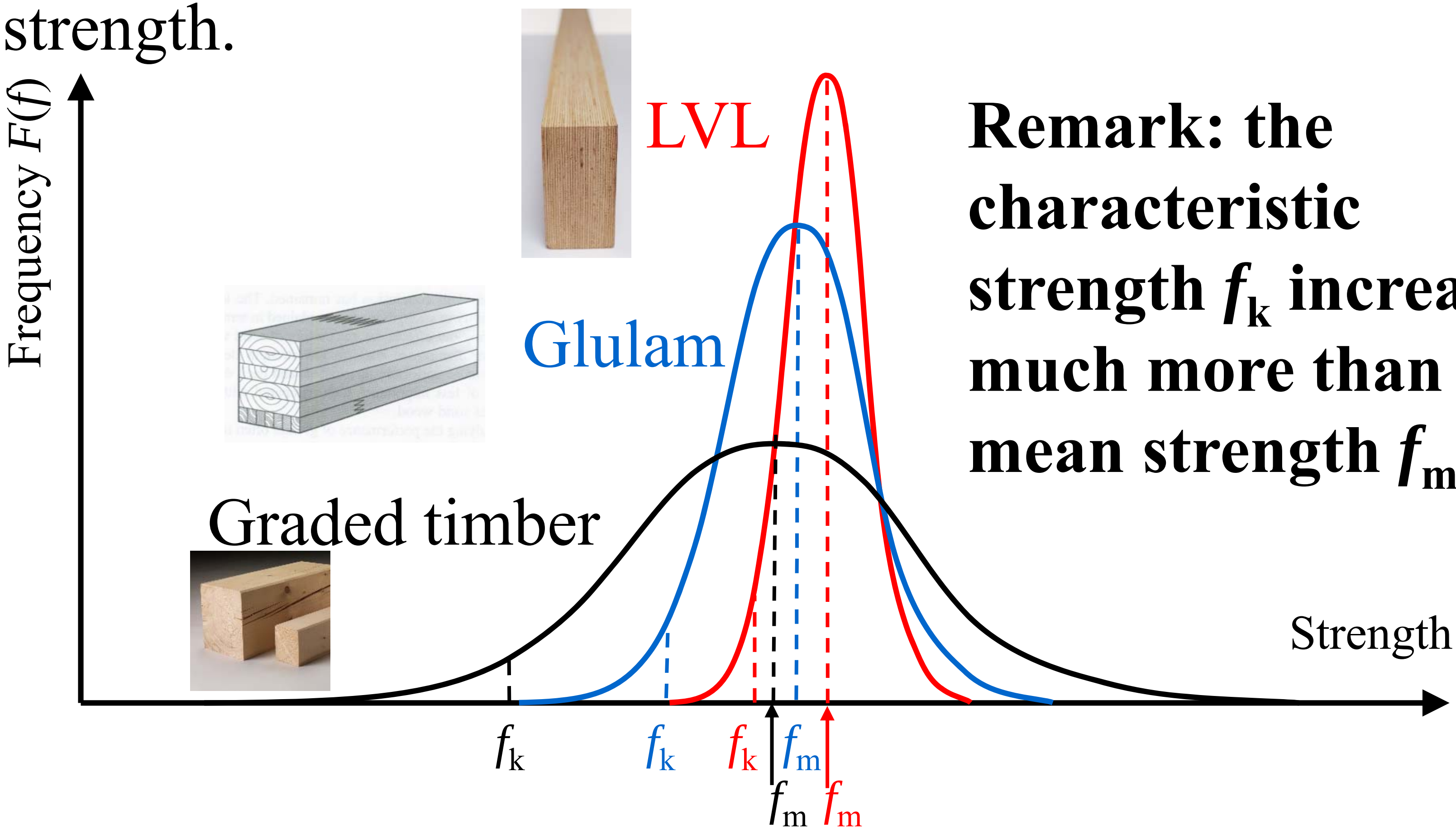
WHY HAS GLULAM GOT BETTER MECHANICAL PROP.?



Because the manufacturing process leads to a **more homogeneous material** (with more smaller defects instead of few larger defect) with a **higher mean and, mostly, characteristic strength** compared to sawn timber.

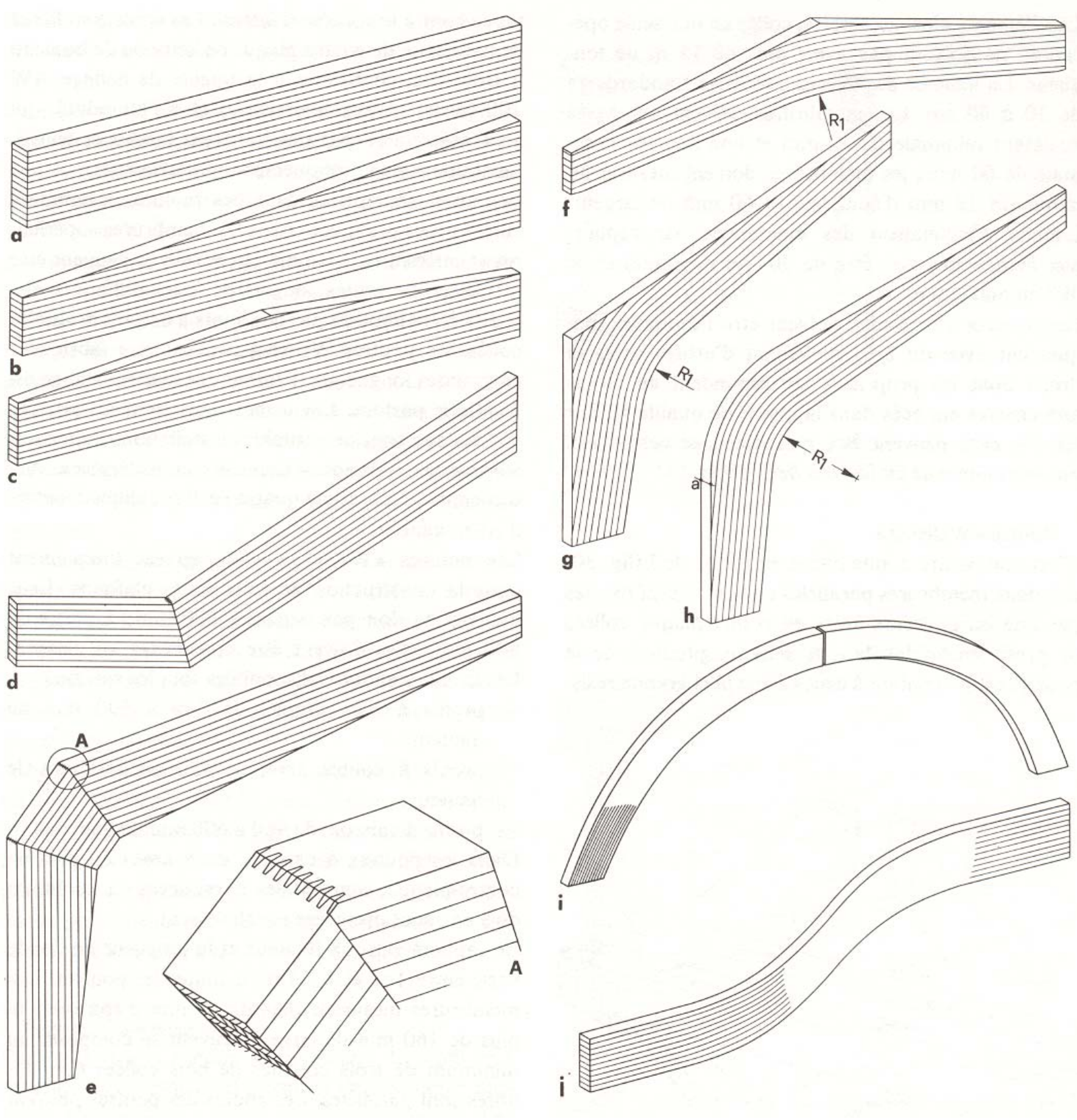
WHY HAS GLULAM GOT BETTER MECHANICAL PROP.?

Reducing material variation (heterogeneity) is equivalent to reduce uncertainty, which will result in increased strength.

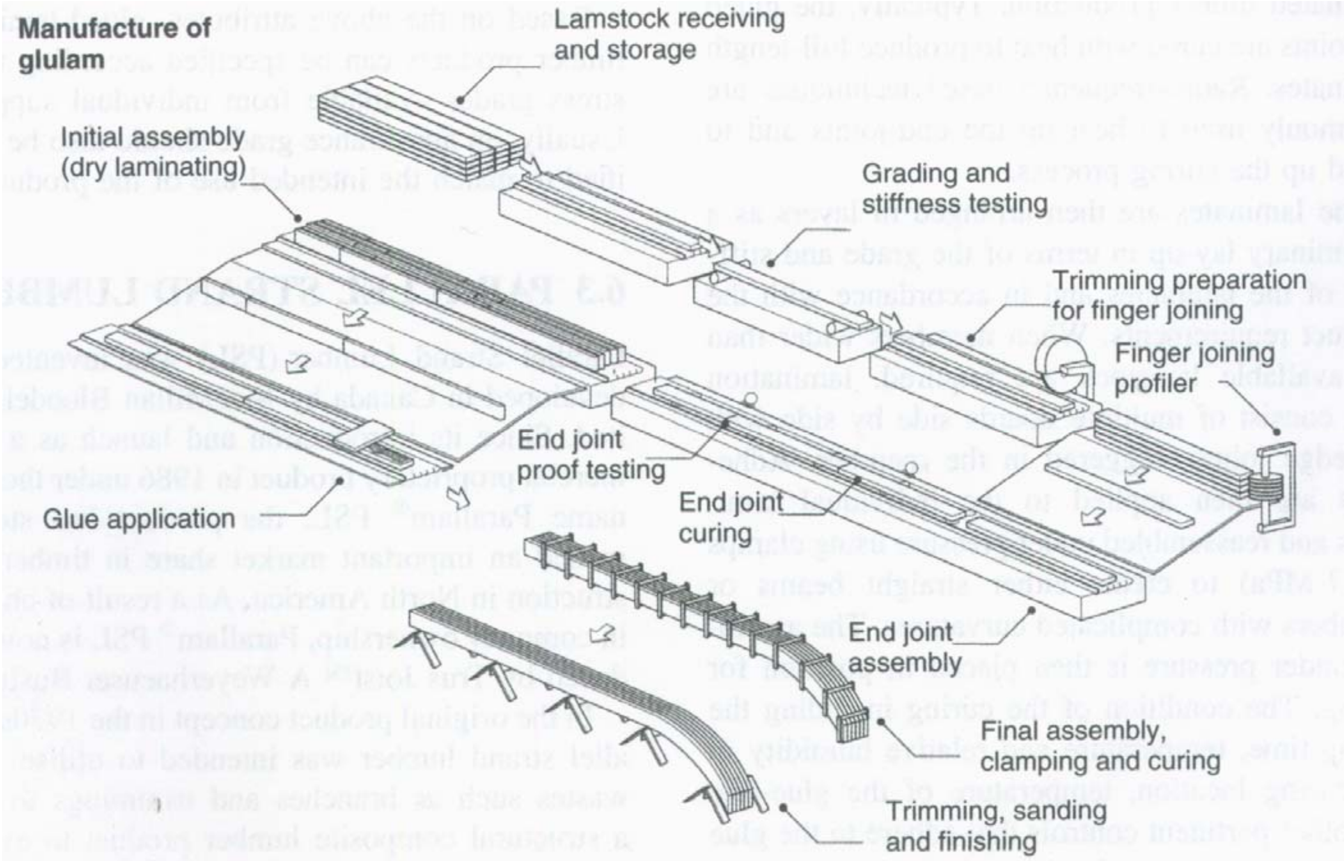


Remark: the characteristic strength f_k increases much more than the mean strength f_m!!!

GLUE LAMINATED TIMBER



HOW IS GLULAM MANUFACTURED?



Manufacture of glue-laminated timber

HOW IS GLULAM MANUFACTURED?

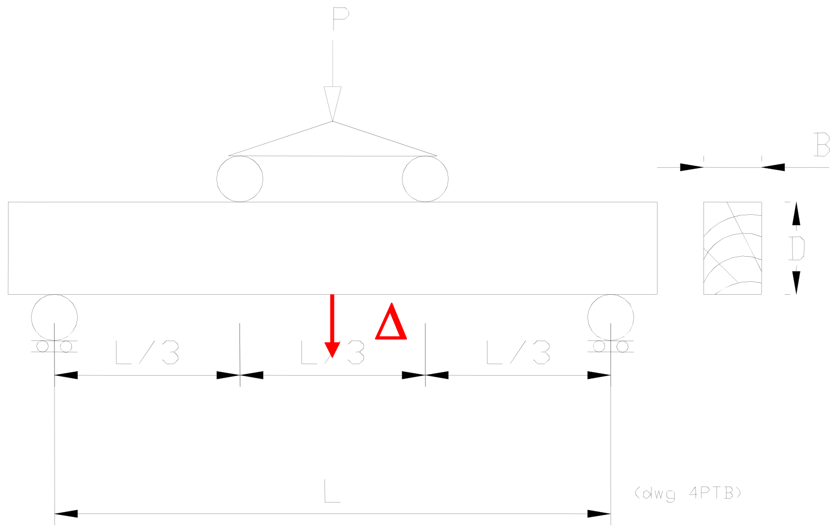
Logs are **cut into** 50 mm thick **planks** with lengths ranging from 1500 to 5000 mm.

HOW IS GLULAM MANUFACTURED?

The **planks** are **kiln dried** because the adhesives used require the m.c. of wood be 15% maximum.

The **planks** are then **pre-planed** and **strength graded**.

HOW IS GLULAM MANUFACTURED?



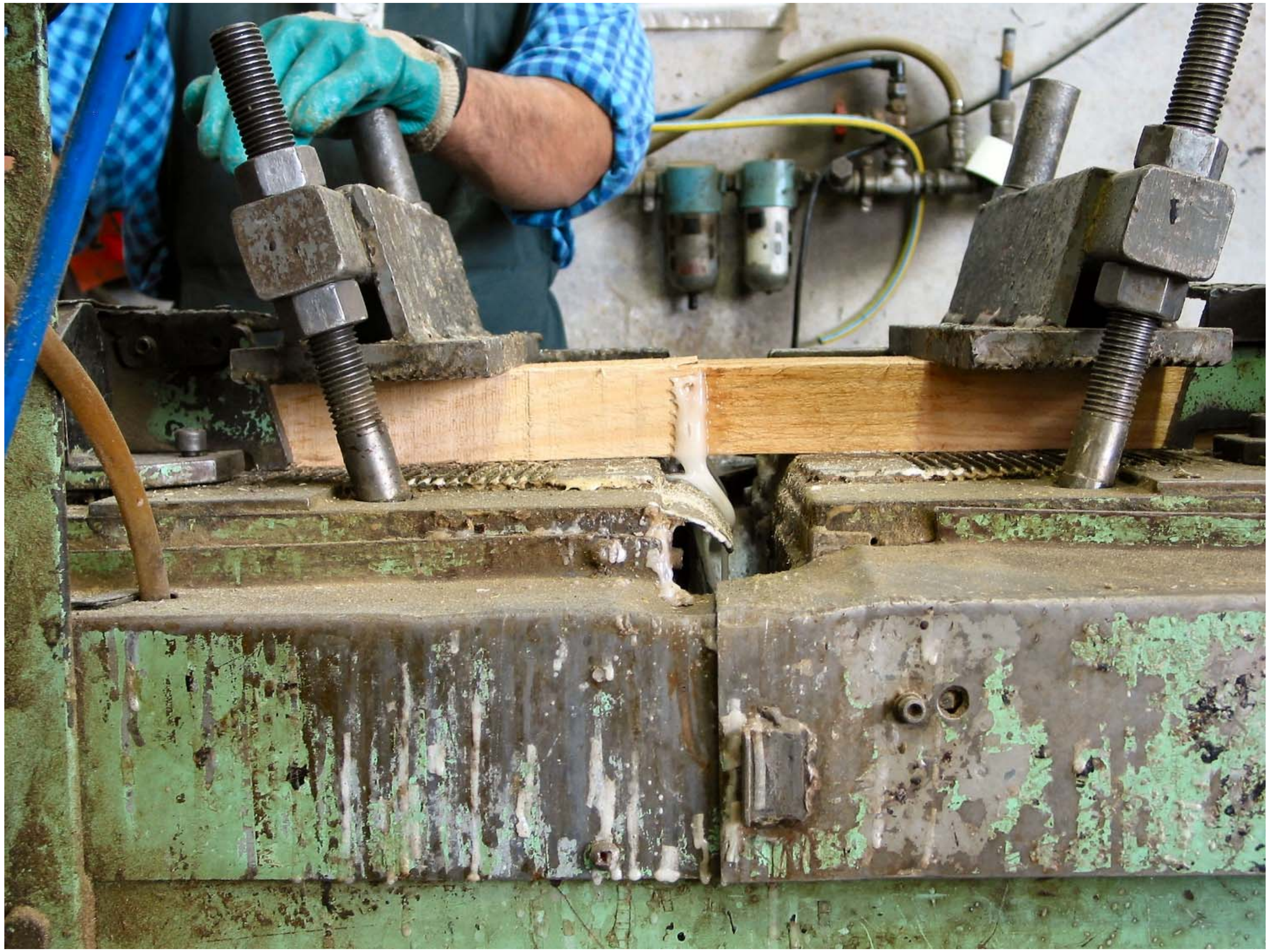
$$MOE = \frac{23}{1296} \cdot \frac{PL^3}{\Delta} \cdot \frac{12}{BD^3}$$

Machine grading (MOE can be evaluated once the deflection Δ under the load P is measured).

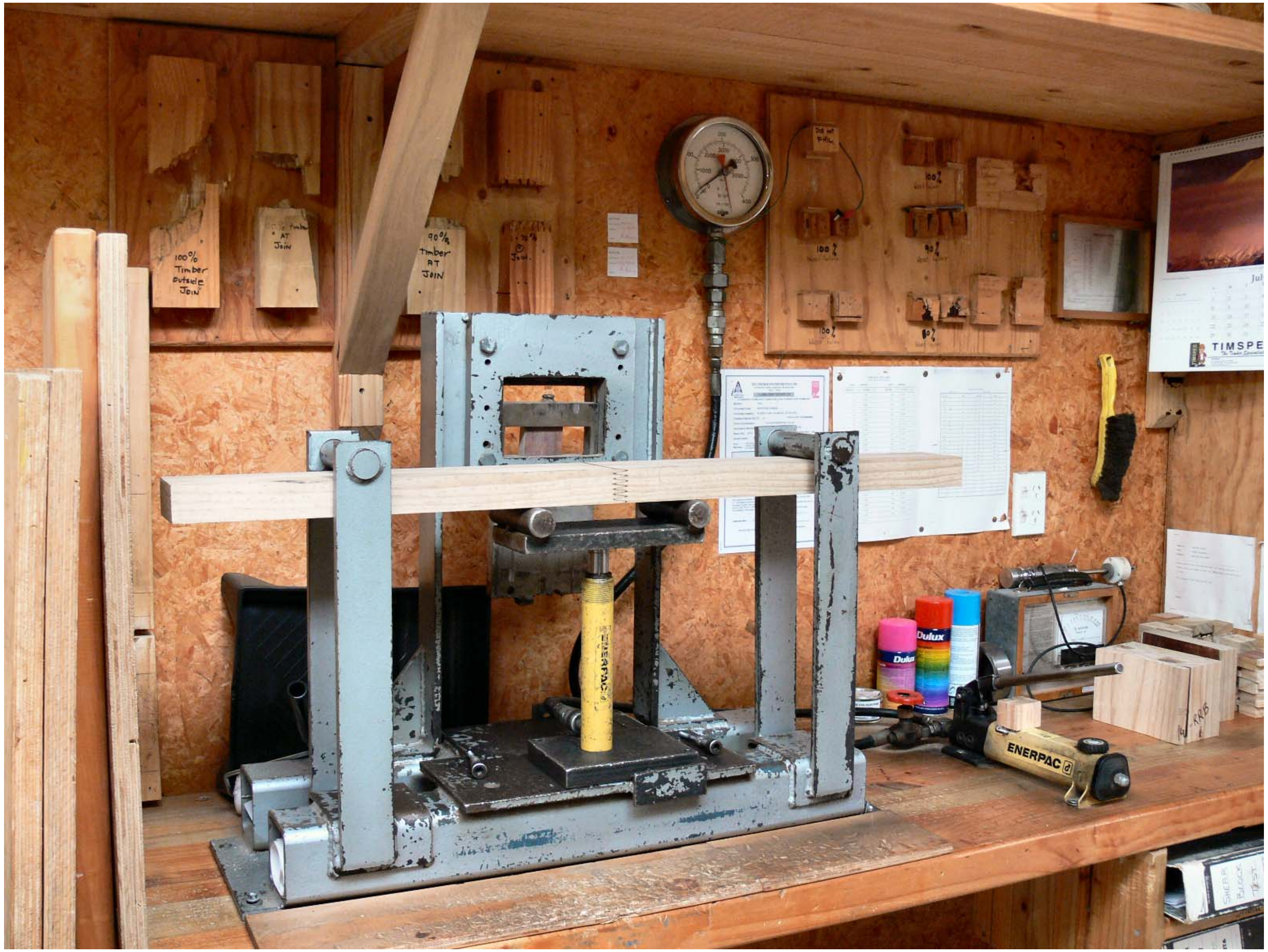
HOW IS GLULAM MANUFACTURED?

The end of the planks are cut off and profiled for **finger joints**. Then the **adhesive** is **applied** and the **planks** are **pressed together** for at least two seconds.

HOW IS GLULAM MANUFACTURED?



HOW IS GLULAM MANUFACTURED?



HOW IS GLULAM MANUFACTURED?

The continuous section is **cut** into **laminations** of the required length and stored for at least 8 hours to ensure the **curing** of the glue.

Then the **glue** is **applied** and the **laminations** are **pressed together** (glueline pressure from 0.4 to 1.2 N/mm^2) giving the final cross-section lying on its side.

HOW IS GLULAM MANUFACTURED?

HOW IS GLULAM MANUFACTURED?

Jigs and pressing devices for straight members

HOW IS GLULAM MANUFACTURED?

Jigs and pressing devices for curved members

HOW IS GLULAM MANUFACTURED?

The **gluelines are kept under pressure** in controlled climate at 20°C and 65% relative humidity for at least 6 hours before the clamps are released and the beams are stacked ready for **finishing**.

HOW IS GLULAM MANUFACTURED?

The **beams** are **planed** on each side.

HOW IS GLULAM MANUFACTURED?

At the end the **beams** are **finished** (drilling of holes for conn, application of coatings, etc.).

HOW IS GLULAM MANUFACTURED?

HOW IS GLULAM MANUFACTURED?

Important: since the **finger joints** are weak points, they must **not be aligned** on the cross-section.

WHAT IS LVL?

- LVL is Laminated Veneer Lumber

- LVL is obtained by gluing together under pressures veneers of wood 2 to 4 mm thick produced by the rotary peeling of steamed logs.

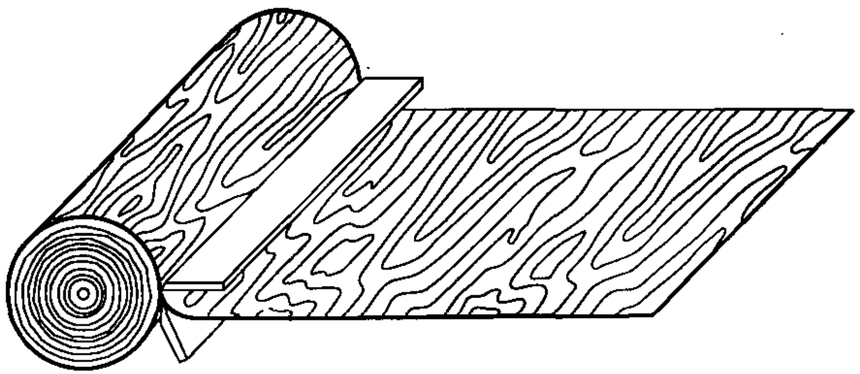
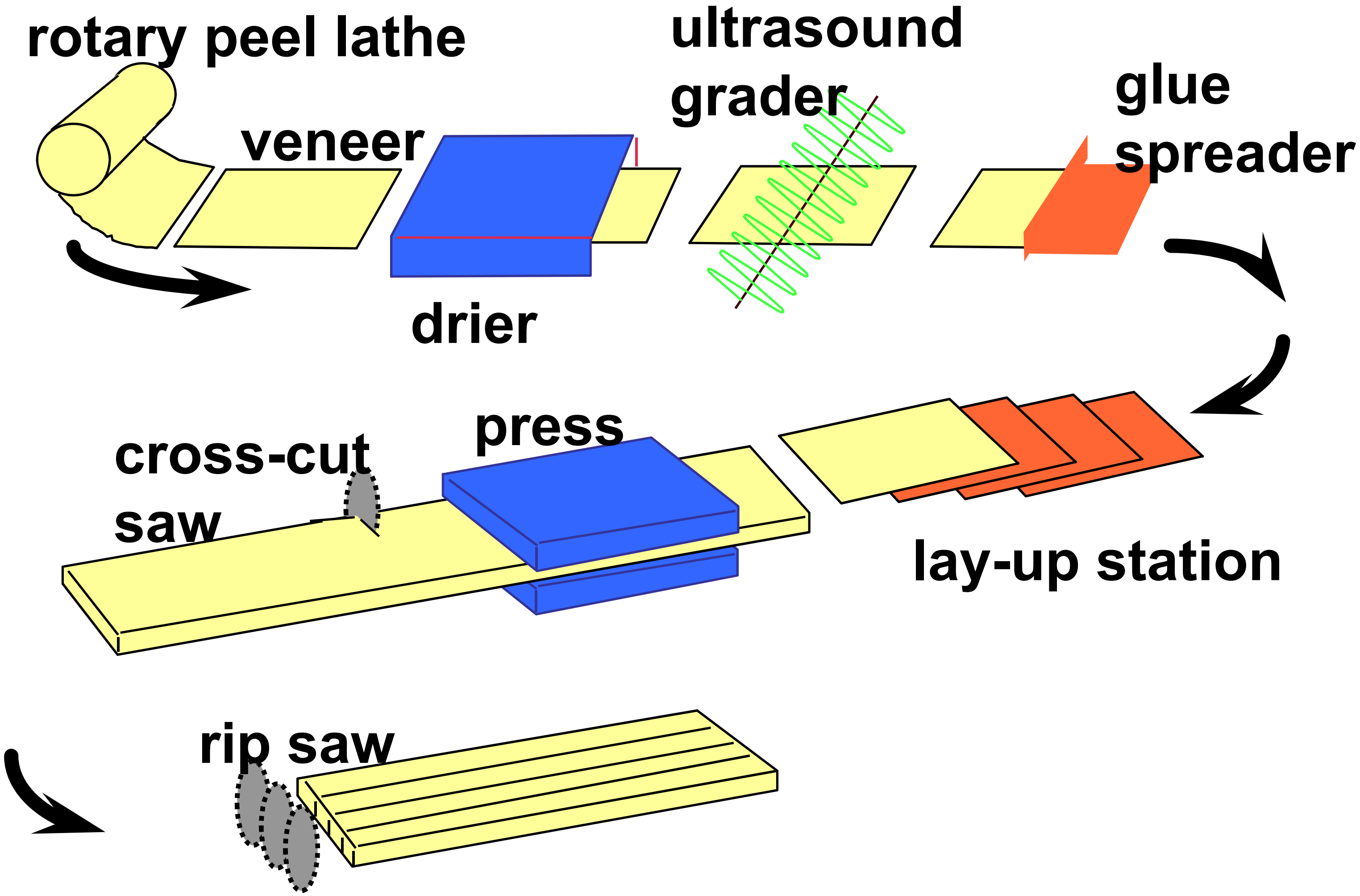


Figure 1 *Production of an "endless" ply ribbon by rotary peeling.*

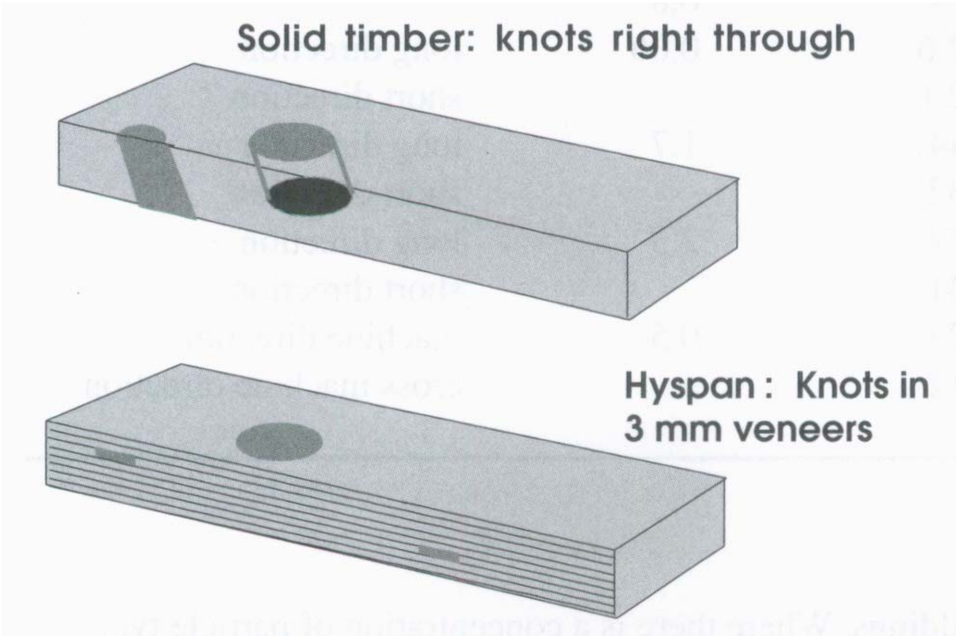
HOW IS IT PRODUCED?



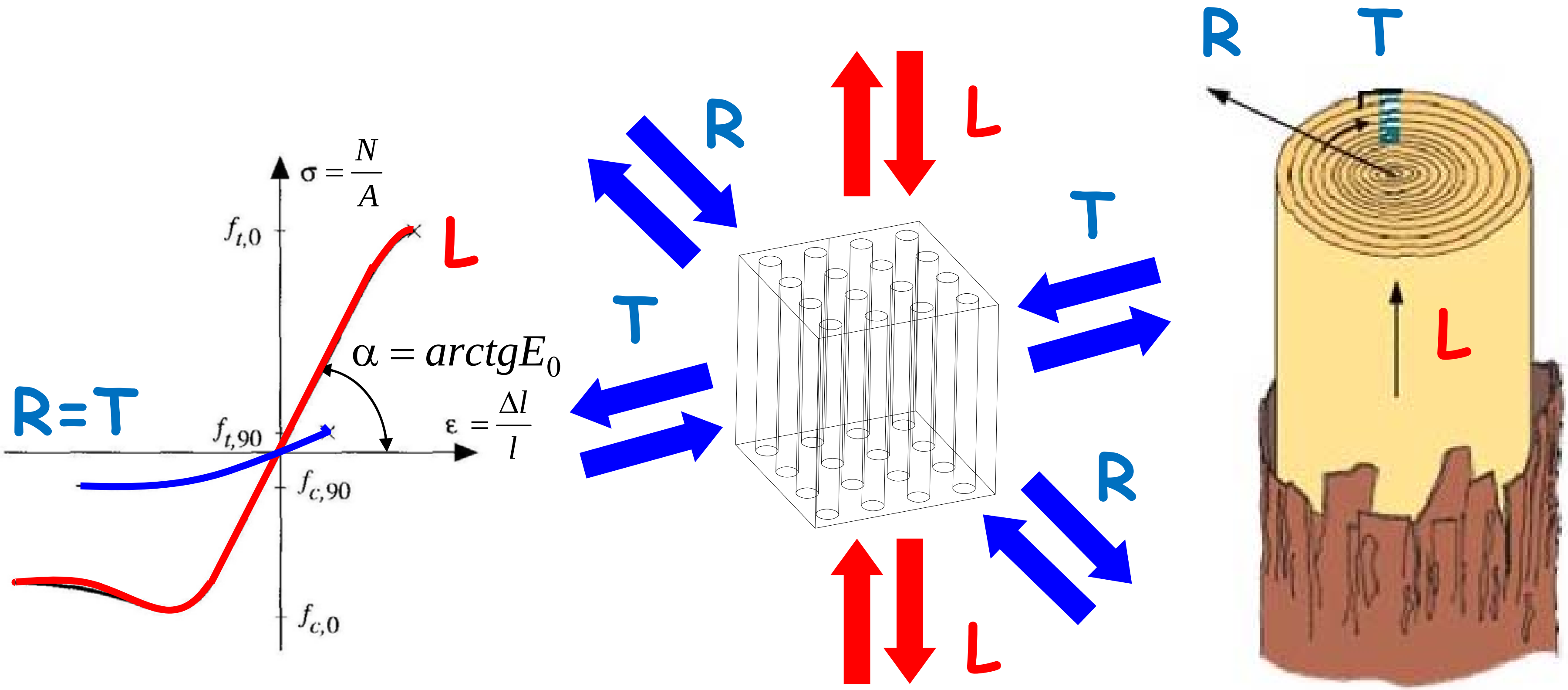
WHY IS IT PRODUCED?

The better properties are achieved because the defects such as knots are smaller and spread throughout the beam volume.

Therefore each defect is less critical compared to the case of sawn timber. LVL behaves almost as clear wood.



ANISOTROPY:

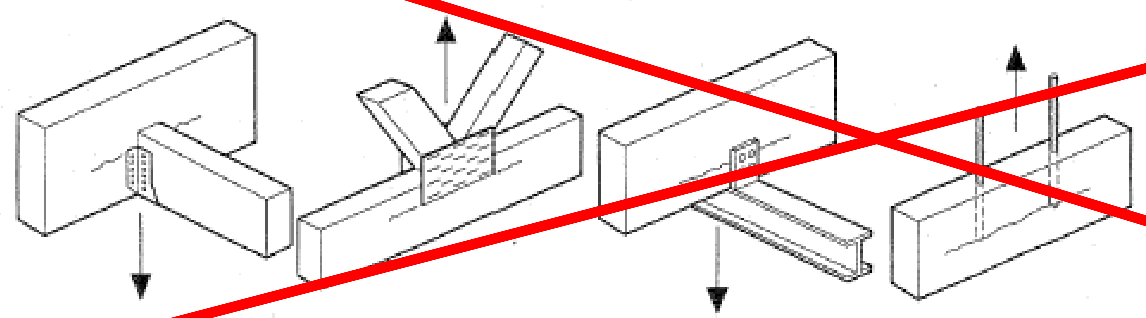


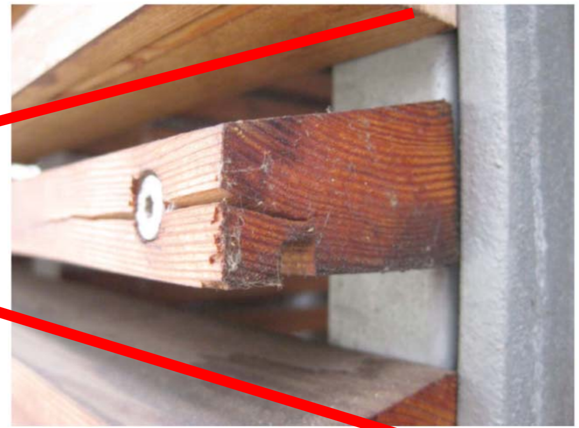
EXCELLENT behaviour parallel to grain (L dir.)

VERY BAD behaviour perpendicular to the grain (R, T directions)

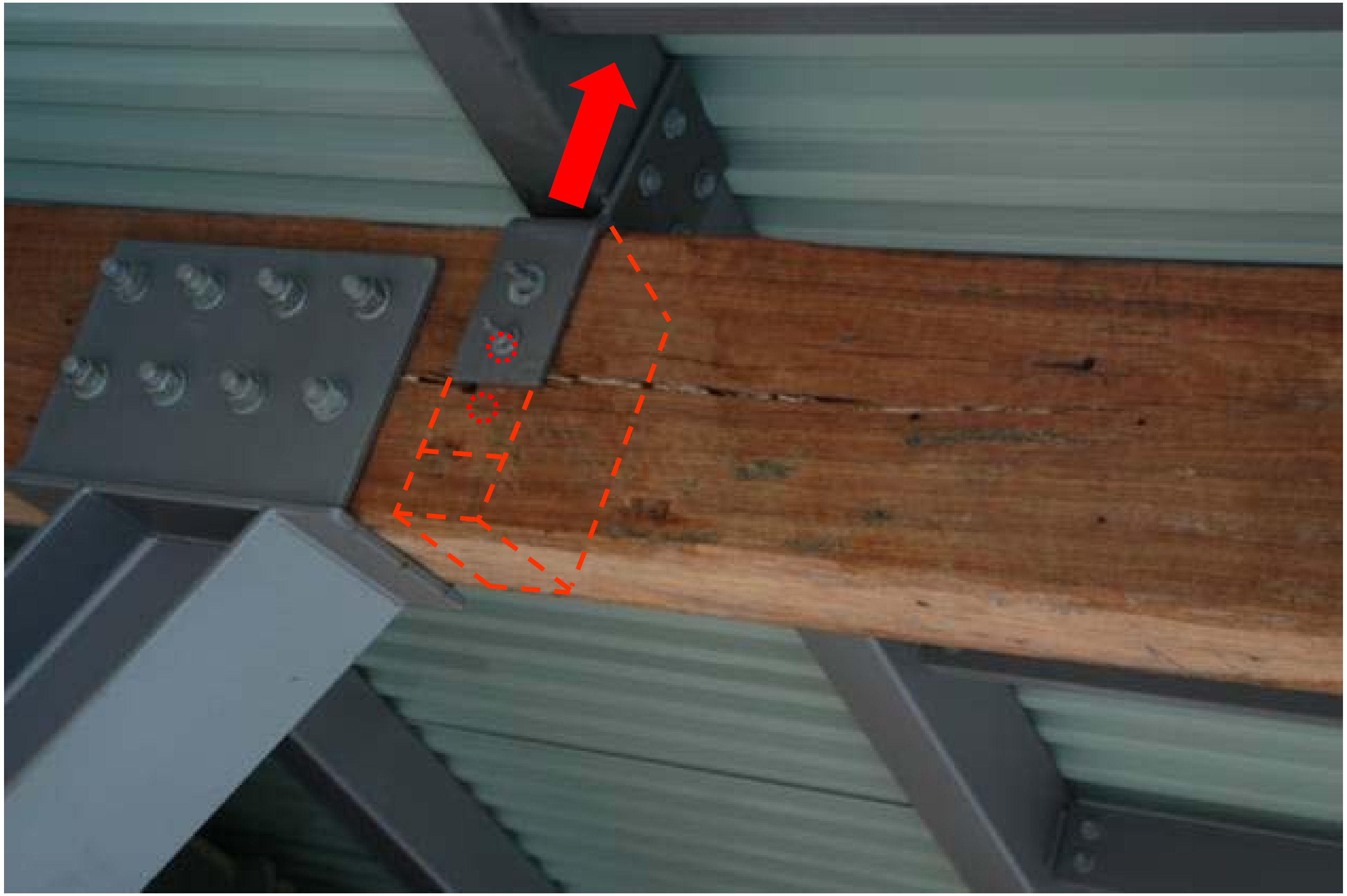
ANISOTROPY:

Be careful of the connection design because of anisotropic behaviour!!!



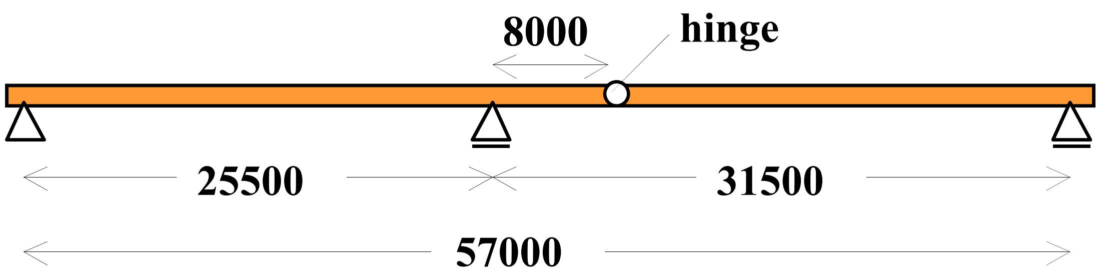


ANISOTROPY:



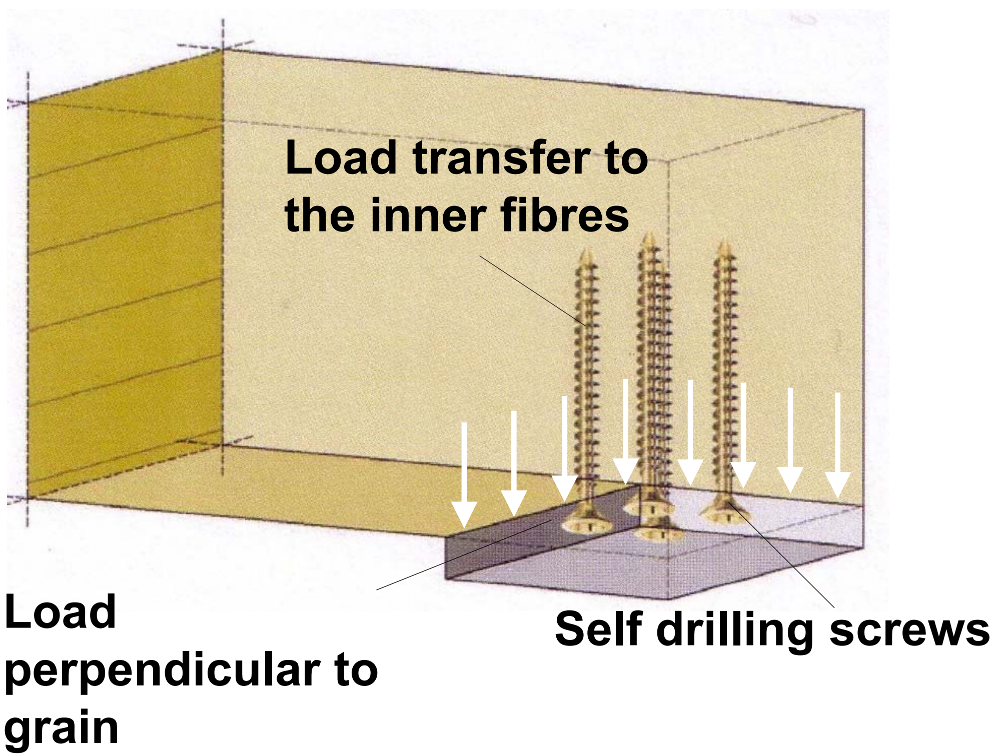
ANISOTROPY:

Also compression stresses perp. to grain should be limited!

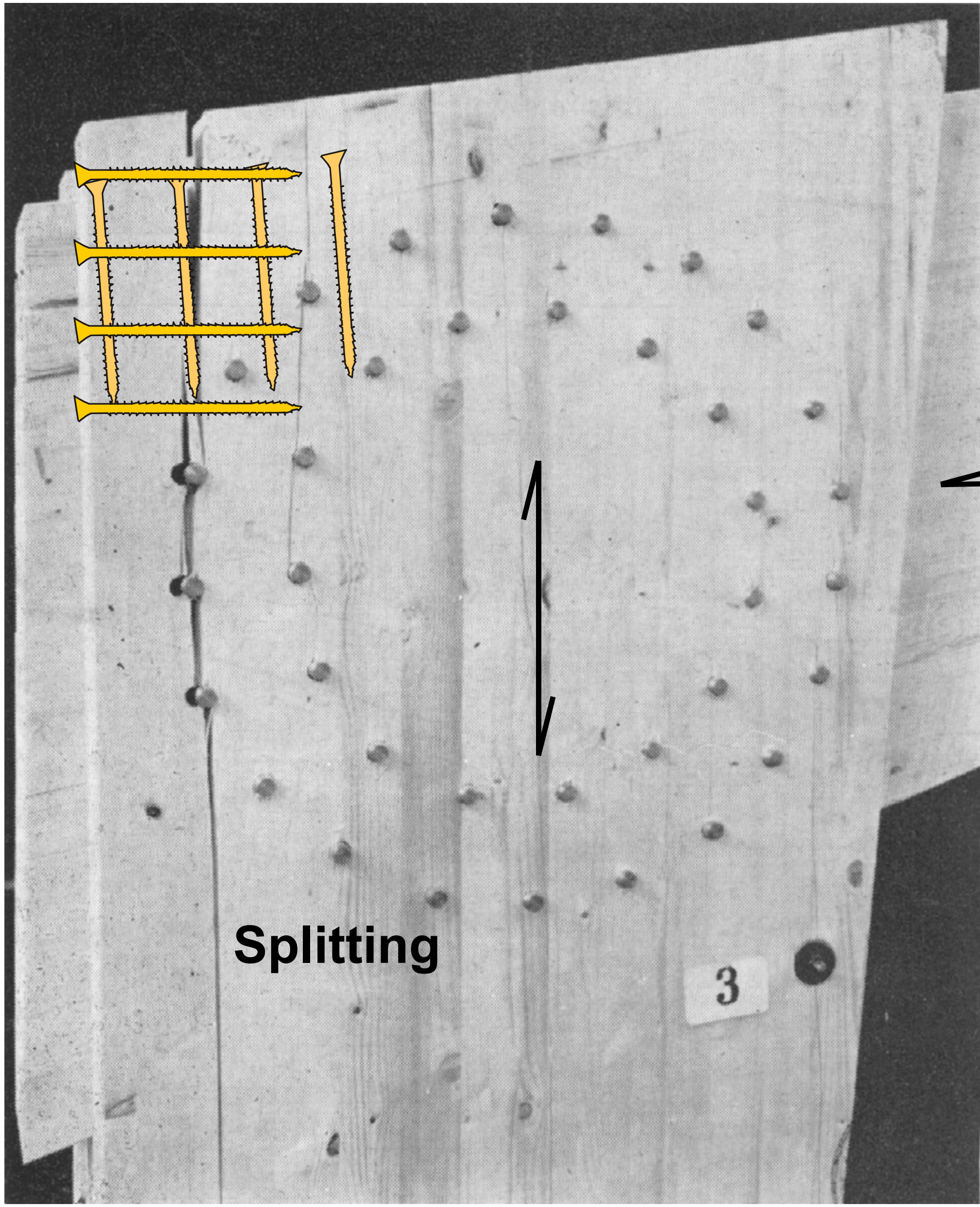


ANISOTROPY:

How to prevent squashing of timber perp. to grain? For example by reinforcing the beam on the support with self-drilling screws:



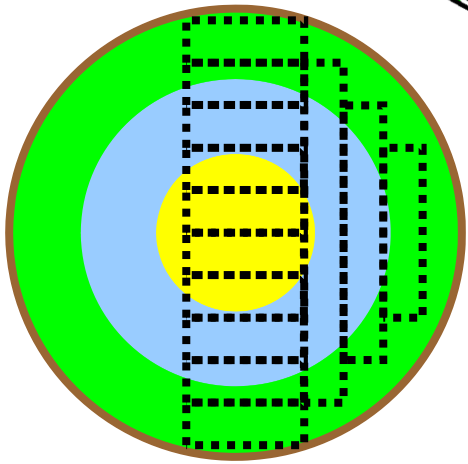
ANISOTROPY:

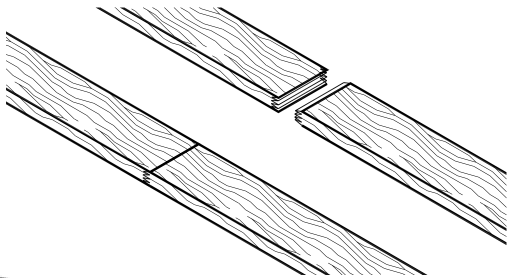


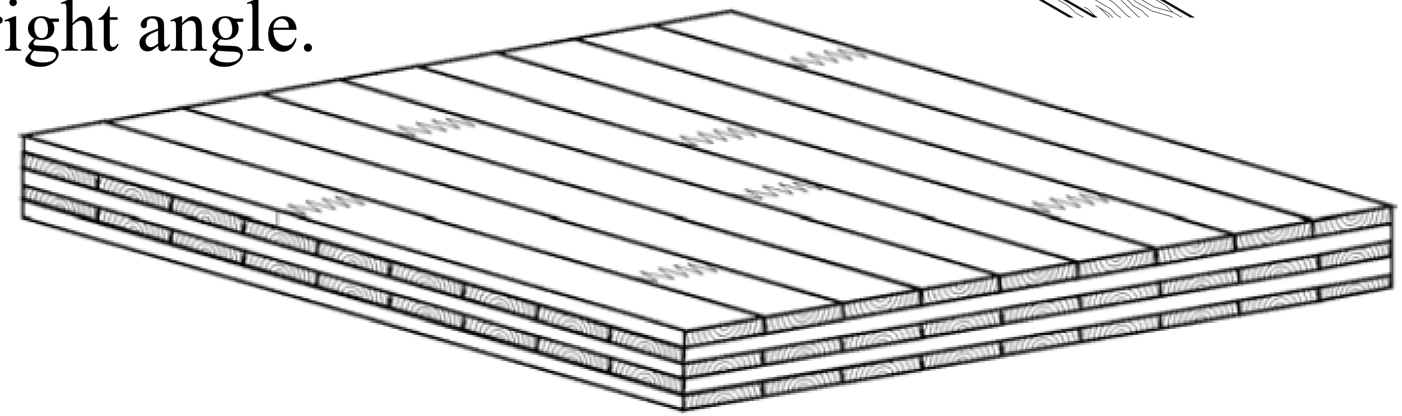
HOW TO CREATE A MORE ISOTROPIC PRODUCT?

The idea is to:

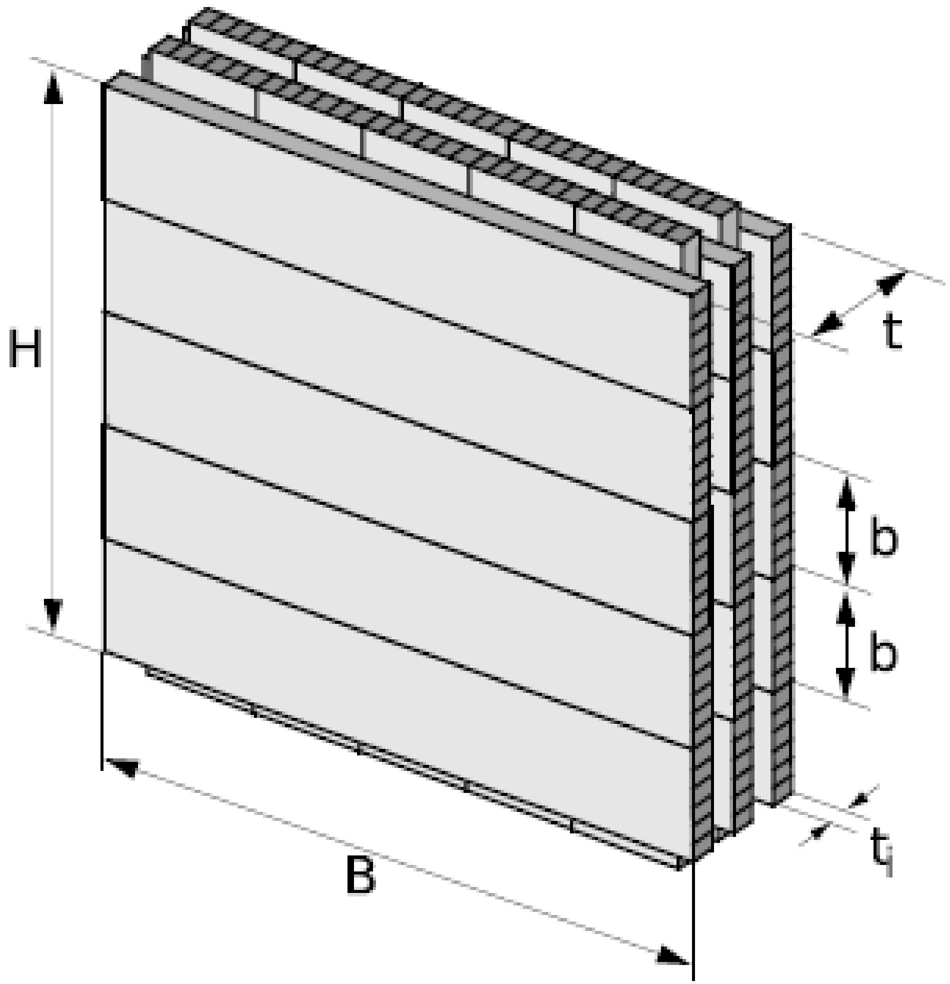
- **cut** some **planks** (50 mm thick, 1500 to 5000 mm long) from a tree;
- **join** them **lengthwise** (finger joints);
- **glue** layers of **laminations** together at a right angle.







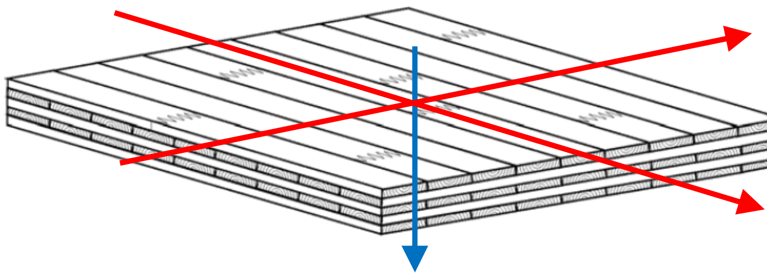
CROSS-LAMINATED PANELS:

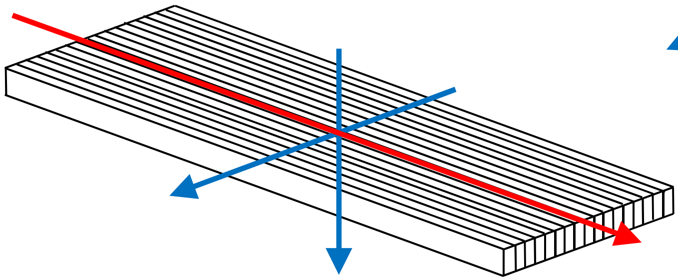


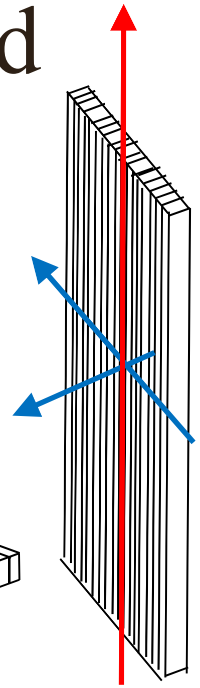
CROSS-LAMINATED PANELS:

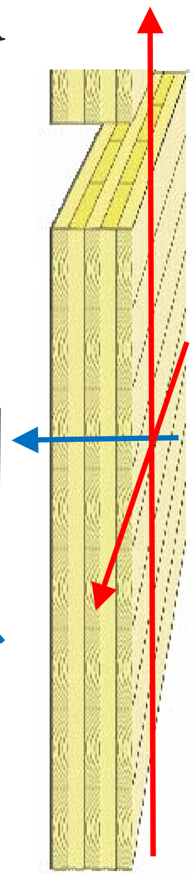
Advantages:

- More **in-plane isotropic strength and stiffness** compared to sawn timber - therefore can be used for slabs and walls (red: strong direction, blue: weak direction)



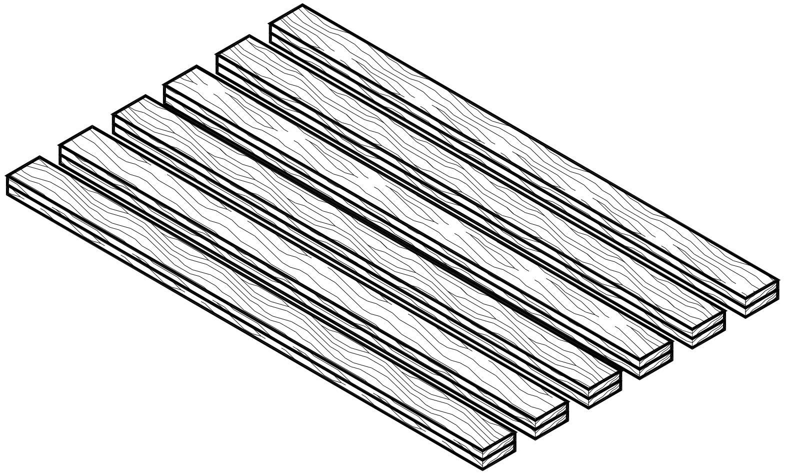




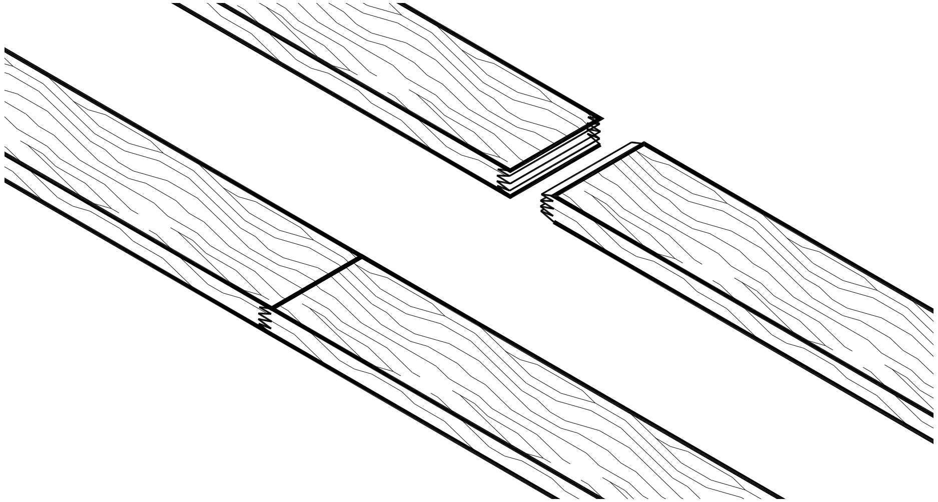


CROSS-LAMINATED PANELS: PRODUCTION

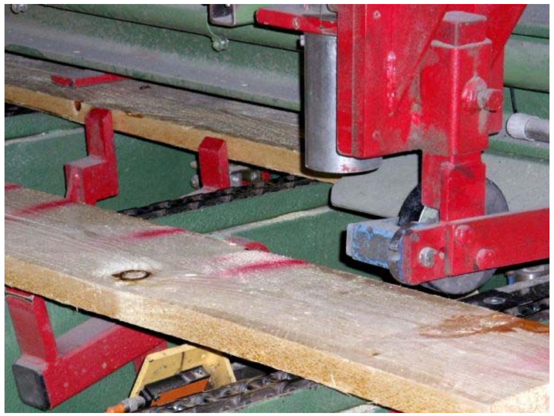
Spruce boards of thicknesses varying from 17 to 27 mm and width from 160 to 200 are machine dried up to 10-12 % of m.c. and planed…



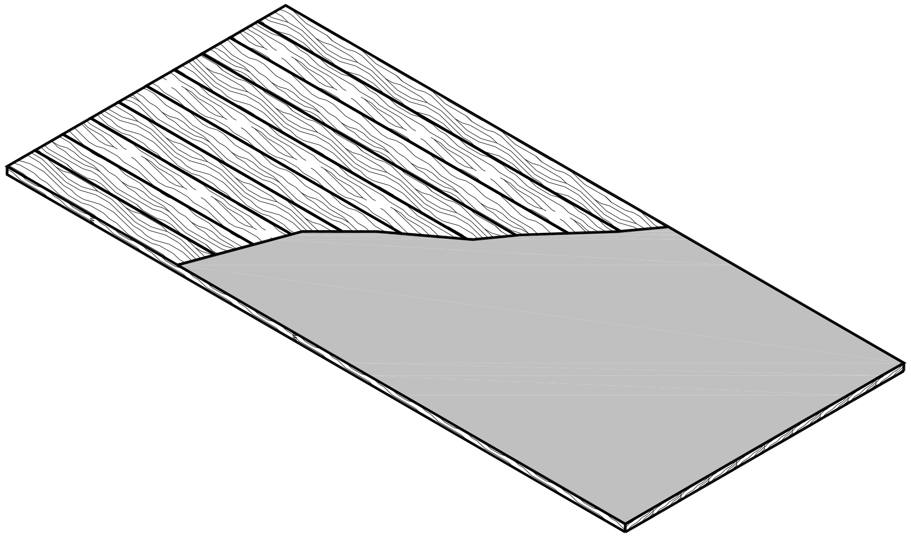
CROSS-LAMINATED PANELS: PRODUCTION



… machine graded, checked for defects and finger jointed in length…

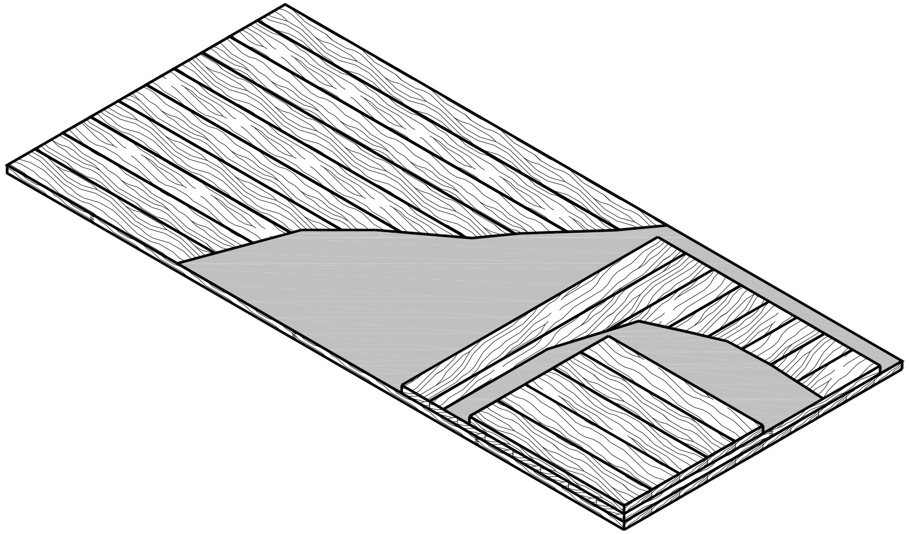


CROSS-LAMINATED PANELS: PRODUCTION



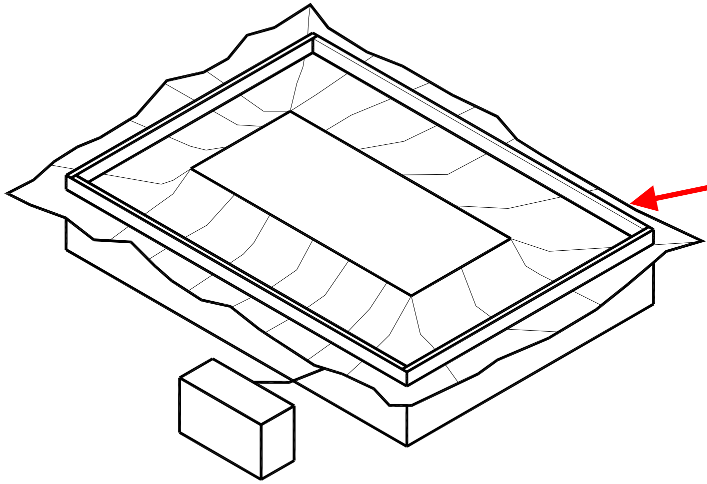
… then assembled in layers…

CROSS-LAMINATED PANELS: PRODUCTION

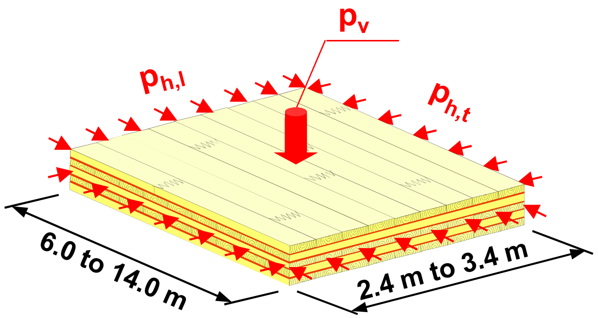


…and cross glued with melamine-urea-formaldehyde glue (from a minimum of 3 layers up to a maximum of 11 layers) and…

CROSS-LAMINATED PANELS: PRODUCTION



…finally vacuum or hydraulically pressed and assembled in big size panels (up to 4.8x20 m with thicknesses between 50 and 300 mm)……..



CROSS-LAMINATED PANELS: TRANSPORT AND ASSEMBLING

storage of CLT elements (production site)

charging and transport

discharging (building site)

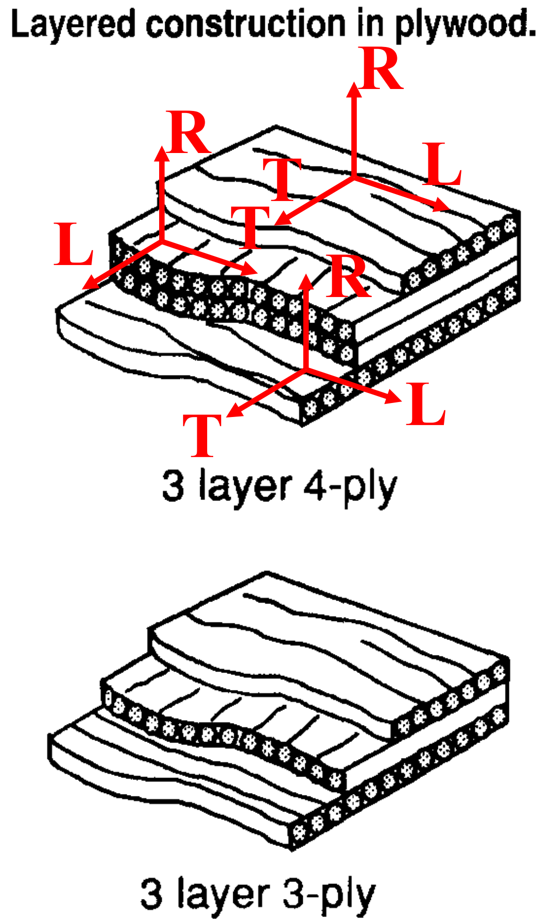
mounting parts for roof elements

mounting parts for ceiling elements

mounting parts for wall elements

PLYWOOD:

Plywood is manufactured like LVL, but with the adjacent veneers laid at a right angle.



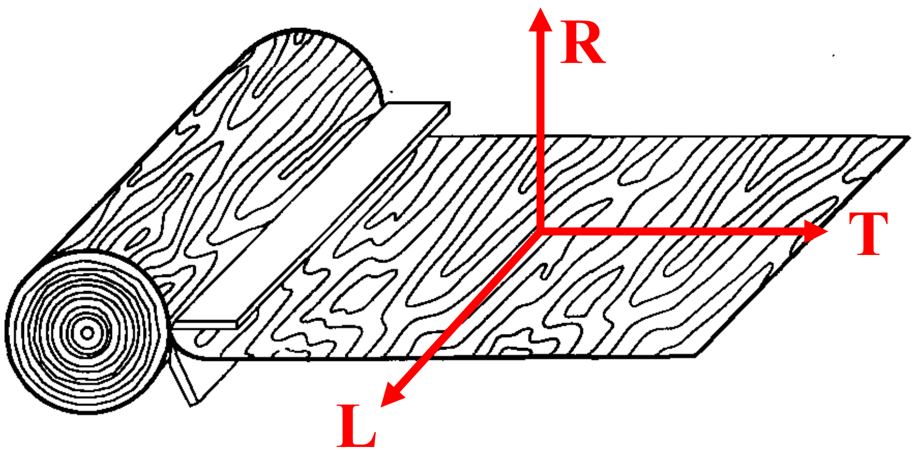
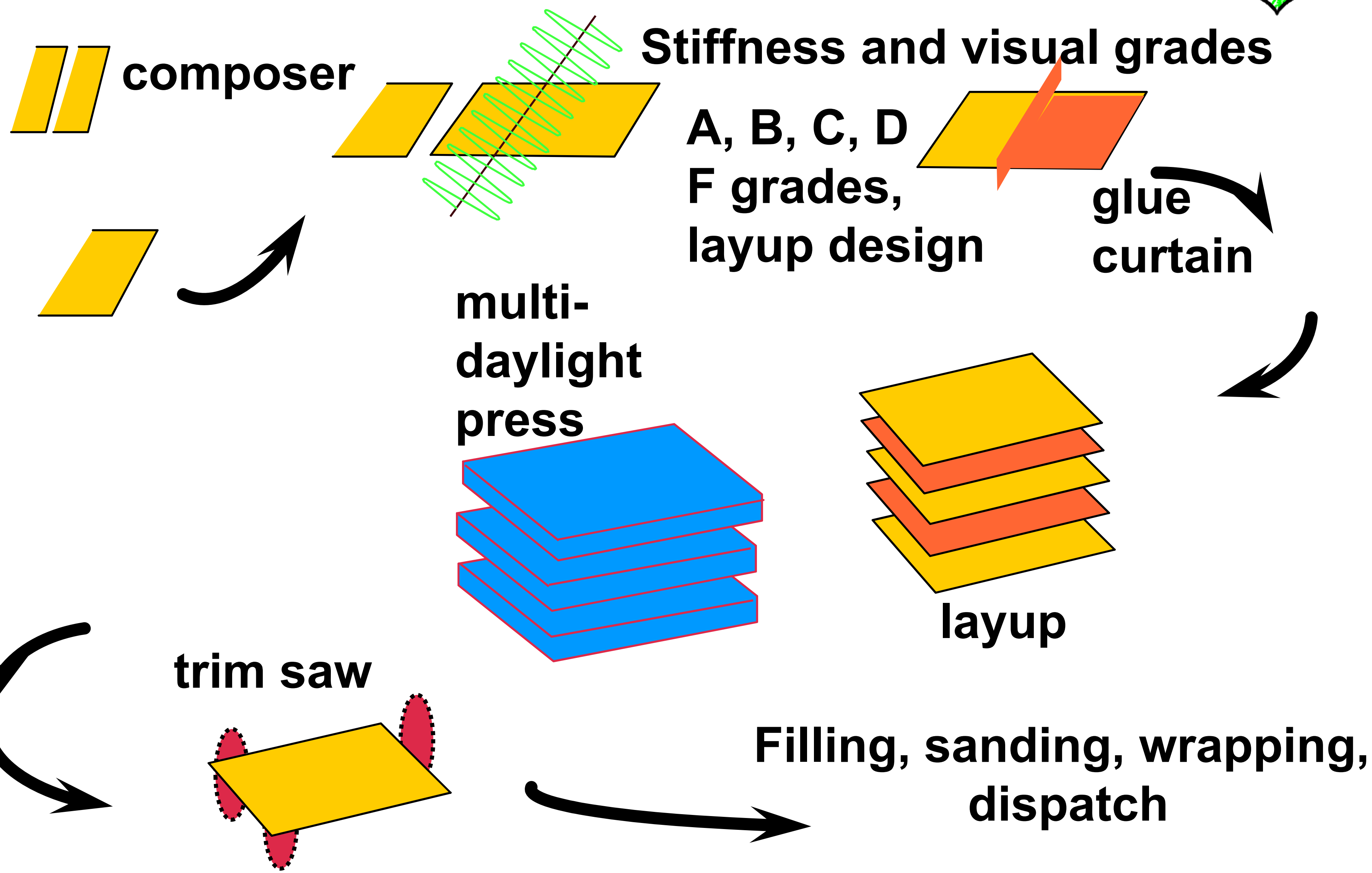


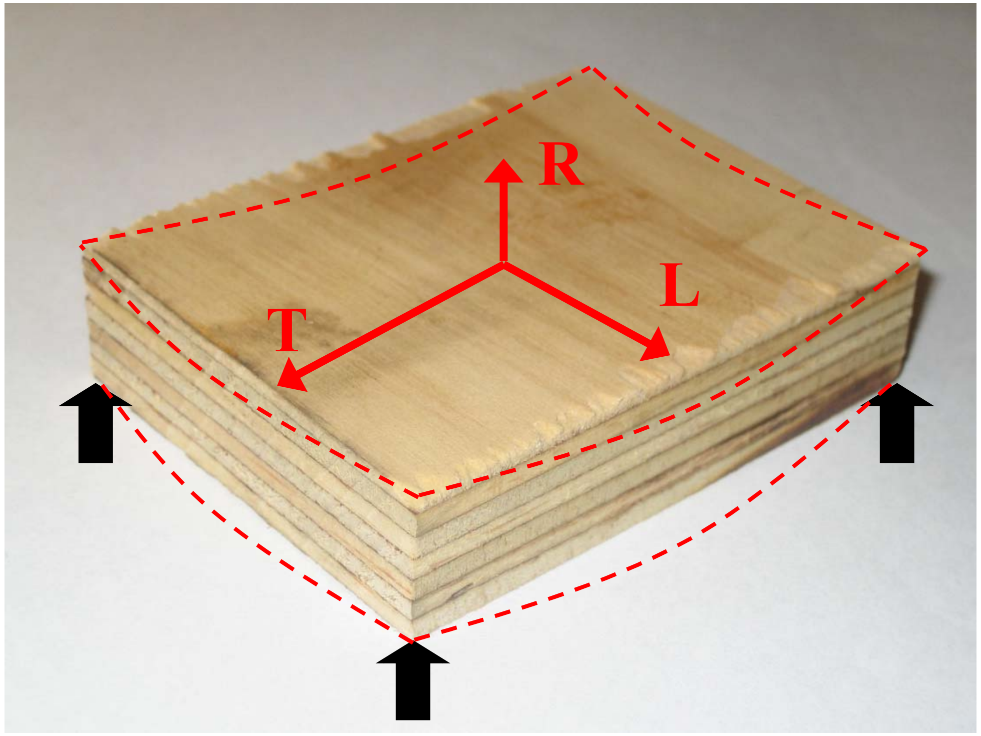
Figure 1 Production of an "endless" ply ribbon by rotary peeling.

PLYWOOD MANUFACTURE:



PLYWOOD:

Unlike LVL, Plywood experiences strength and stiffness comparable in any in-plane direction. It is produced in panels which are mainly used for 2D members such as floor deckings and shear walls.



PLYWOOD:

PARTICLEBOARD:

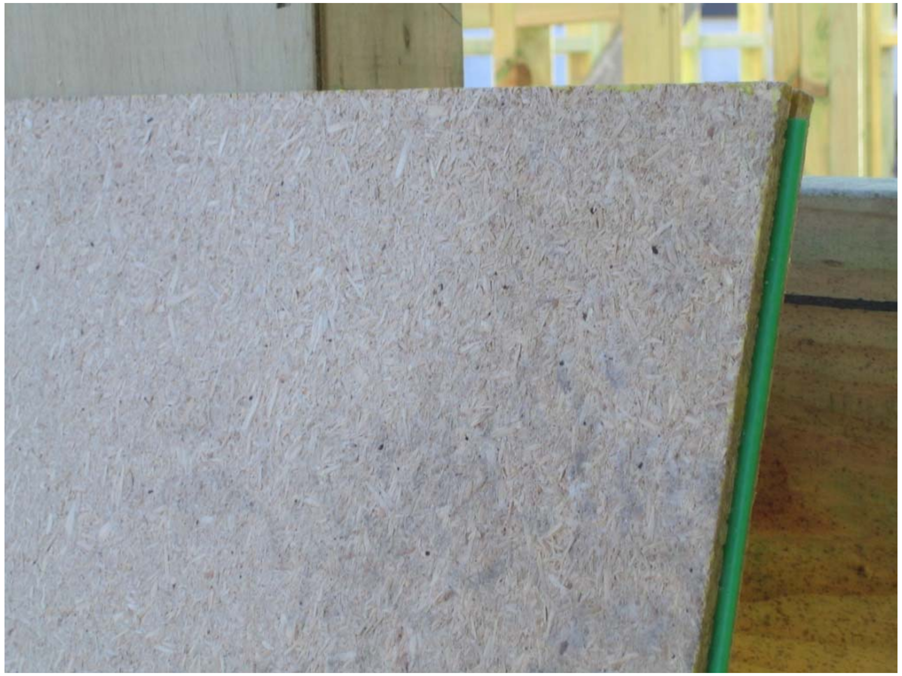
Are obtained from wood particles mixed with glue, then heated and compressed.

Advantages: Isotropy, dimensional stability, less scatter of mechanical properties.

Disadvantages: less strength (f_b=17 MPa), less stiffness (E=4 GPa), greater creep.

PARTICLEBOARD:

Particleboard



Plywood

ORIENTED STRAND BOARD (OSB)

REDUCED MODULUS OF ELASTICITY:

PROPERTY	TIMBER	STEEL	CONCRETE
Modulus of Elasticity [GPa]	10	210	30

REDUCED MODULUS OF ELASTICITY:

REMARK: Suppose we want to design a beam subjected to a uniform load q.

Since **timber exhibits** about **1/3rd of the Young modulus of concrete, a high deflection** (about 3 times) **is expected:**

$$\boxed{\eta_{inst} = \frac{5}{384} \cdot \frac{ql^4}{EI_x}}$$

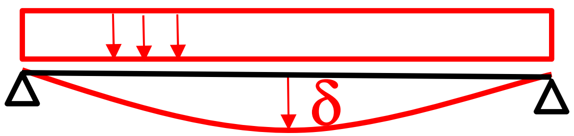
In addition, the **creep of timber will increase the deflection in the long term**, particularly for high moisture cont.:

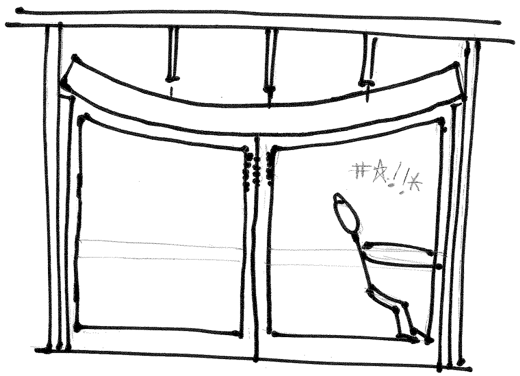
$$\boxed{\eta_{fin} = \eta_{inst}\left(1 + k_{def}\right) = \frac{5}{384} \cdot \frac{ql^4}{EI_x} \cdot \left(1 + k_{def}\right)}$$

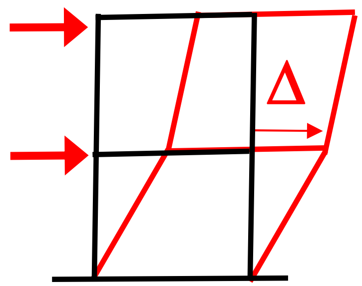
REDUCED MODULUS OF ELASTICITY:

CONSEQUENCE: timber structures may suffer from:

- **Excessive deflection,** under gravity and lateral loading (Serviceability Limit State)
- **Excessive vibrations** (SLS)

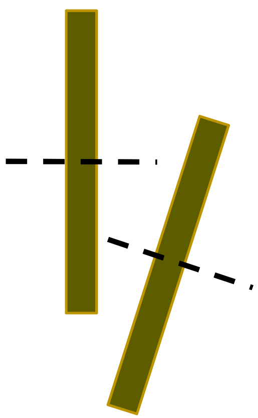


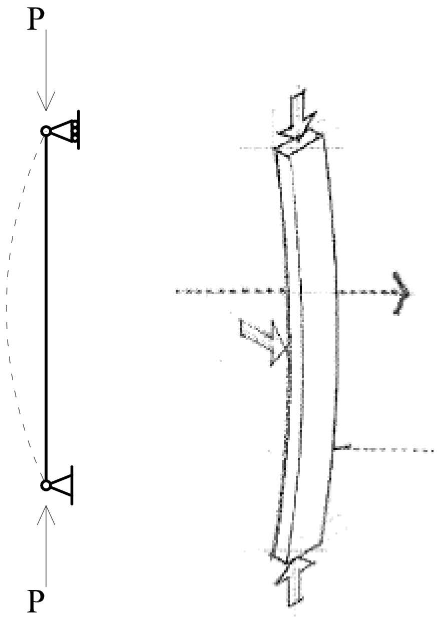


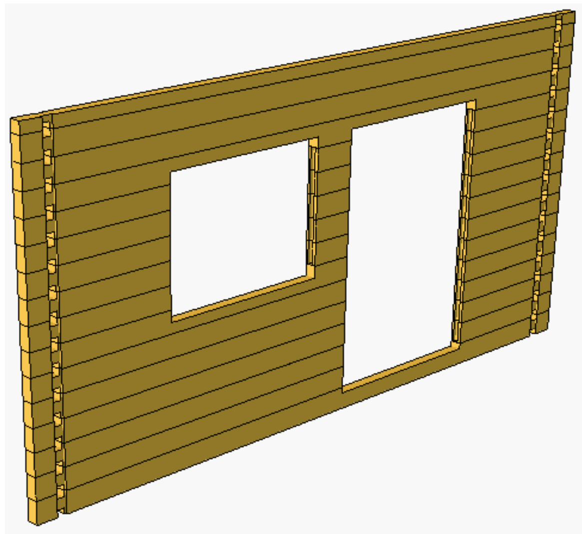


REDUCED MODULUS OF ELASTICITY:

- **Lateral-torsional buckling** in deep beams and **flexural buckling** in columns (strength limit state) ($P_{cr}=\pi^2 EI/l_0^2$: since E is low, also P_{cr} is low)







INFLUENCE OF THE MOISTURE CONTENT:

$$m.c. = \frac{weight\ of\ water}{weight\ of\ dried\ wood} \cdot 100$$

The **m.c. depends on** the **environmental relative humidity, seasoning** of wood and **cross-sectional area** of the wood member

The higher the m.c., the lower the strength and stiffness, and the greater the creep coefficient

HOW TO MEASURE THE M.C.?

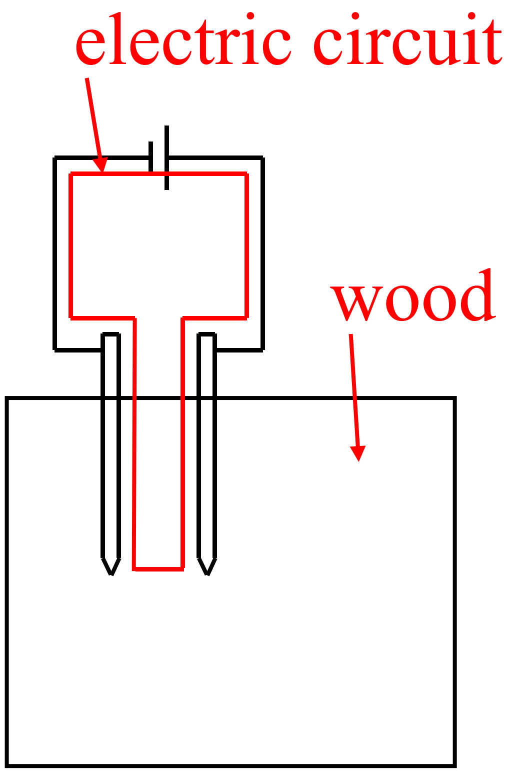
How to measure m.c.?

- **by oven dry** to 102 °C (most accurate but not applicable for whole beams):

$$m.c. = \frac{weight\ of\ \ wood\ before\ drying - weight\ of\ \ wood\ after\ drying}{weight\ of\ \ wood\ after\ drying} \cdot 100$$

HOW TO MEASURE THE M.C.?

• **by electric moisture meters** (less accurate but applicable for whole beams):



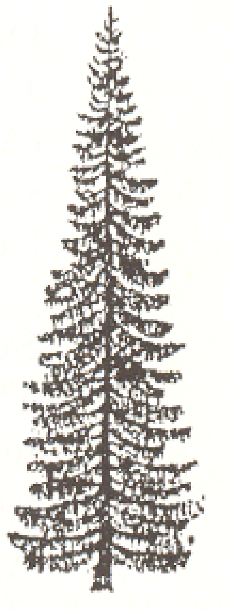
The m.c. will depend upon the electrical resistance measured between the two probes. The instrument needs to be calibrated on different wood species. It can be used for 6%<m.c<28%.

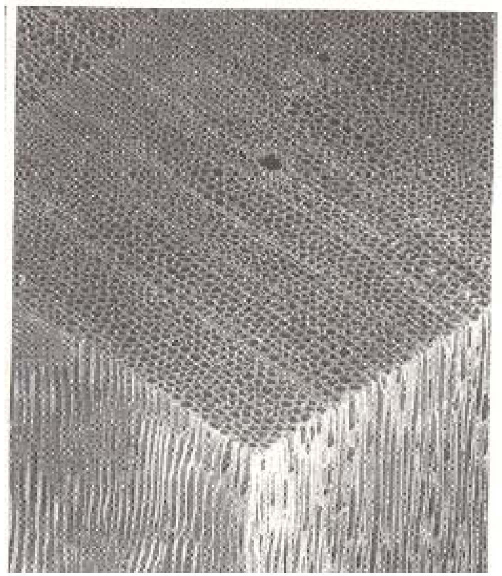
HOW TO MEASURE THE M.C.?

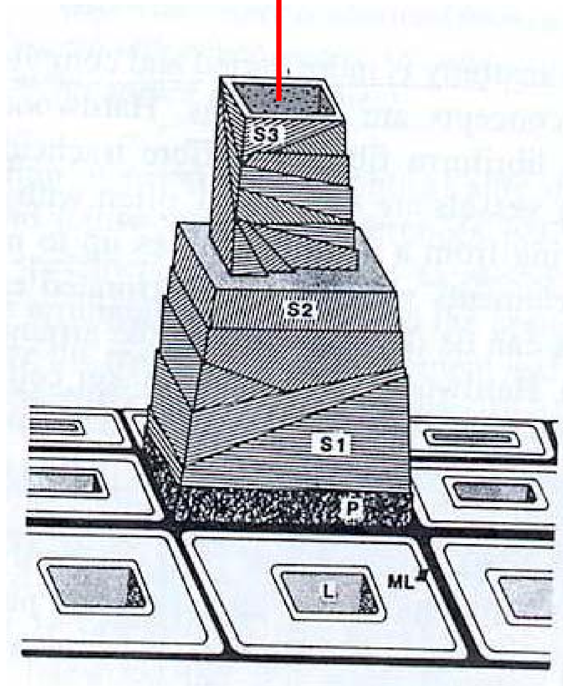
Electric moisture meter

WOOD AND WATER:

The **living tree sucks water** from the ground. The water moves **into the cell lumens**. m.c.= 40 – 200 %







WOOD AND WATER:

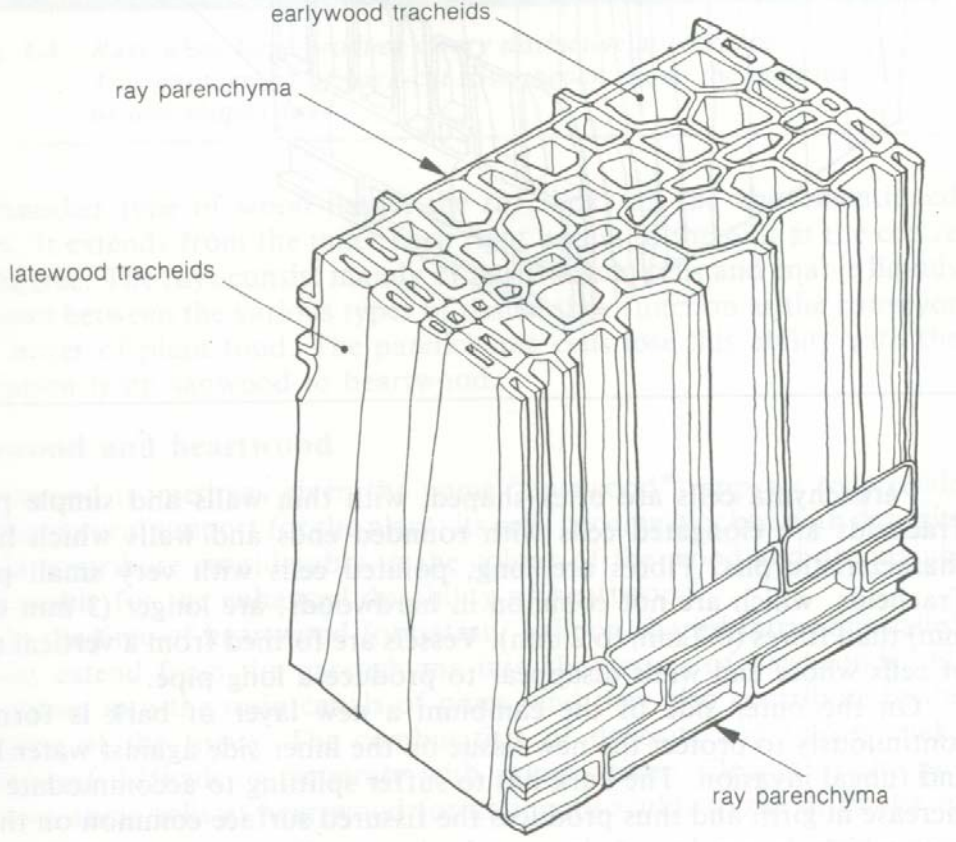
When the **tree** is **cut down**: **the amount of water starts decreasing**.

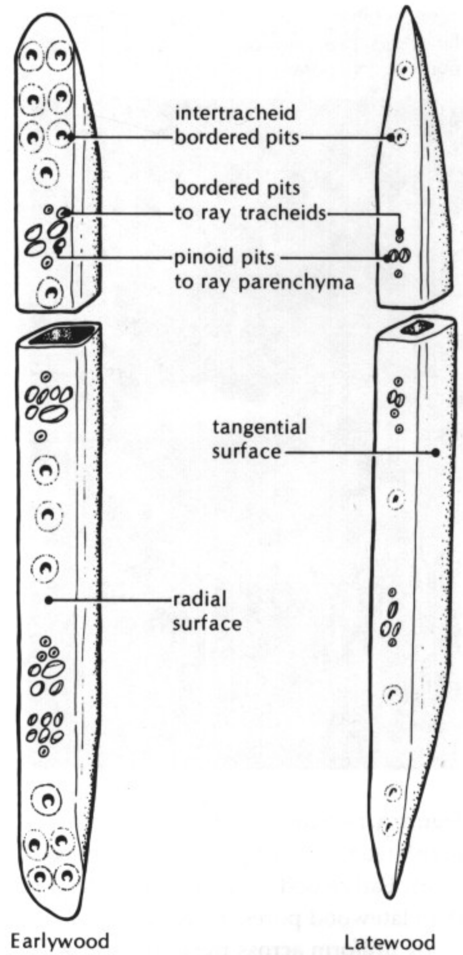
Water in wood

- **free**: contained in the cell lumens
- **bound**: combined with the cell wall substances (hydrogen bonds and van der Walls forces)

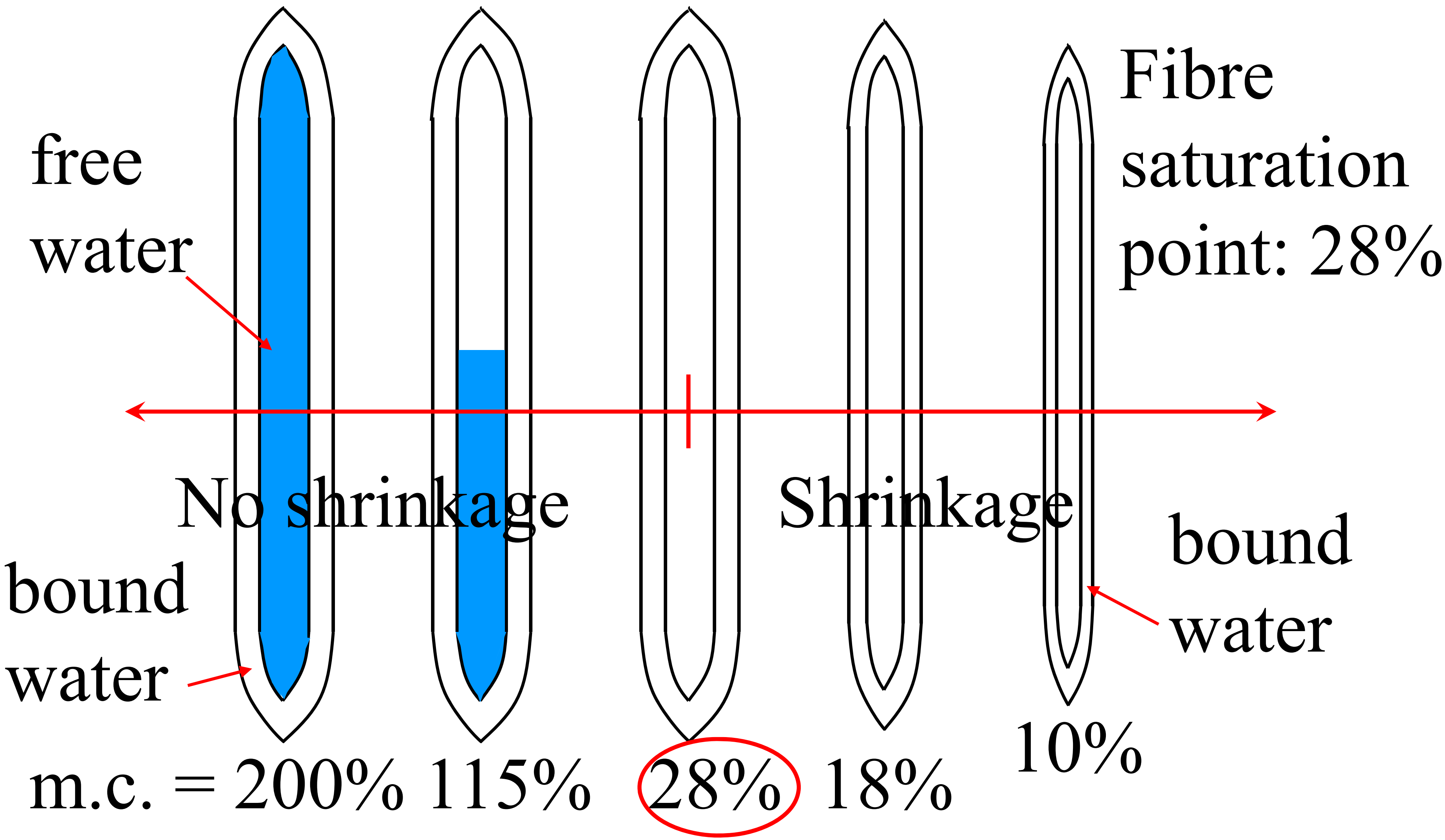
ENLARGEMENT OF A CELL:

Fig. 1.2 *Diagram of a cube of softwood. Magnification ×250. The pits in the cell walls have been omitted*





CROSS-SECTION OF A CELL:



FIBRE SATURATION POINT:

The **FSP** is the **moisture content when** the **cell walls** are **saturated** by water (bound water) **but no free water exists** in the cell lumens (usually 28%).

For m.c **above the FSP**: wood experiences **no dimensional changes** and **no variations in mechanical properties** (E, strengths).

FIBRE SATURATION POINT:

If the wood is dried **below the FSP**: the **bound water reduces** and that leads to:

- **Shrinkage** (reduction in volume)
- **Increase in mechanical properties** (E, strengths) and **reduction in creep**

SHRINKAGE AND SWELLING

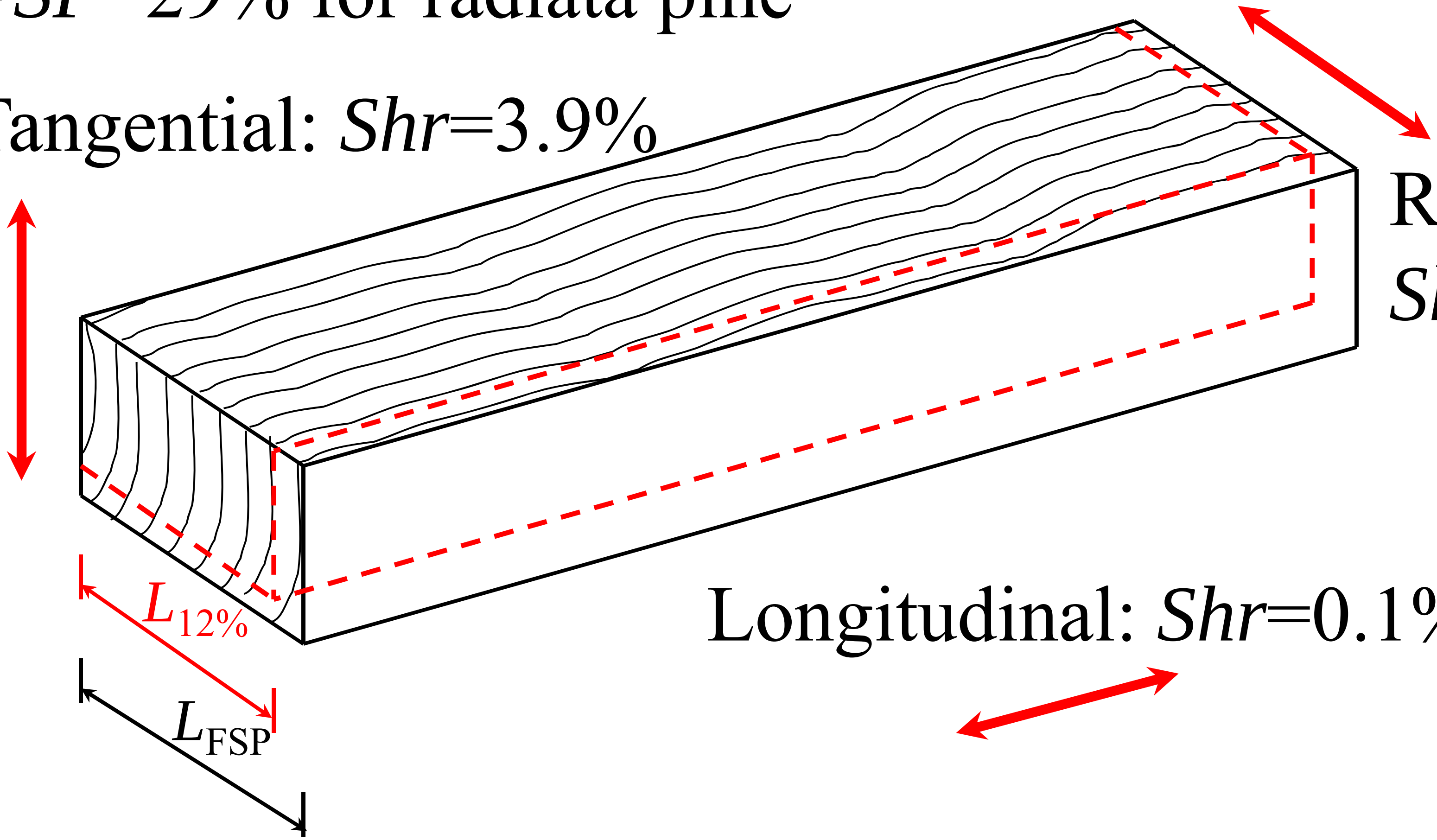
$$Shr = Shrinkage\ from\ green\ to\ 12\%\ m.c. = \frac{L_{FSP} - L_{12\%}}{L_{FSP}} \cdot 100$$

FSP=29% for radiata pine

Tangential: *Shr*=3.9%

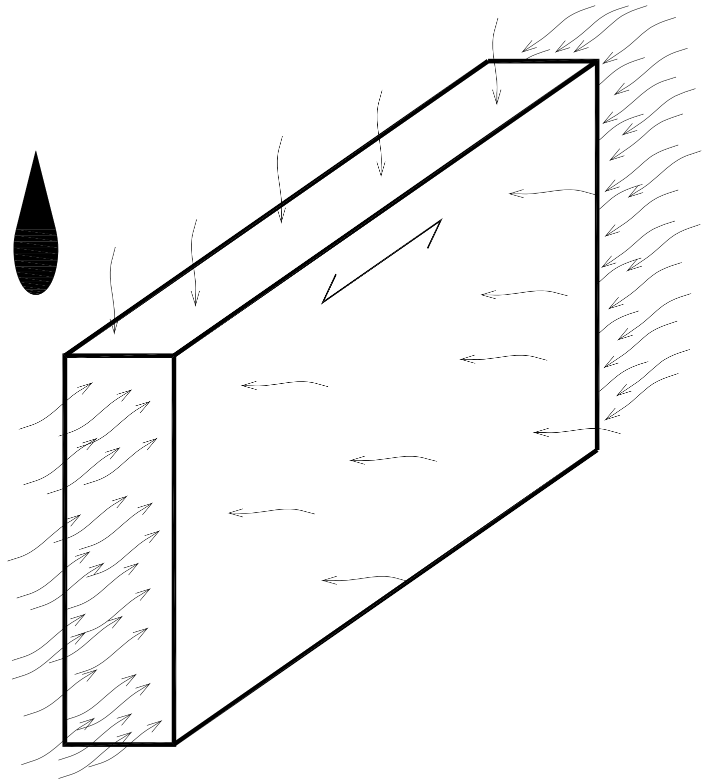
Radial: *Shr*=2.1%

Longitudinal: *Shr*=0.1%



EQUILIBRIUM M.C.:

A piece of wood exchanges moisture content mostly through the end sections, parallel to the grain.



EQUILIBRIUM M.C.:

When the tree is cut down: the m.c. will reduce from 200% to the equilibrium moisture content for the given *T* and *RH* of the environment (8% to 30% for *RH*=40% to 100% at *T*=21°C).

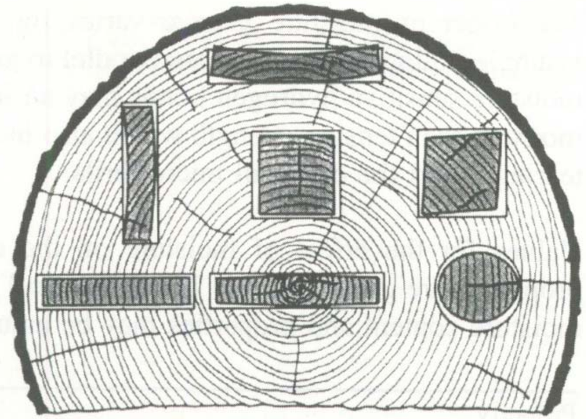
The larger the cross-section, the longer the drying process.

SUGGESTED M.C. FOR TIMBER:

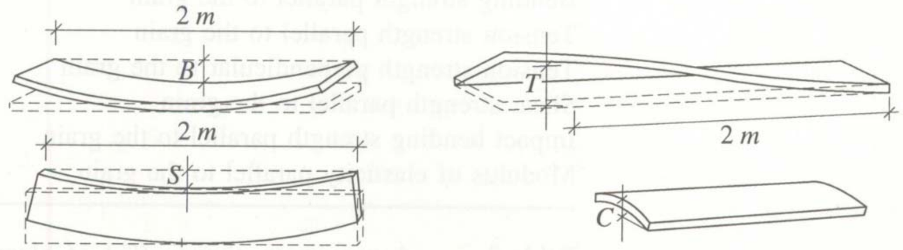
Use category	Air conditioned or centrally-heated buildings	Intermittently heated buildings	Unheated buildings
Structures inside the insulation	14-18%	14-18%	14-18%
Flooring exposed to ground atmosphere	10-14%	12-16%	14-18%
Flooring not exposed to ground atmosphere	8-12%	10-14%	12-16%

DISTORTIONS

The difference between tangential and radial shrink. leads to **distortion** of the cross-section.



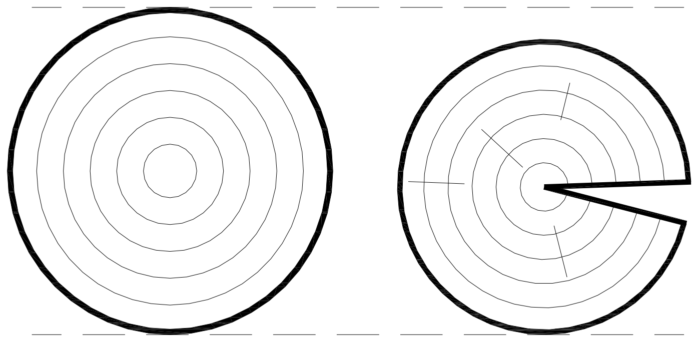
Distortions of various cross sections after drying, cut from different locations in a log.



Distortions. B: bow; T: twist; S: spring; C: cup.

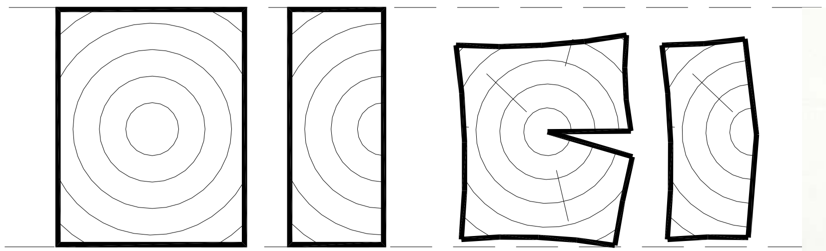
Possible **cracks** can also occur during the drying of timber. In order to minimize the distortion: **timber must be dried** and then planed.

CRACKS:

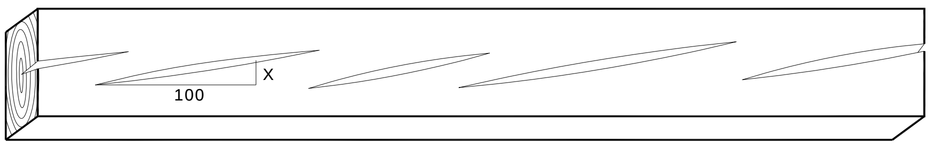


U>30% U<30%

If the log is not sawn: an extended crack will form, together with smaller cracks



U>30% U<30%



If the section contains the pith: a crack will form during drying

DRYING OF TIMBER:

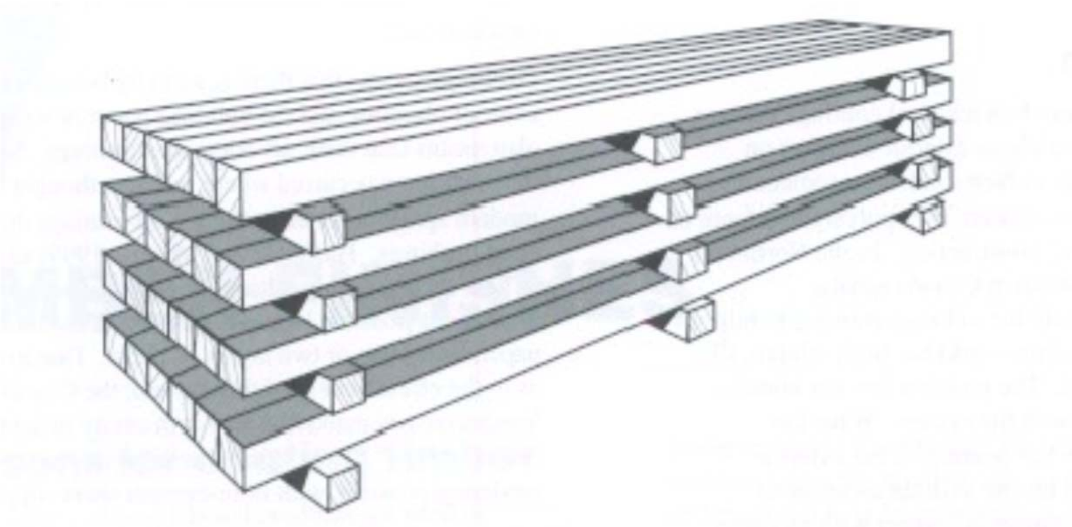
To attain the suggested value of m.c.:

TIMBER MUST BE DRIED!!!

Drying methods
- Air drying
- Kiln drying

DRYING OF TIMBER:

Air drying: timber filleted, stacked and allowed to dry with the passage of natural air (may take several weeks).



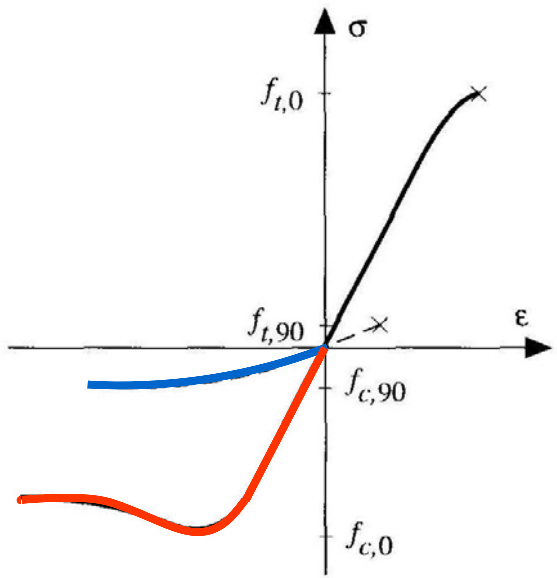
DRYING OF TIMBER:

Kiln drying: using heat and air flow in a controlled cycle (conventional: one week; using high temperature: 24 hours).

REDUCED DUCTILITY:

Timber has little ductility and only in compression

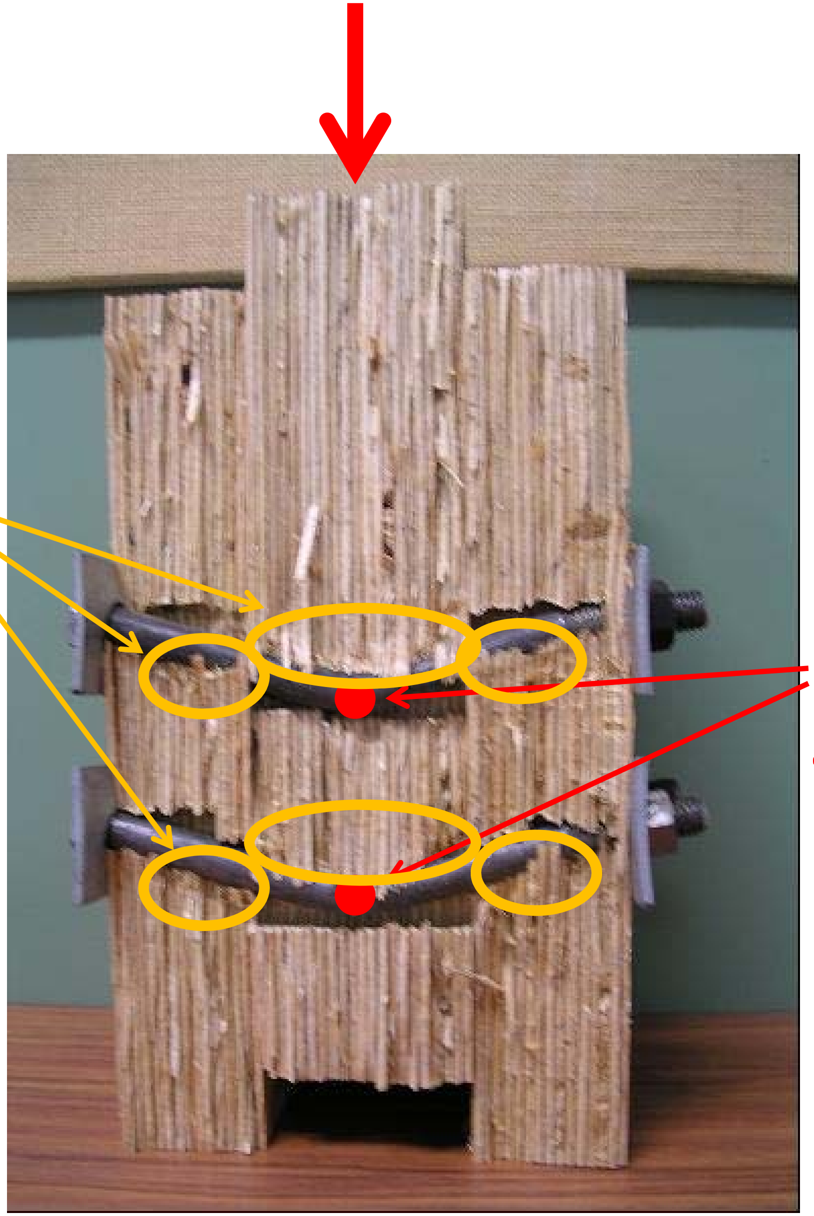
Disadvantage in seismic design.



The only source of ductility for a timber structure comes from the connections, which shall be made of steel fasteners (nails, screws, bolts, dowels, etc.) so as to exploit the ductility of steel.

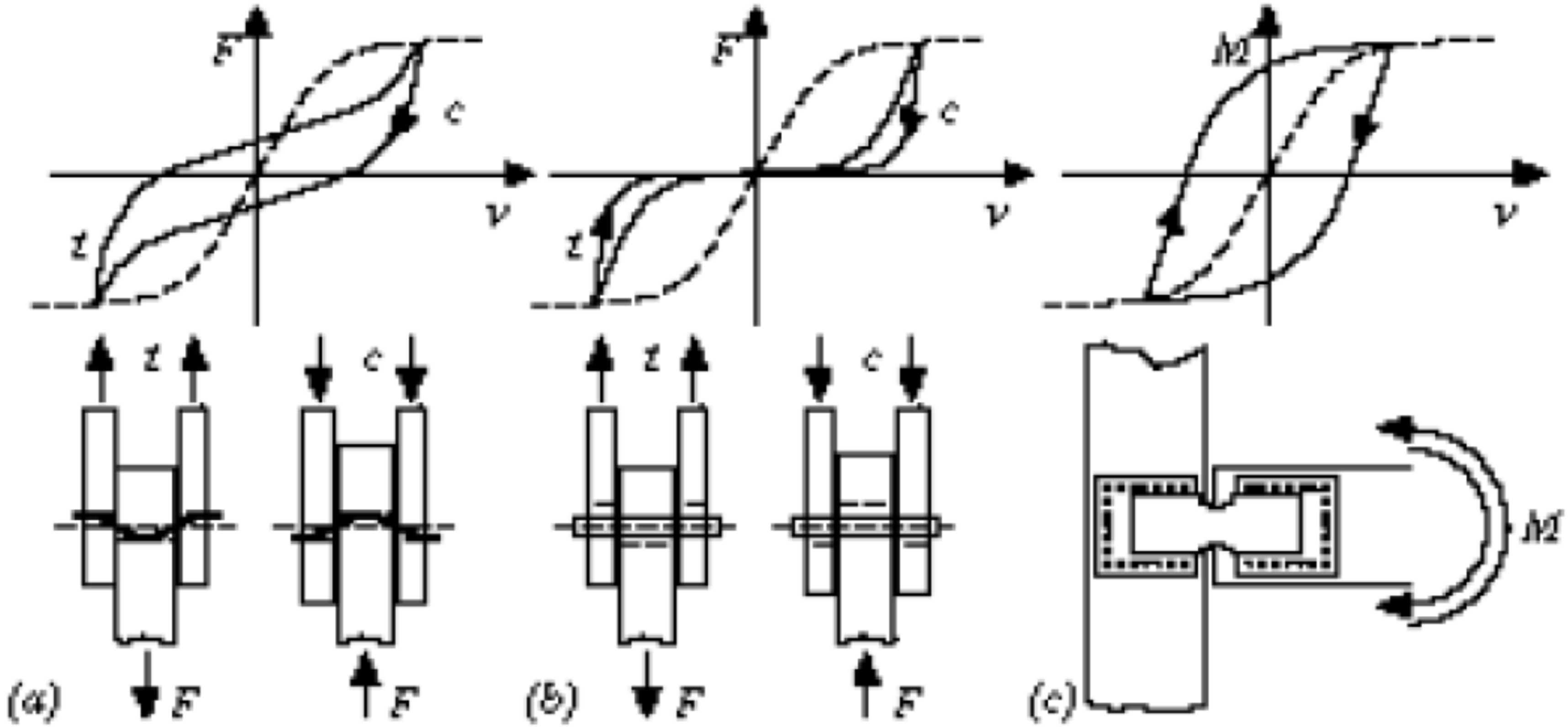
DUCTILE FAILURE MECHANISM:

Plasticization of timber in compression at the interface with the dowel



Plastic hinge formation in the dowel

DIFFERENT FAILURE MECHANISMS:



Dissipative mechanism: fastener plasticization and timber plasticization in compression at the interface with the fastener

Non dissipative mechanism: timber plasticization in compression at the interface with the fastener, with fastener still in elastic phase

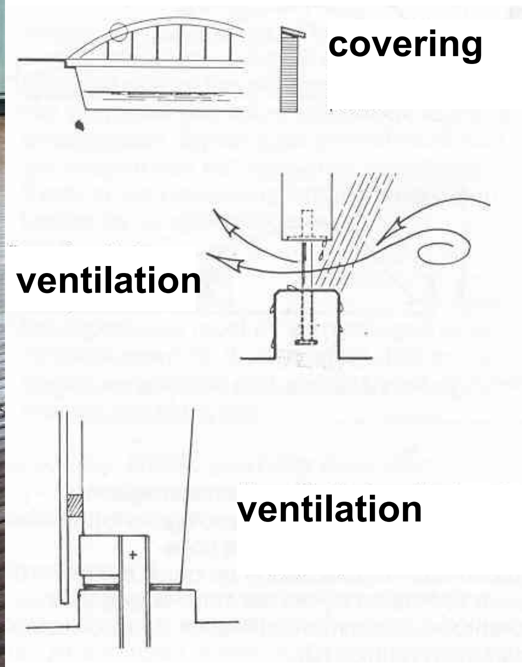
Very dissipative mechanism: plasticization of steel plate with fasteners in elastic phase without timber plasticization at the interface with the fasteners

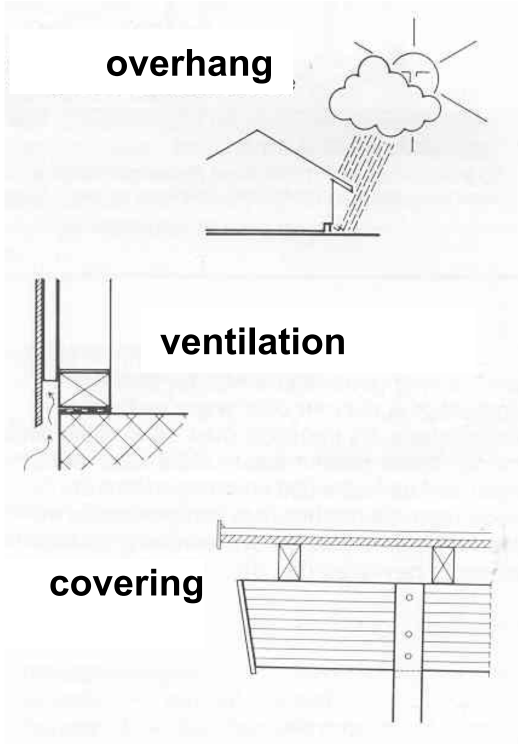
DURABILITY:

Timber may suffer from durability issues if in contact with water and oxygen, or when exposed to high values of moisture content (greater than 20%)

Timber should therefore be kept to lower values of m.c., and suitable details to prevent water stagnation and ensure water eveporation shall be adopted for structures exposed to the rain

DURABILITY:



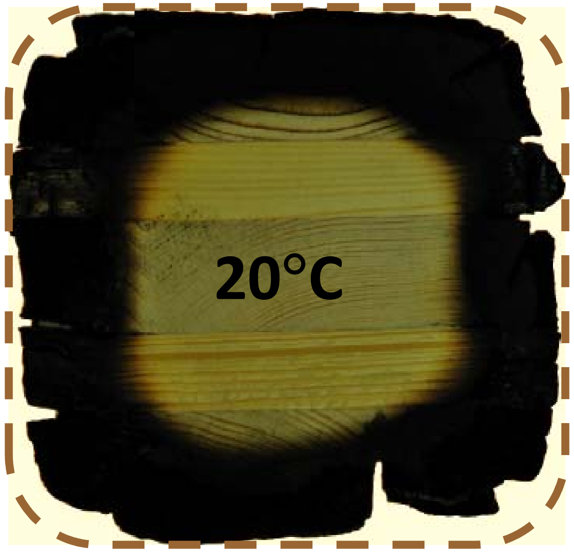


Examples of details to reduce durability problems

COMBUSTIBILITY:

Timber burns – however it is an excellent insulation material, therefore while burning on the exterior surface, the inner volume is still at ambient temperature and therefore resistant.

If the cross-section is sufficiently large (minimum size > 90 mm), it is possible to achieve a good fire resistance without additional protective measures.



COMBUSTIBILITY:

Conversely, steel does not burn, but has a large heat conductivity

Consequently, after little time from exposure to fire, steel quickly raises its temperature, and the mechanical properties (particularly E) quickly degrade leading to a sudden failure

COMBUSTIBILITY:

A new challenge: multi-storey timber buildings

Murray Grove, London: 9 storeys

Prov. Of Bolzano: 7 storeys (Italy)

7-storey buildings tested on a shaking table in Japan (SOFIE and Capstone Research Projects)

A new challenge: multi-storey timber buildings

9 storeys – Polaris Milan (Italy)

14 storeys - Bergen (in construction - Norway)

Wood building systems:

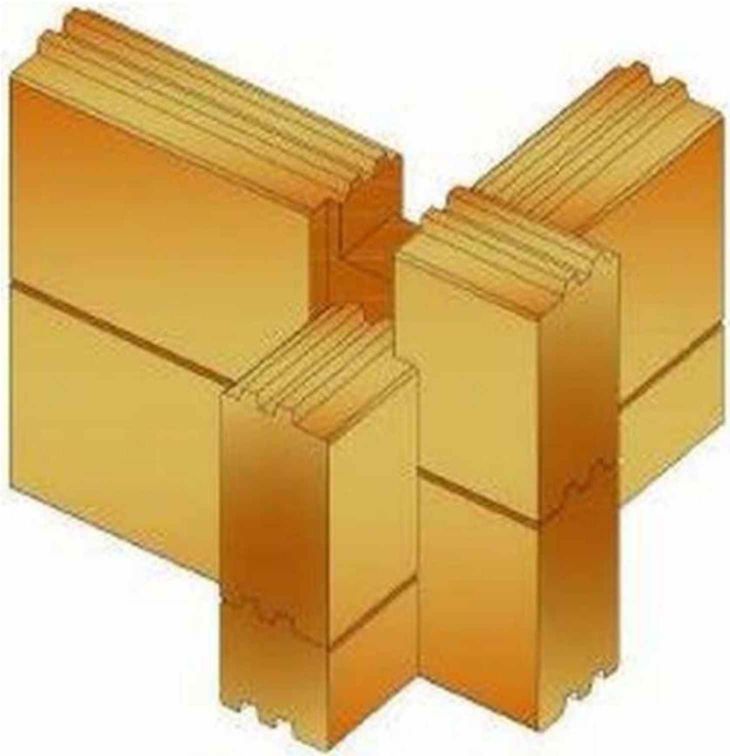
- Log-house system
- Light-frame construction
- Solid panel construction (glulam, crosslam, LVL)
- Hybrid systems (with different materials/systems for gravity and lateral load resistance)
- With seismic base isolation

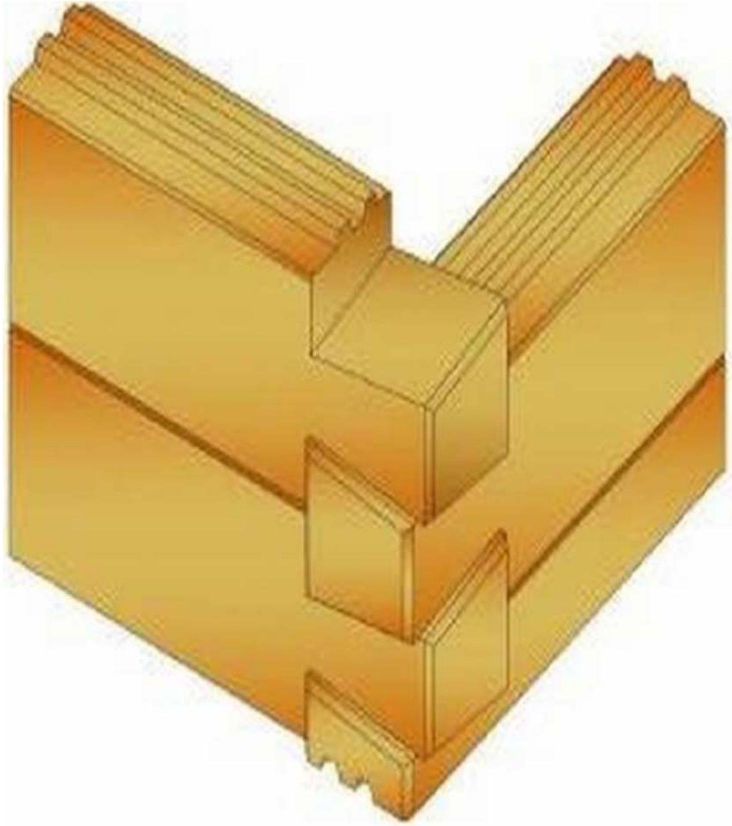
Log-house system

- Suitable for residential applications (many walls and short-span floors)
- Max: 2-3 storeys

Made of timber logs or profiled beams arranged horizontally – timber loaded perpendicular to grain from gravity load

Log-house system



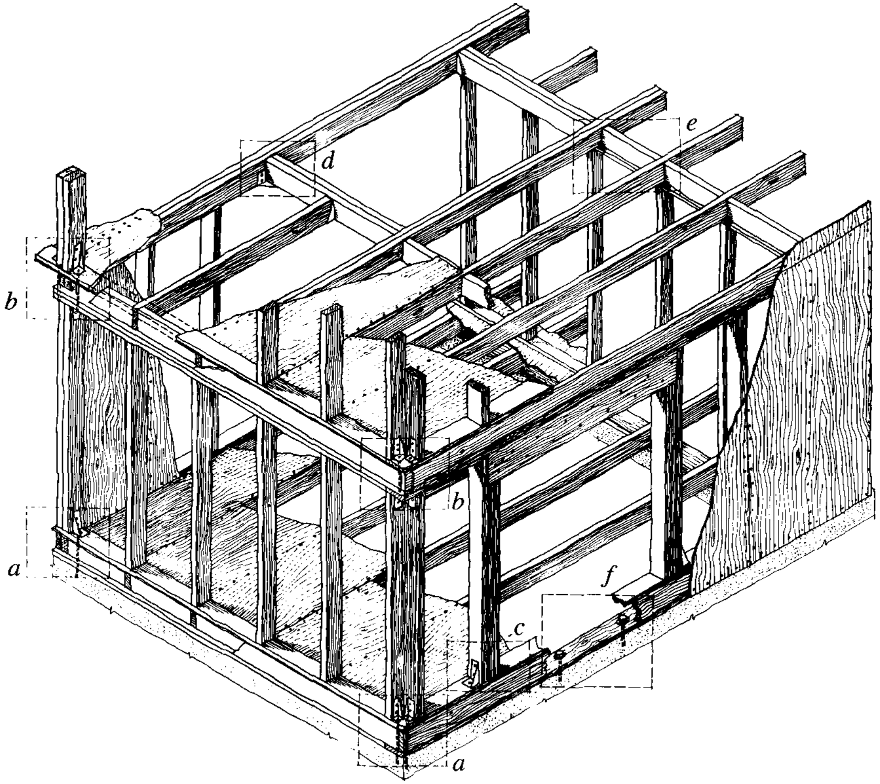


Resistance to lateral load achieved via carpentry joints between perpendicular walls – some energy dissipation under seismic load obtained via friction at contact surfaces between lower and upper logs

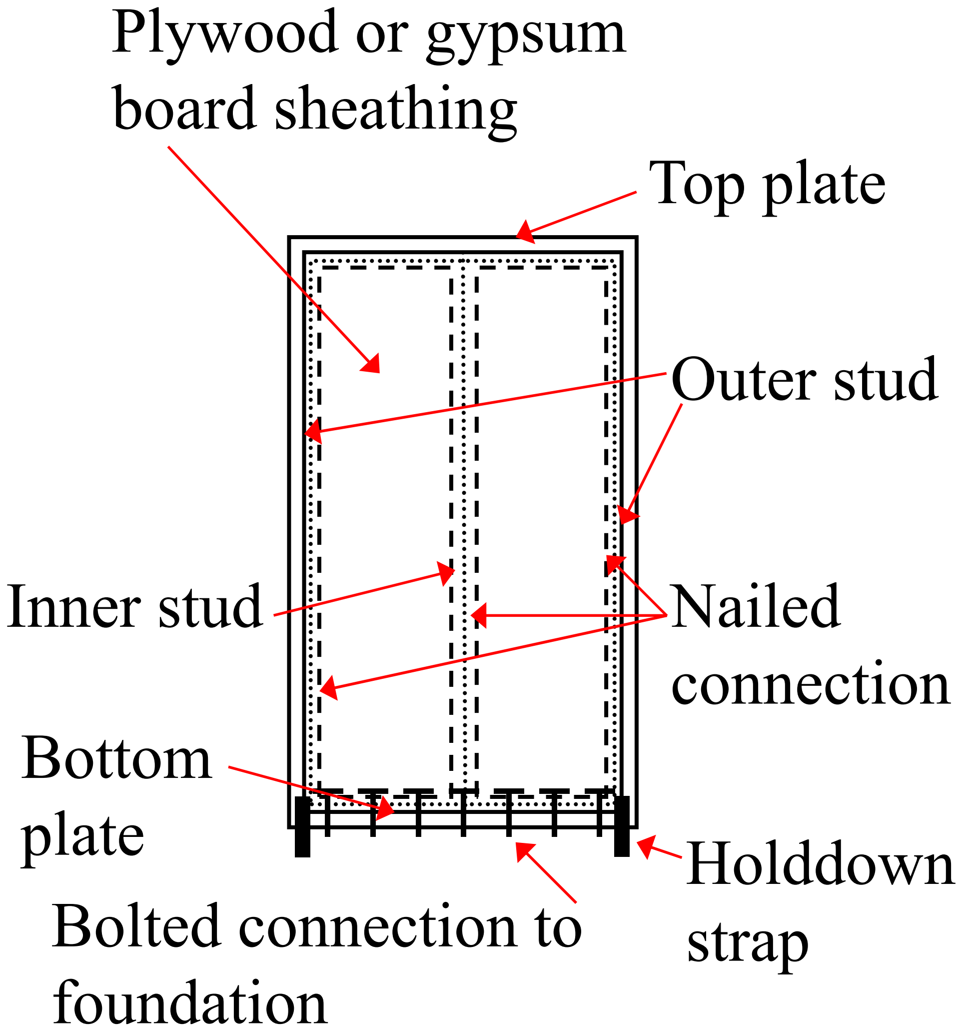
TIMBER FRAMED HOUSES:

TIMBER FRAMED HOUSES:

TIMBER FRAMED HOUSES:

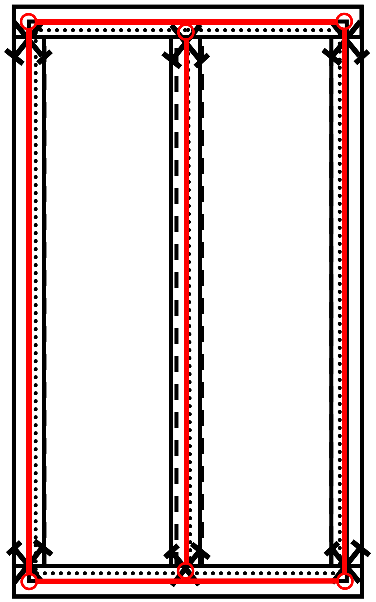


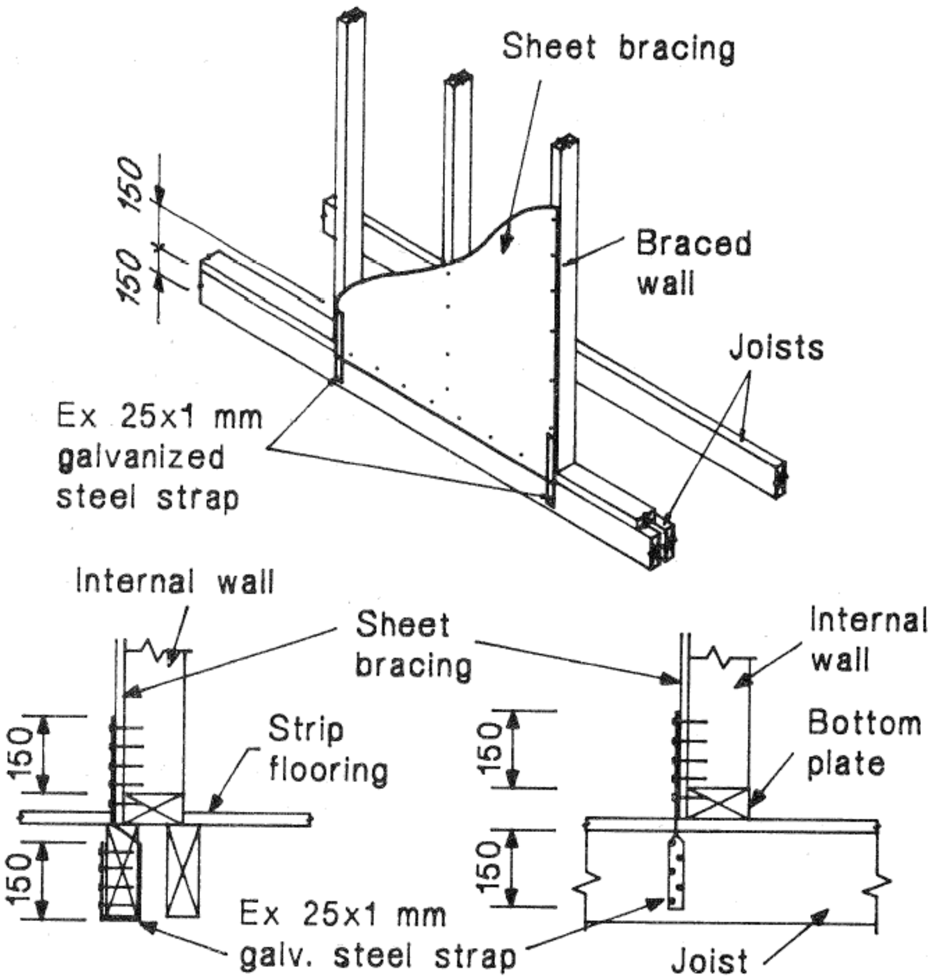
Detailing examples for a timber framed house. (a) prevention of uplift from foundations; (b) continuity of tension members; (c) stiffening of openings in shear walls by framing with additional studs, lintels and corner hangers; (d) stiffening of openings in diaphragms by framing with doubling of trimmer and header joists; (e) stiffening of diaphragm floors (blocking); (f) prevention of sliding of foundations.



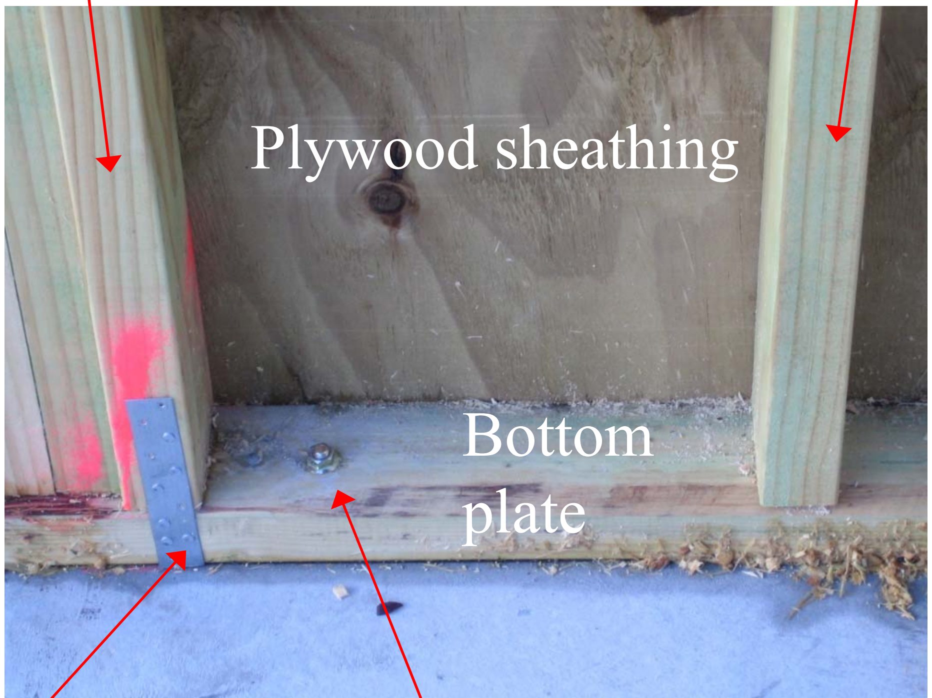
TIMBER FRAMED HOUSES:

Remark: the chord-to-plate joints are pinned. The system is stable only thanks to the nailed connection with the plywood sheet.





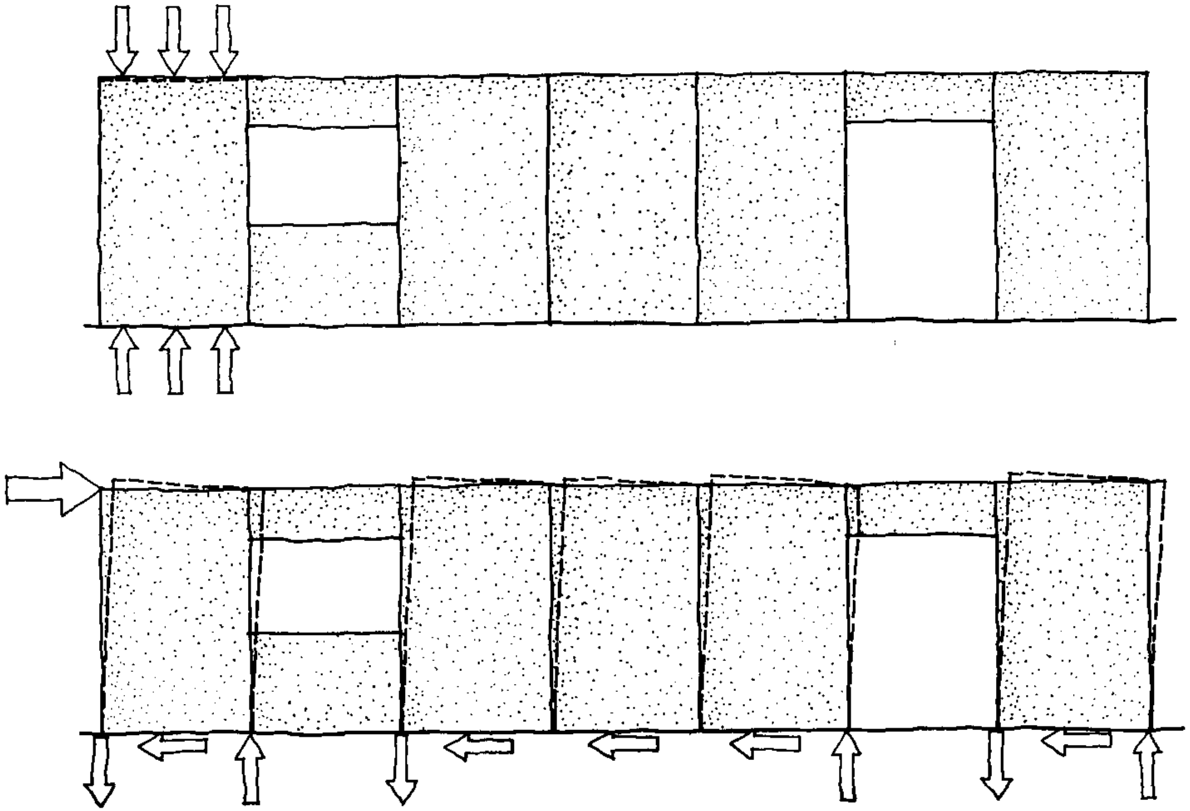
TIMBER FRAMED HOUSES:



TIMBER FRAMED HOUSES:

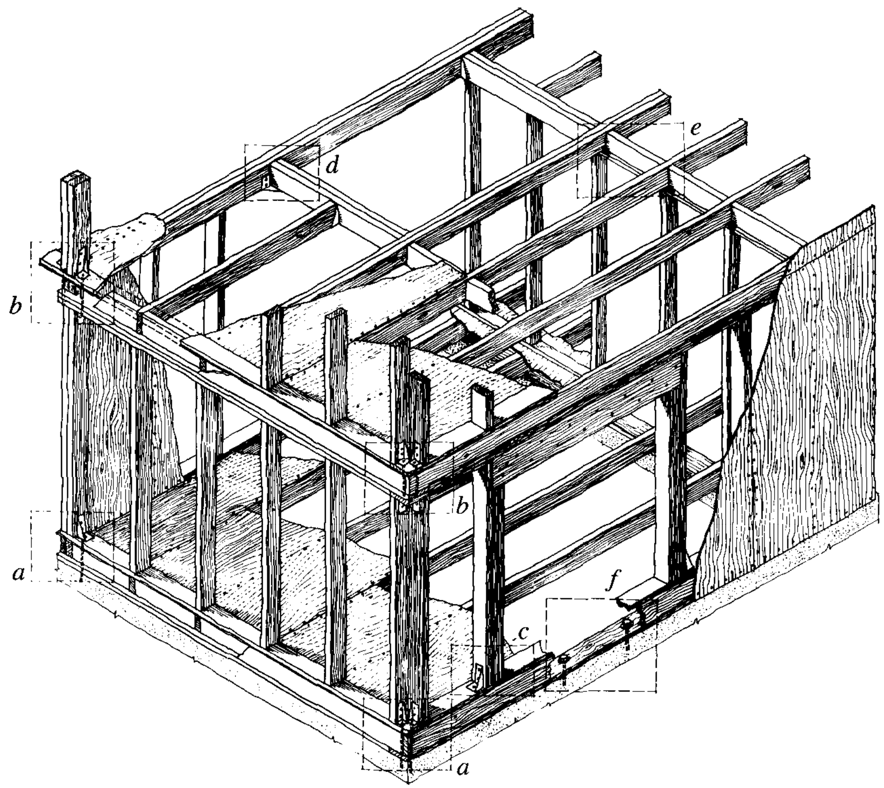
TIMBER FRAMED HOUSES:

SHEAR WALLS:



Different structural effects of vertical and horizontal loading.

TRADITIONAL FLOORS:

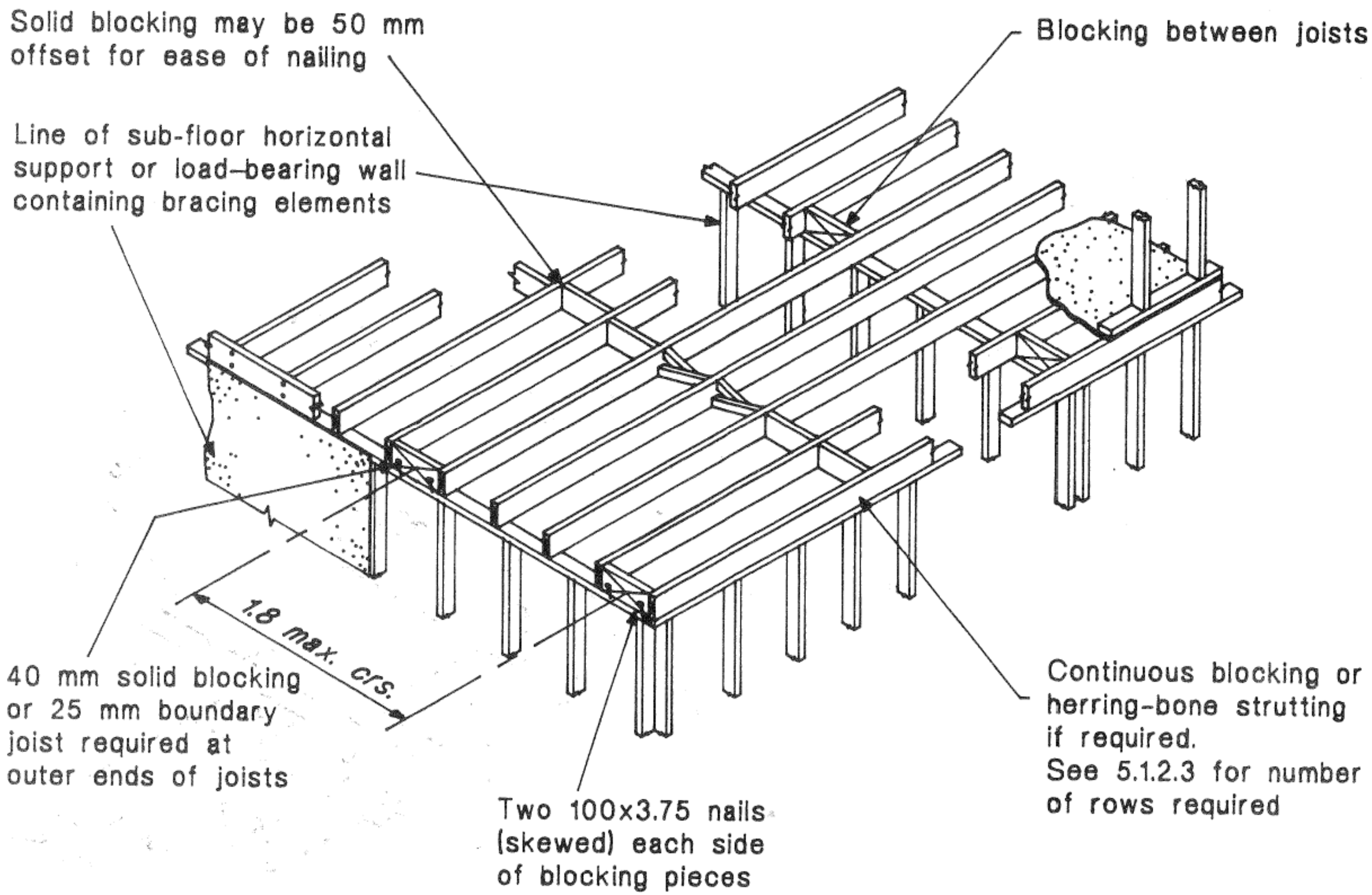


Detailing examples for a timber framed house. (a) prevention of uplift from foundations; (b) continuity of tension members; (c) stiffening of openings in shear walls by framing with additional studs, lintels and corner hangers; (d) stiffening of openings in diaphragms by framing with doubling of trimmer and header joists; (e) stiffening of diaphragm floors (blocking); (f) prevention of sliding of foundations.

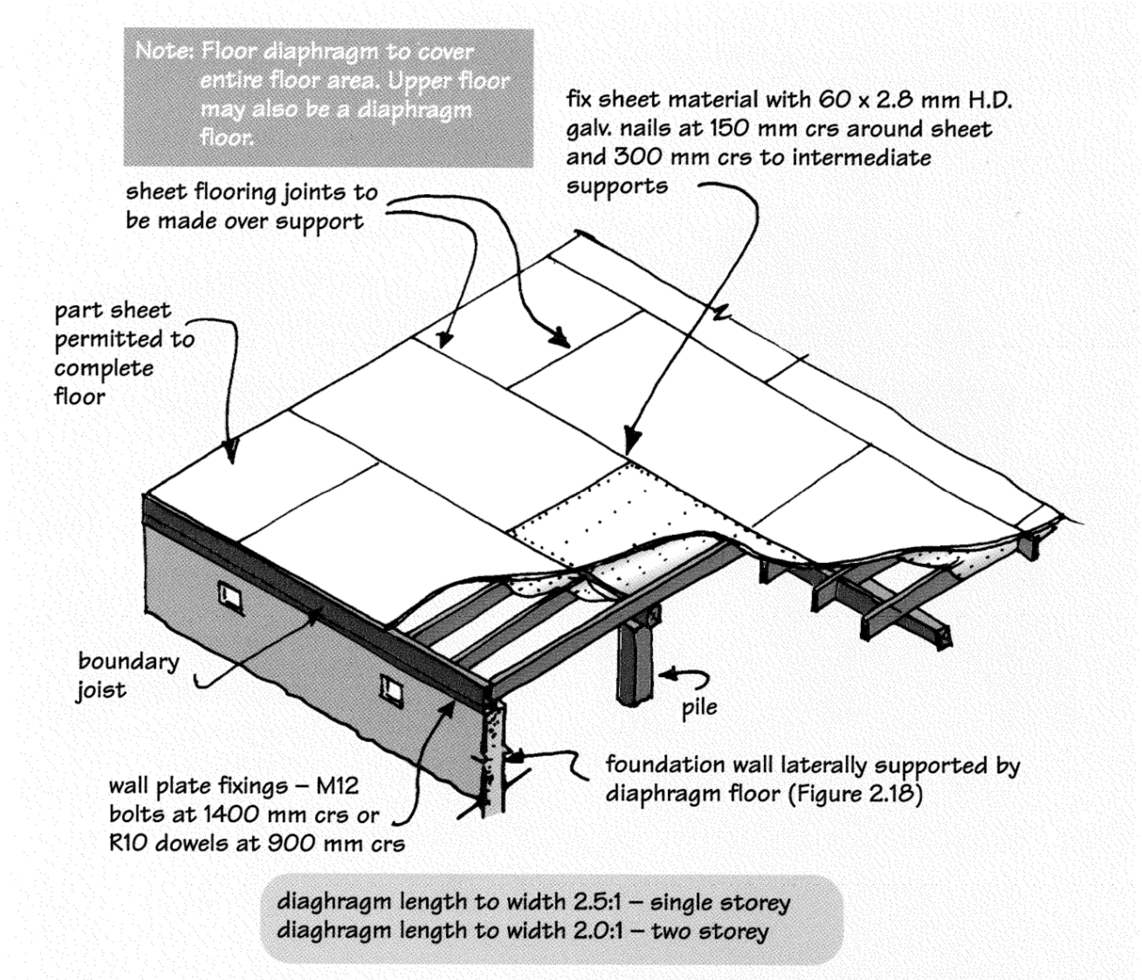
Are **made from joists, flooring panels, and blockings**.

The floor unit can be seen as a sort of shear wall turned over on the horizontal plane

TRADITIONAL FLOORS:



TRADITIONAL FLOORS:



In this case, joists and sheathing will be loaded in out-of-plane bending due to gravity

MULTI-STOREY BUILDINGS:

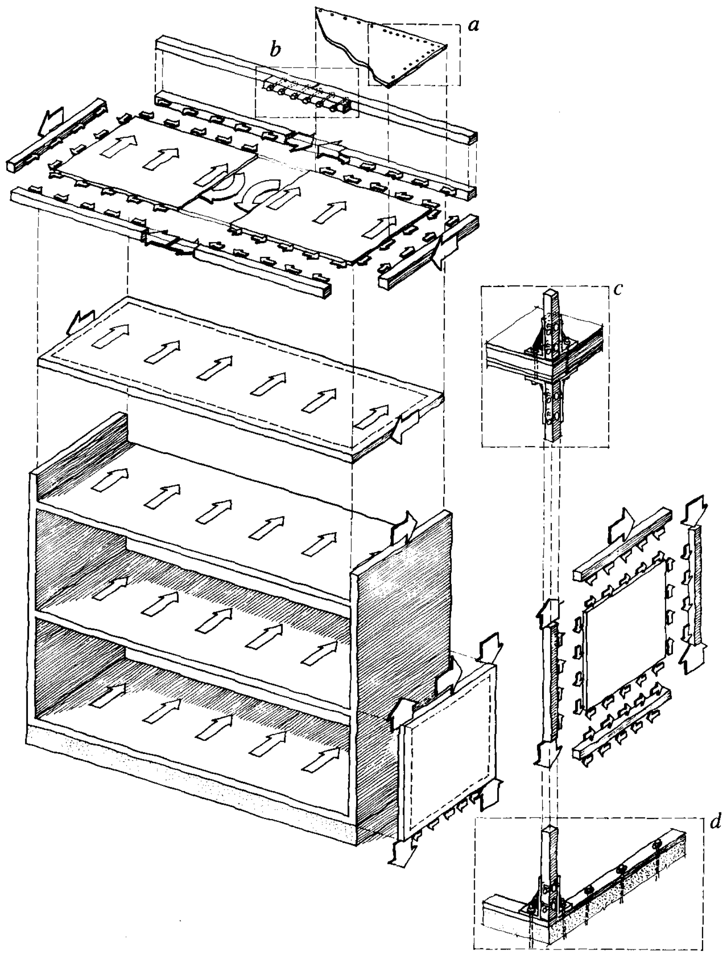
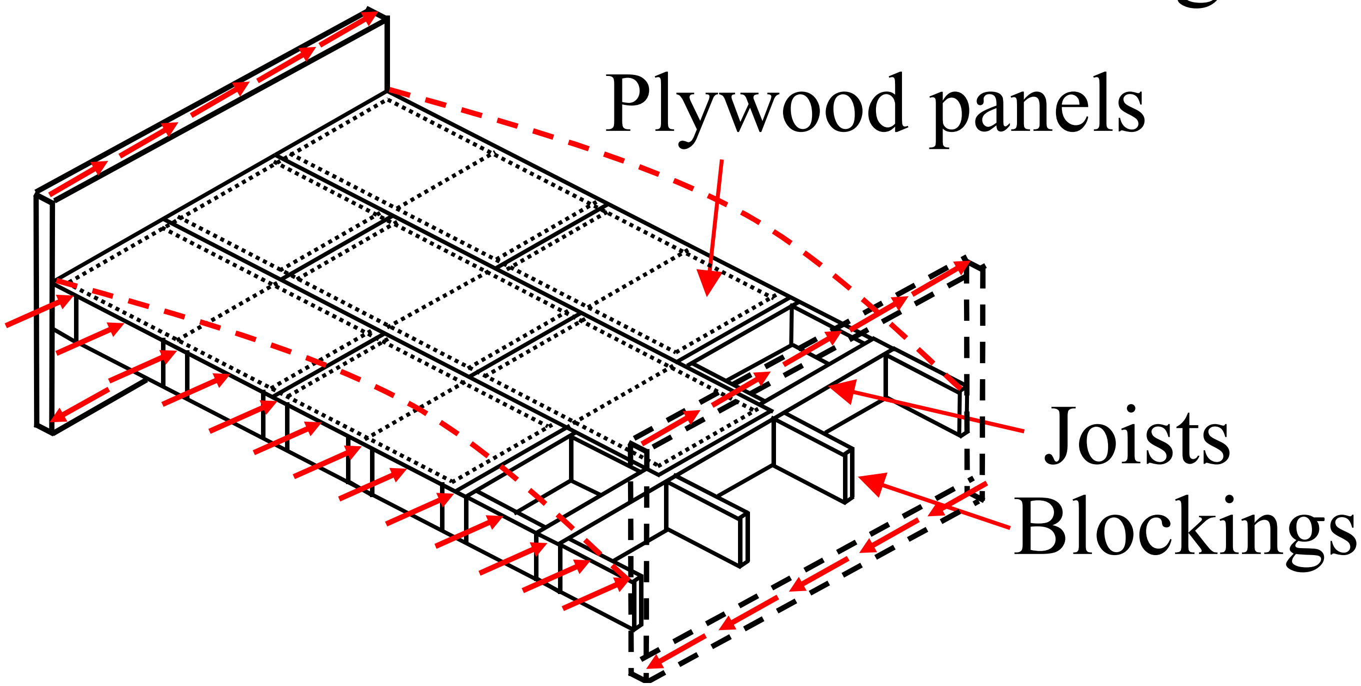


Figure 2 *Details assuring structural continuity under horizontal actions. (a) corner reinforcement; (b) tension girder continuity; (c) continuity of tension studs; (d) prevention of uplifting from foundation and sliding of foundation.*

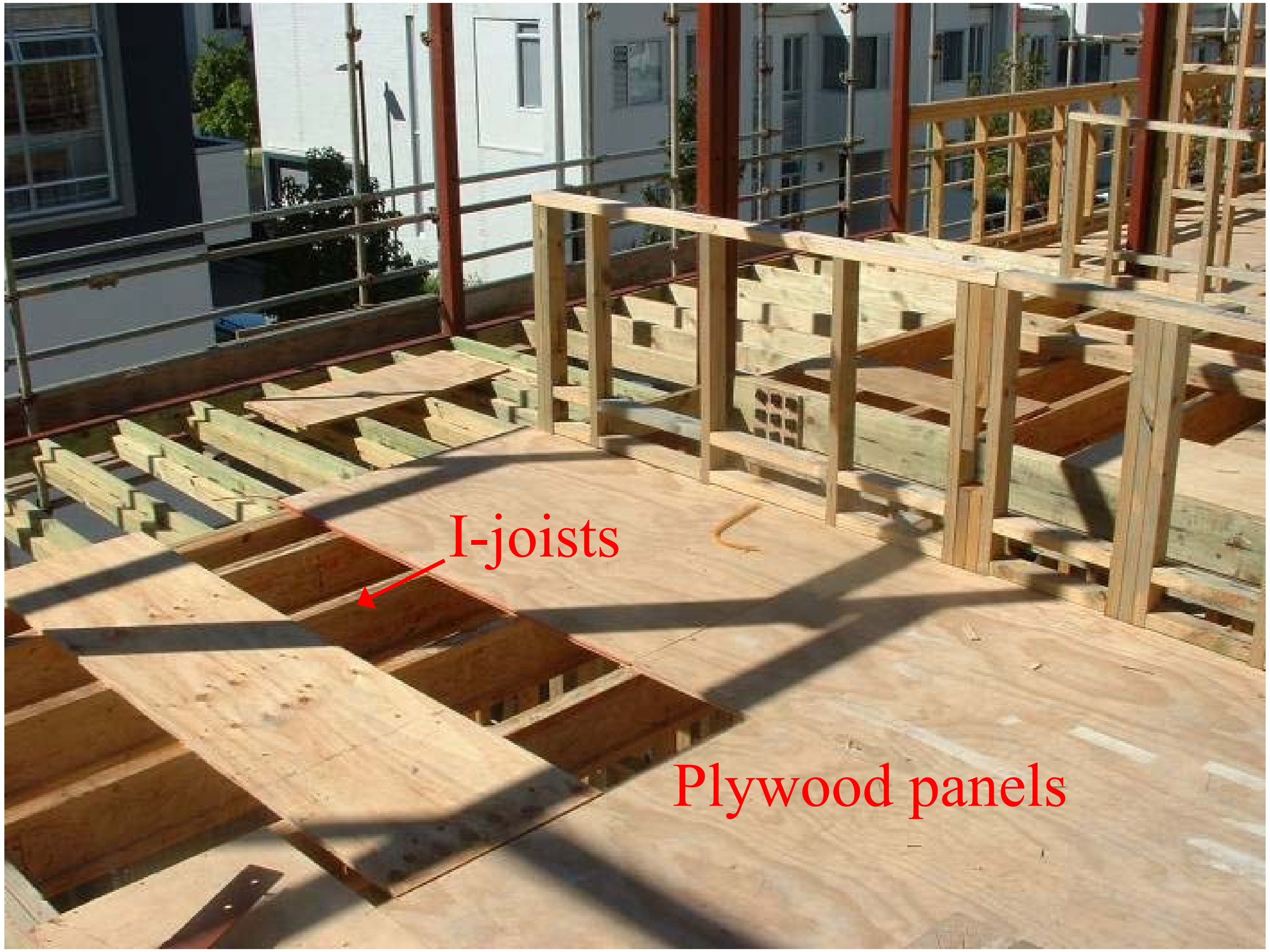
“Traditional” multi-storey timber buildings are made from ply shear walls and joisted floors, exactly like lightframe timber houses. The only difference are the materials: plywood replaces particleboard

FLOOR DIAPHRAGMS:

The plywood panels must be staggered and either nailed or glued to the joists and blockings to obtain a diaphragm action and transmit the horizontal loads to the bracings

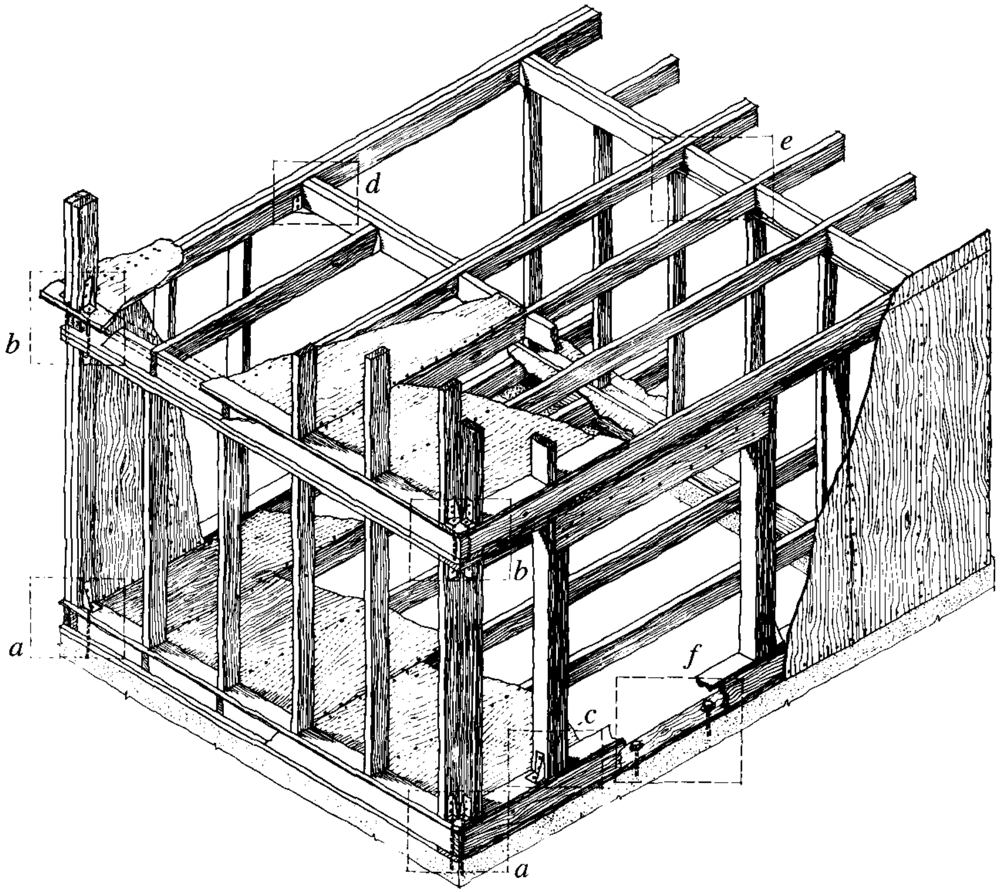


TRADITIONAL LIGHTFRAME FLOOR SOLUTIONS:



Light-frame construction:

- Suitable for residential applications (many walls and short-span floors)
- Max: 5-8 storeys



Light-frame construction:

Miki, Kobe, July 2009, Northridge 0.74g

Light-frame construction:

Miki, Kobe, July 2009, Northridge 0.74g

AN EXAMPLE: MARTIN SQUARE APARTMENT

AN EXAMPLE: MARTIN SQUARE APARTMENT

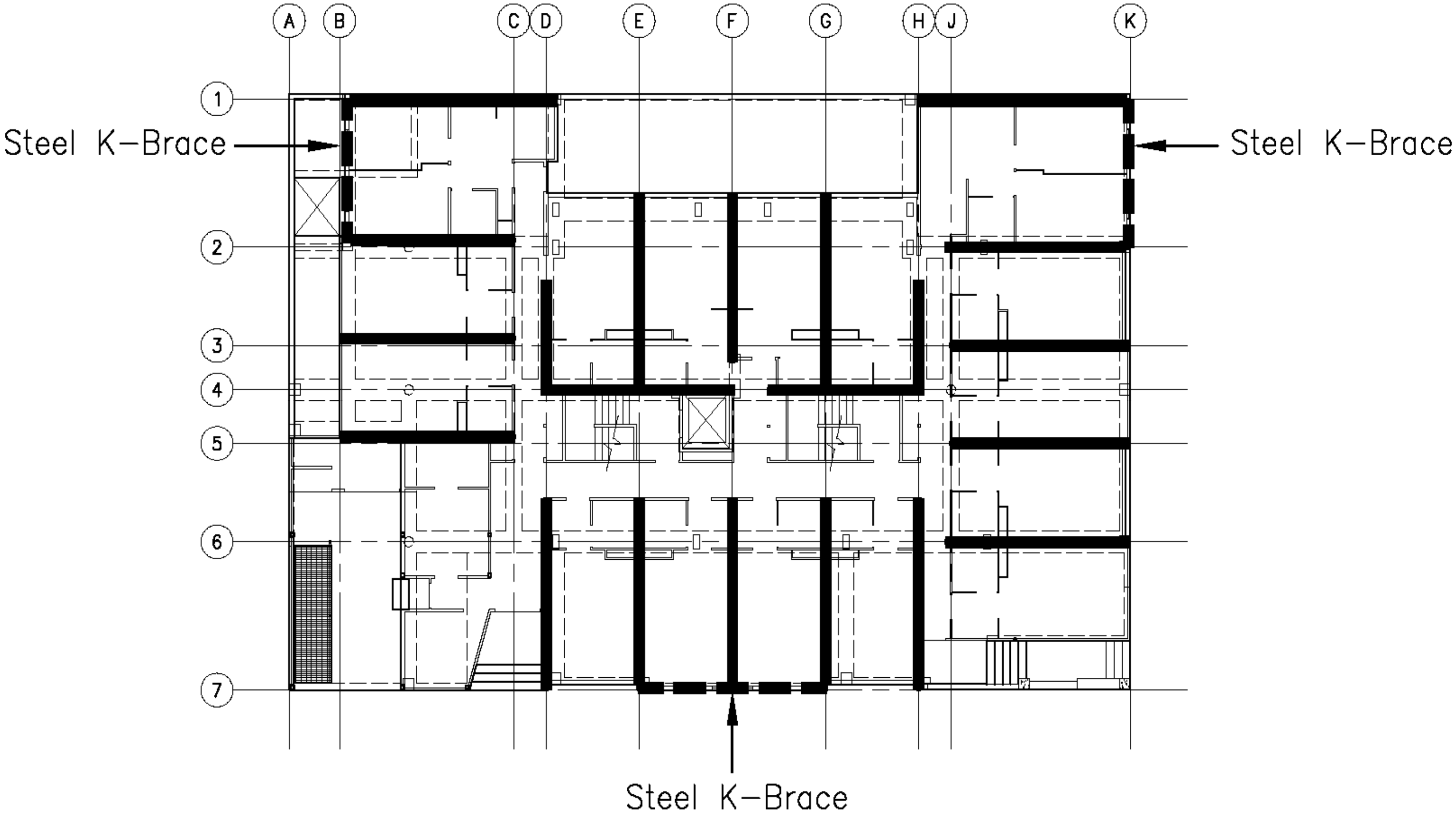
Studio apartments provided many available bracing walls internally, down to top of basement level

Wall continuous over this height, typically with lengths of 5 to 7 metres were considered as bracing elements

Other walls, including external cladding were ignored, but will contribute to resisting serviceability loads

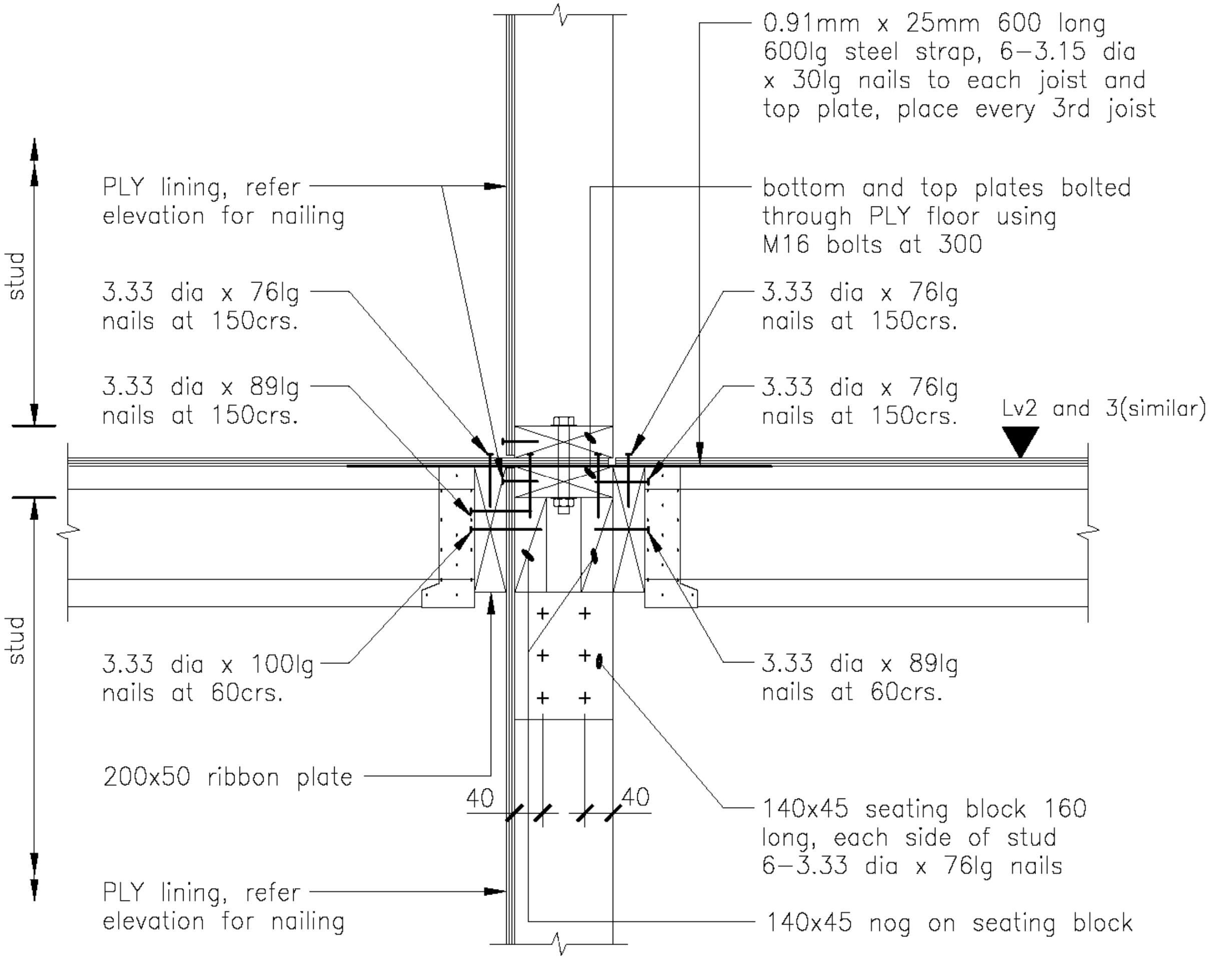
Three light steel k-braces were added around windows in the exterior walls

AN EXAMPLE: MARTIN SQUARE APARTMENT

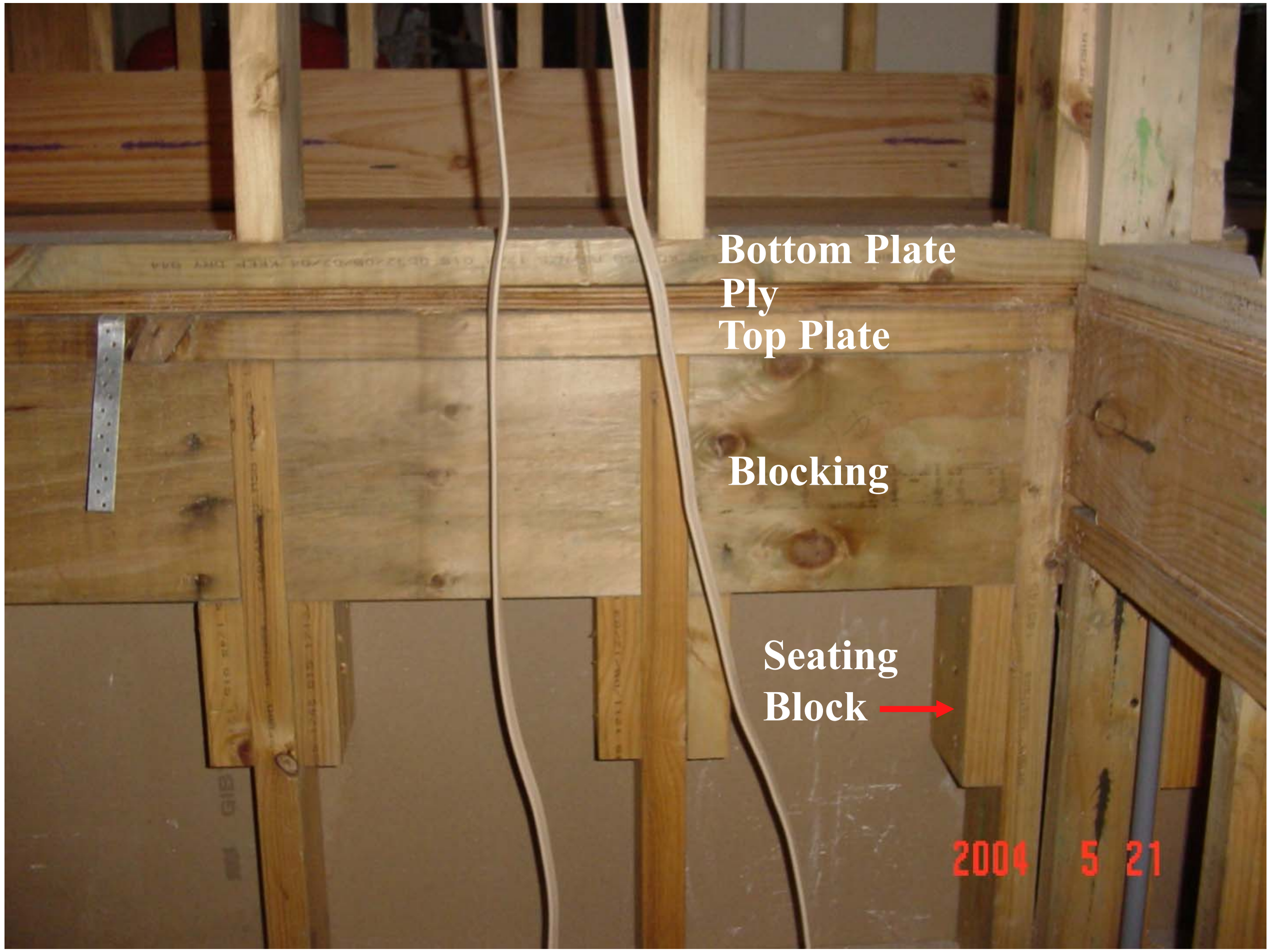


Steel braces included to reduce floor and wall shear forces, and provide good torsional restraint to building.

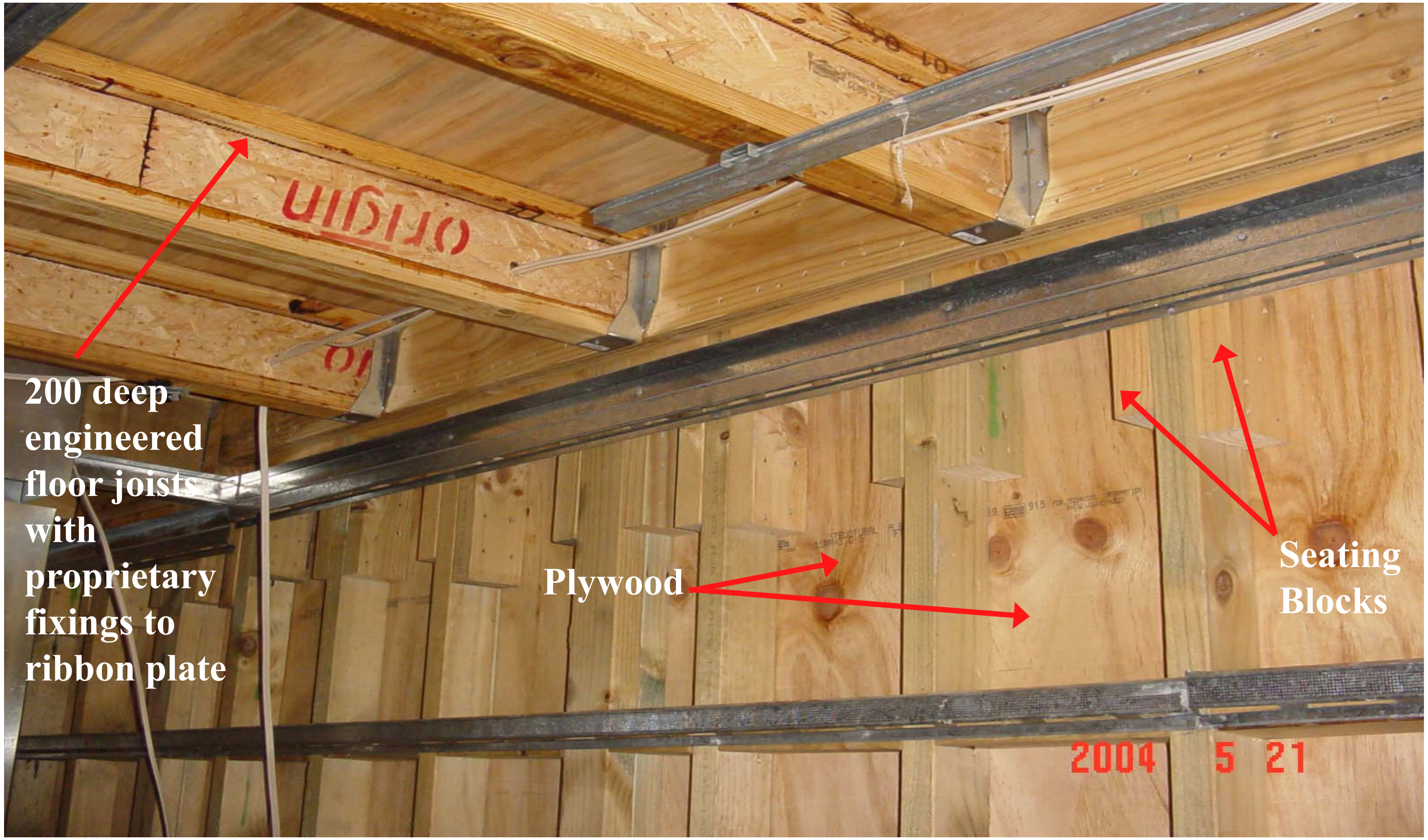
BALLOON CONSTRUCTION



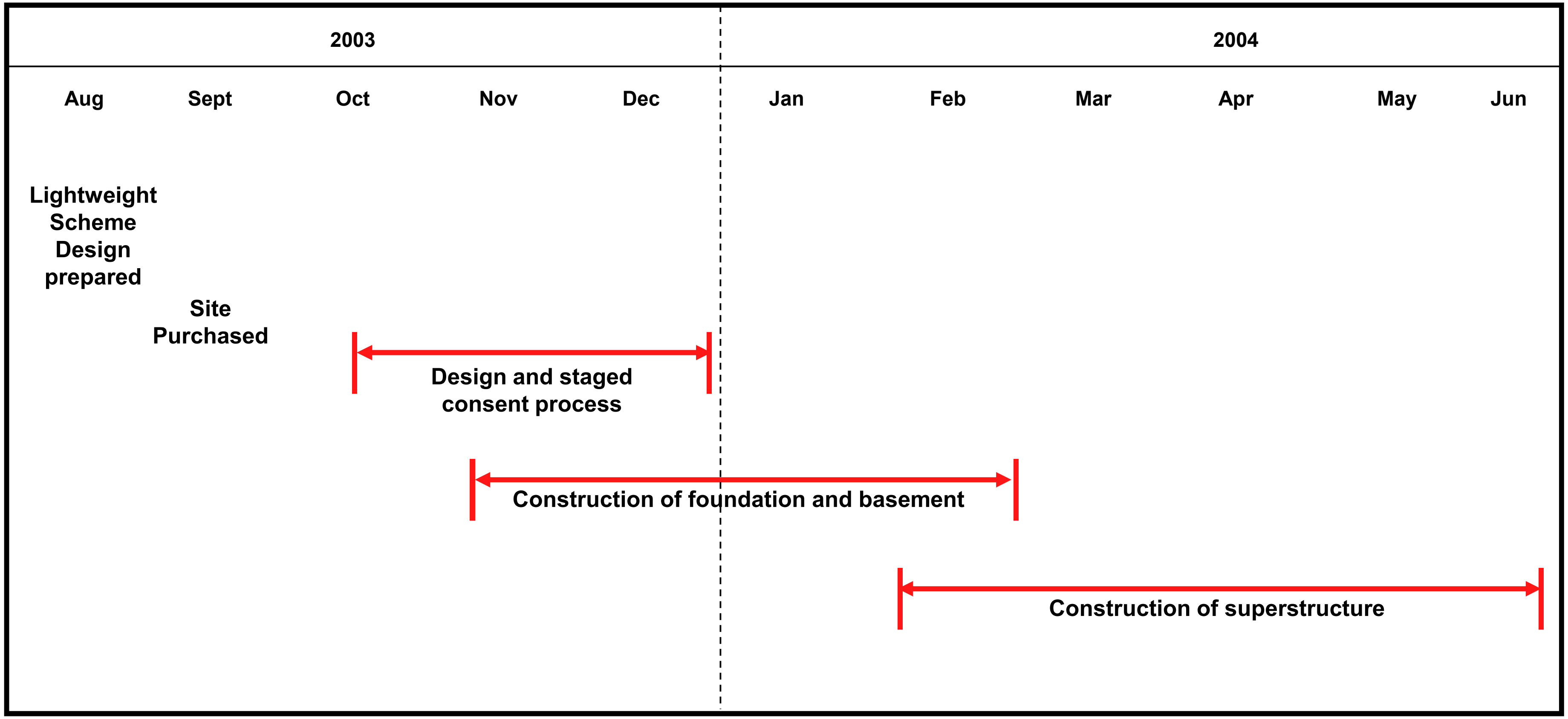
BALLOON CONSTRUCTION



BALLOON CONSTRUCTION



TIMESCALE OF PROJECT:



BUILDING NEAR COMPLETION:

Timber structure started mid February and progressed at about 2 weeks per level

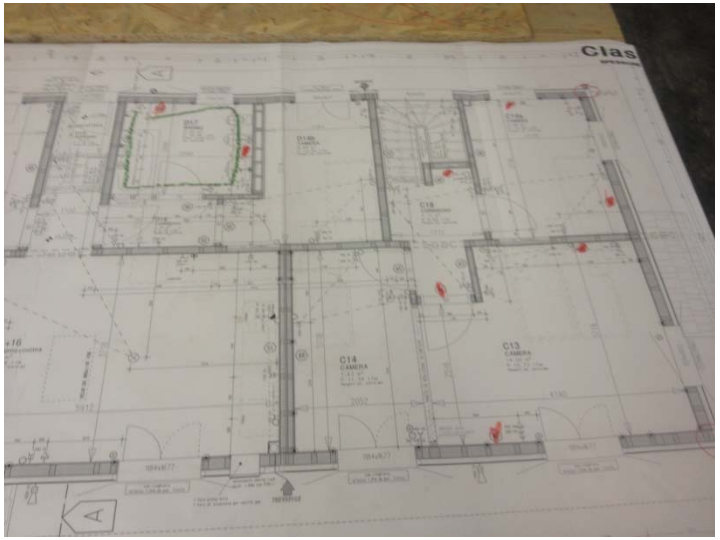
BUILDING COMPLETED:

Construction time:

- 4 months for the reinforced concrete foundations
- 5 months for the timber part

Light-frame construction:

Wall prefabrication in the production plant: (courtesy Rubner Haus)



Light-frame construction:

Wall prefabrication in the production plant: (courtesy Rubner Haus)

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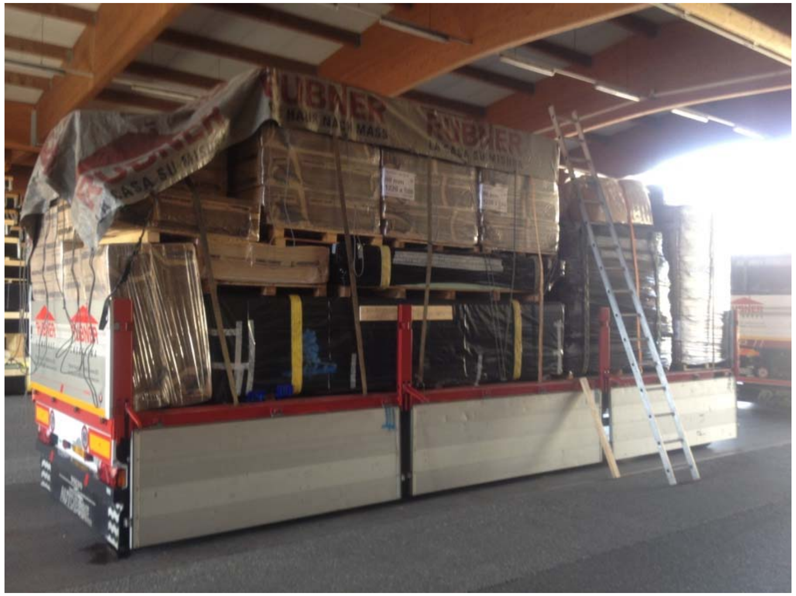
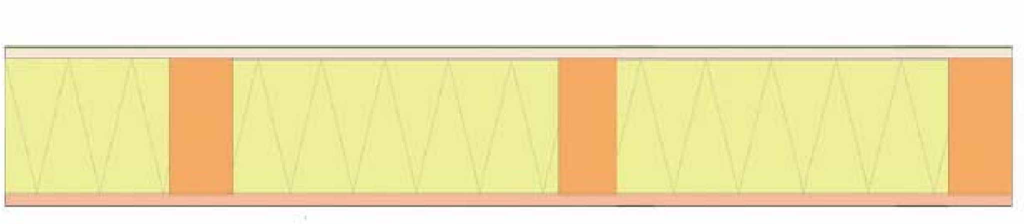


Light-frame construction:

Floor panel prefabrication in the production plant:
(courtesy Rubner Haus)



Light-frame construction:

Floor panel prefabrication in the production plant: (courtesy Rubner Haus)

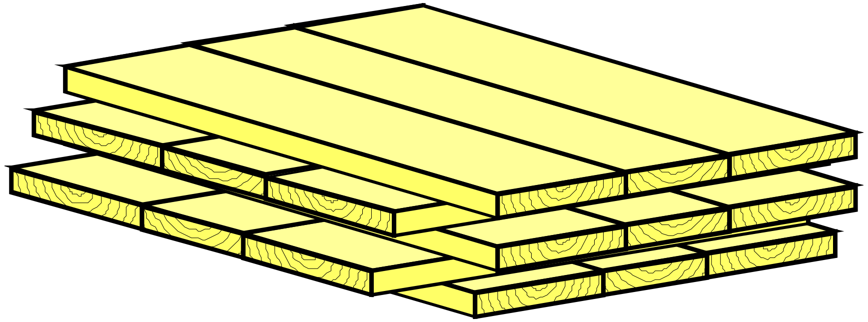
Use for facades:

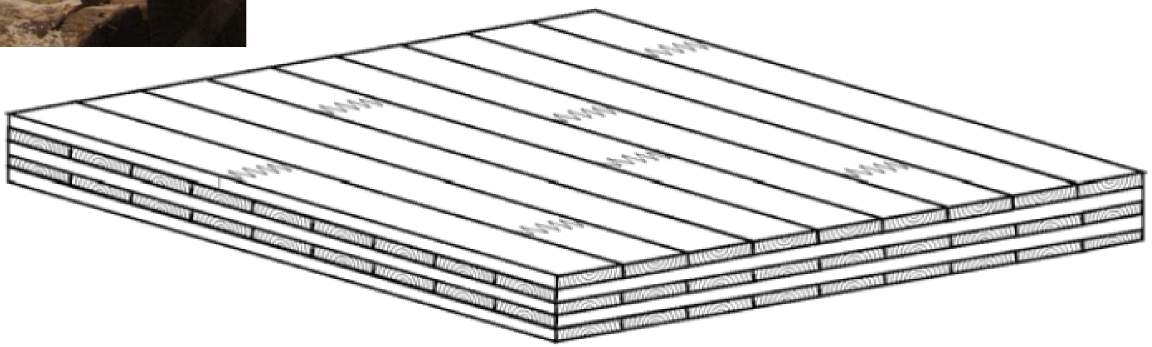
Use for floors/roofs:

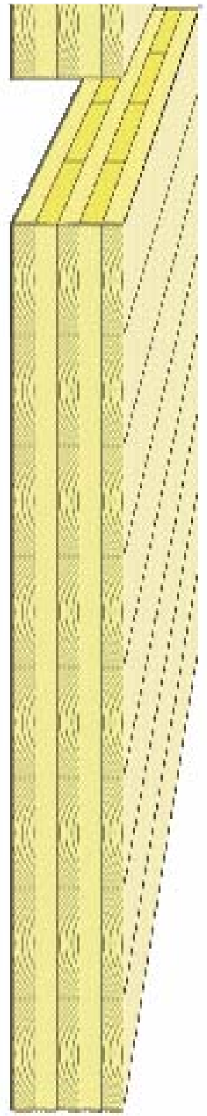
Solid panel construction:

Cross-laminated panels, glued-laminated slabs, and Laminated Veneer Lumber (LVL) can be used, also in combination, to create heavy solid panels.

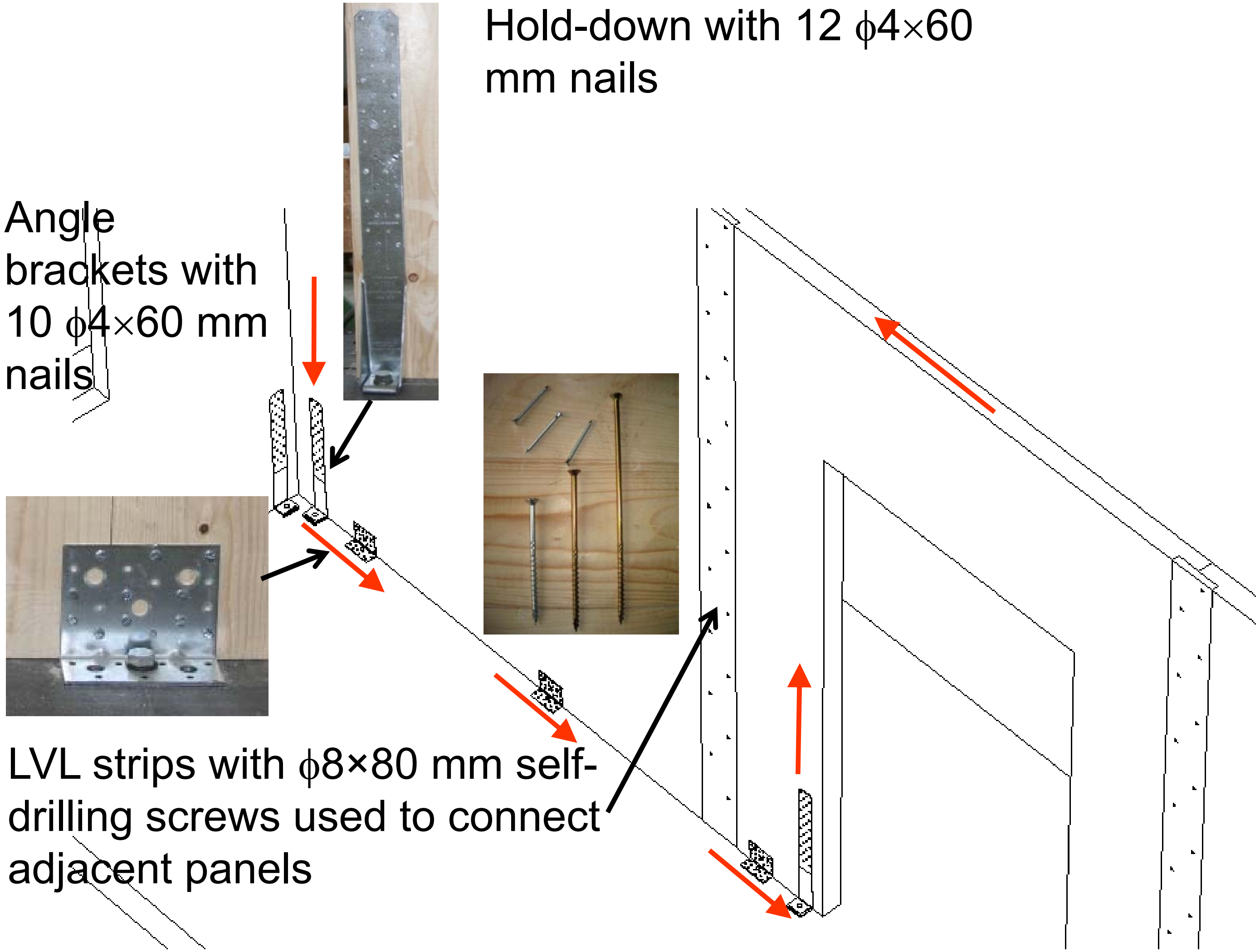
Cross-laminated panels are being used more and more, due to their dimensional stability, the possibility to use also low grade timber, the ease of connection, and the excellent seismic performance.



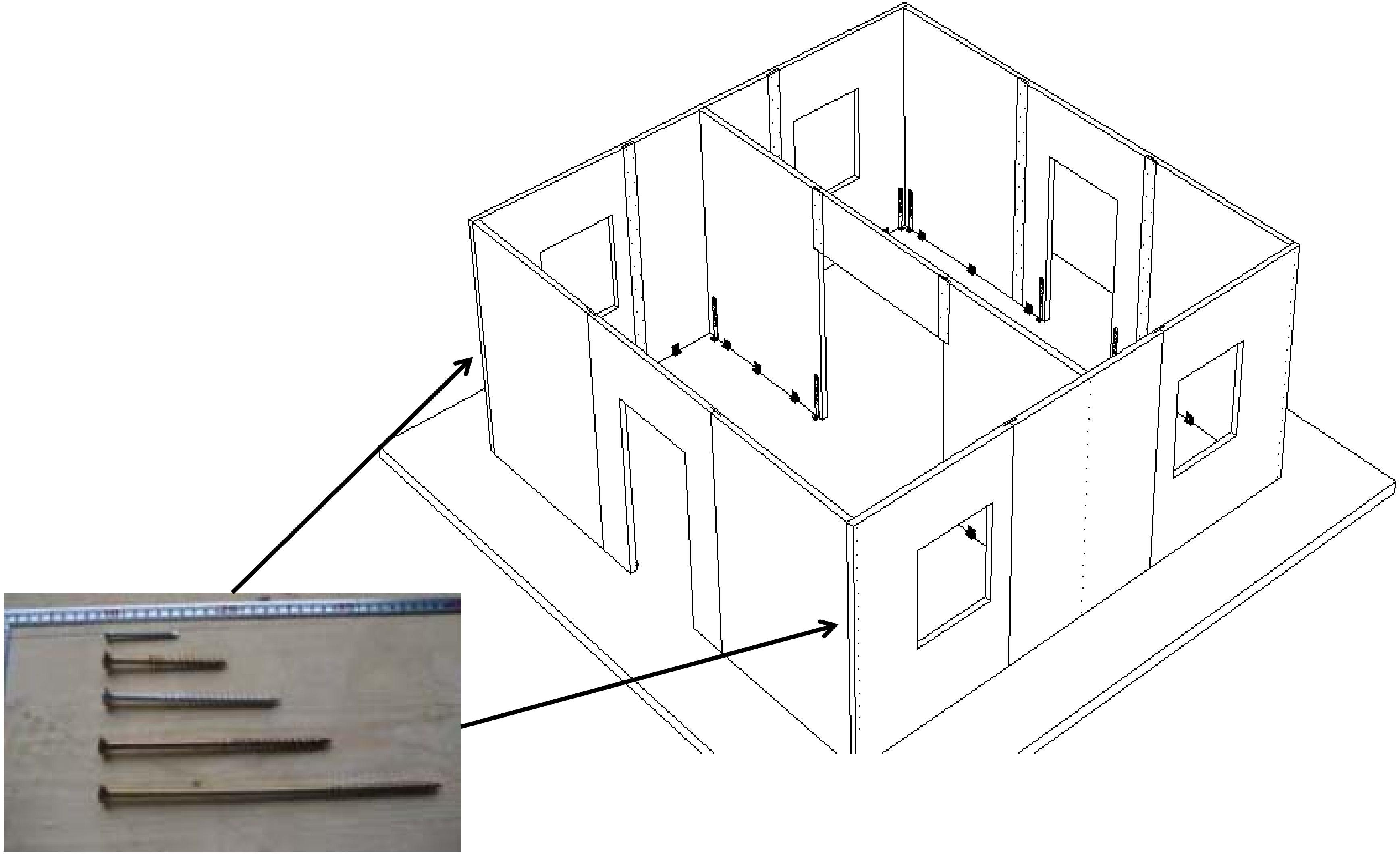




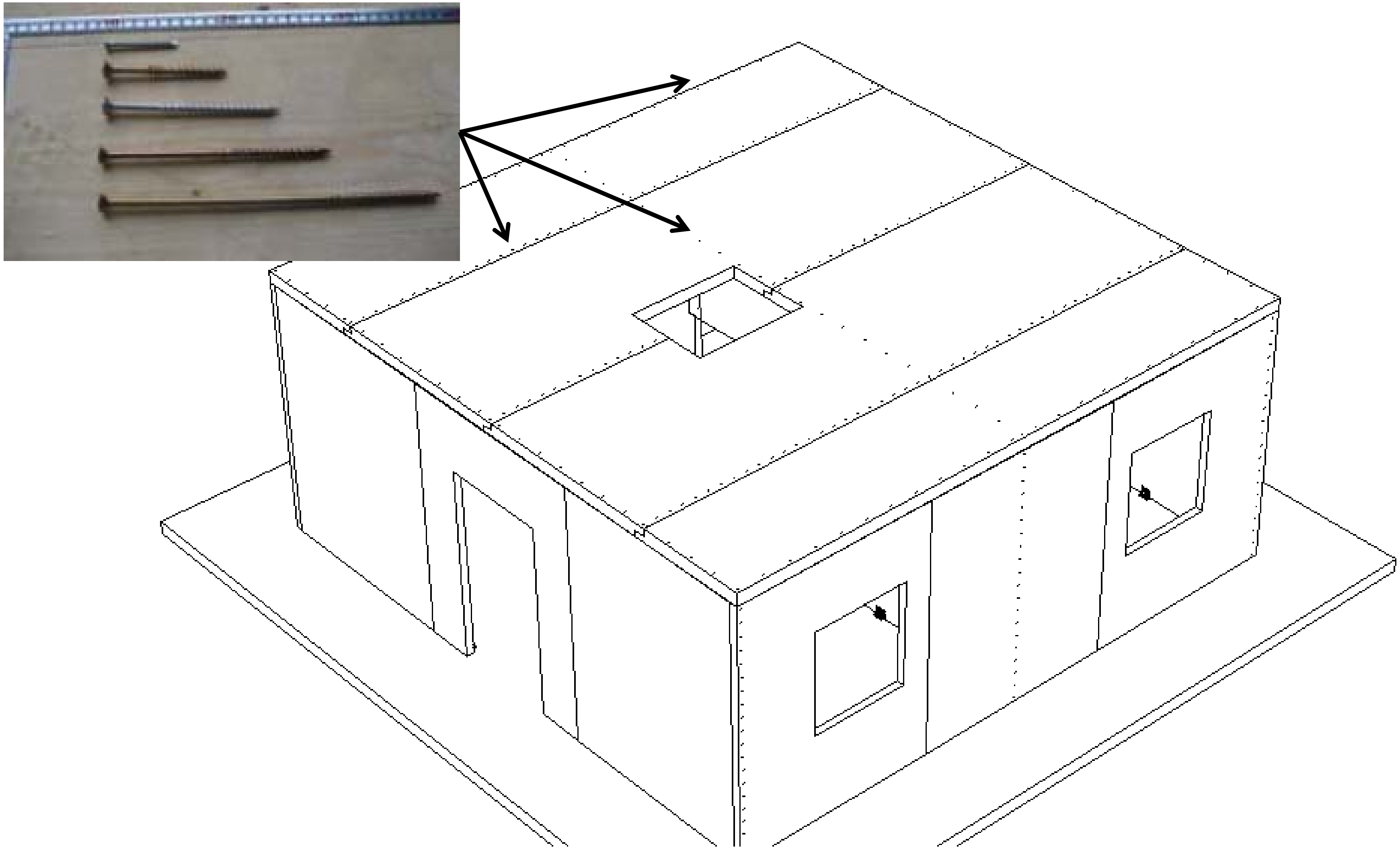
Xlam panel construction:



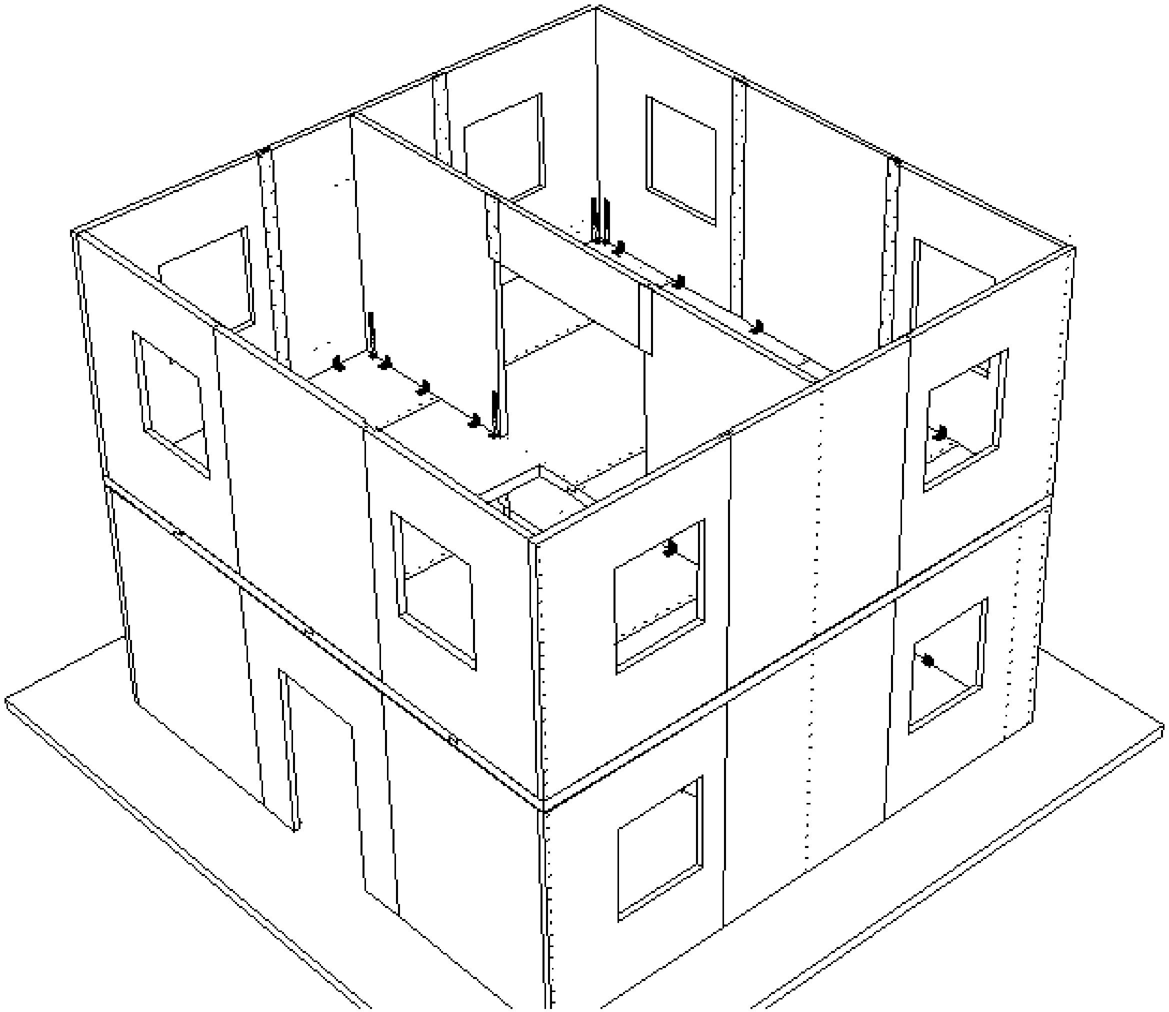
Xlam panel construction:



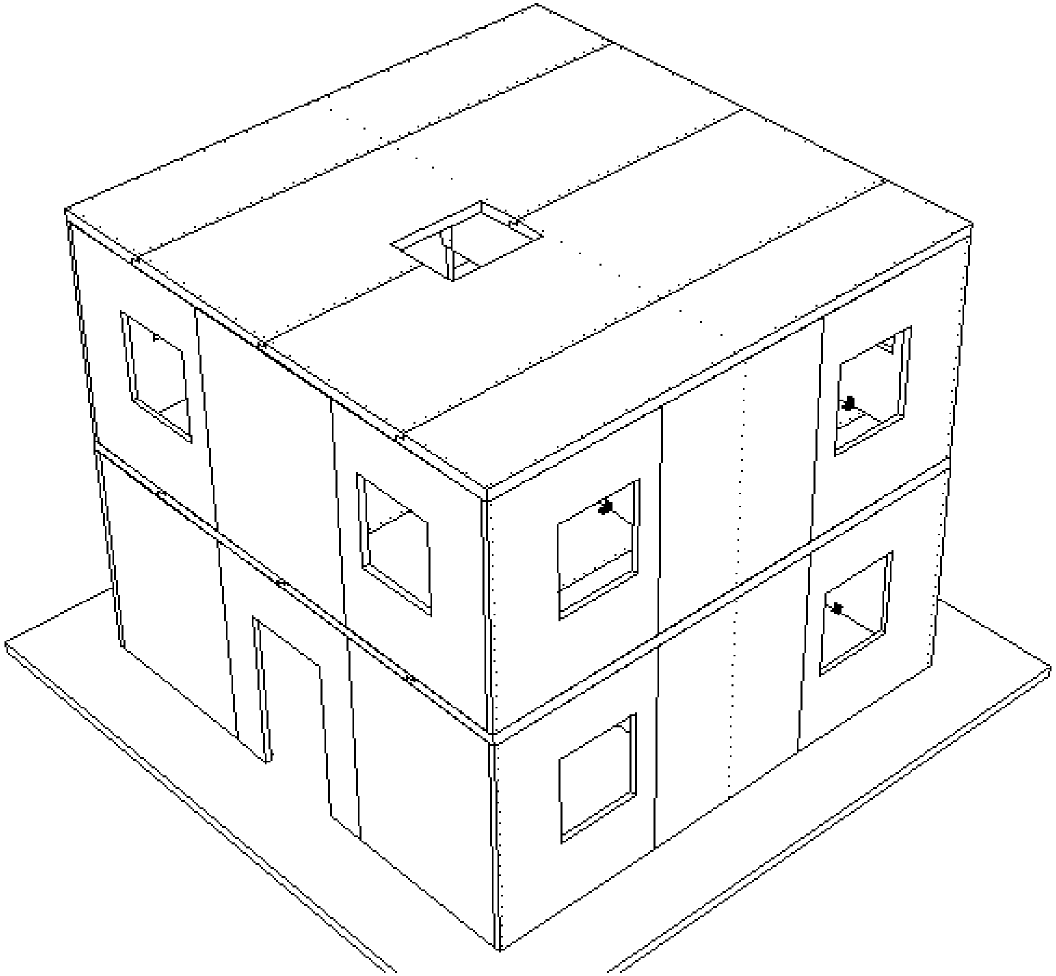
Xlam panel construction:

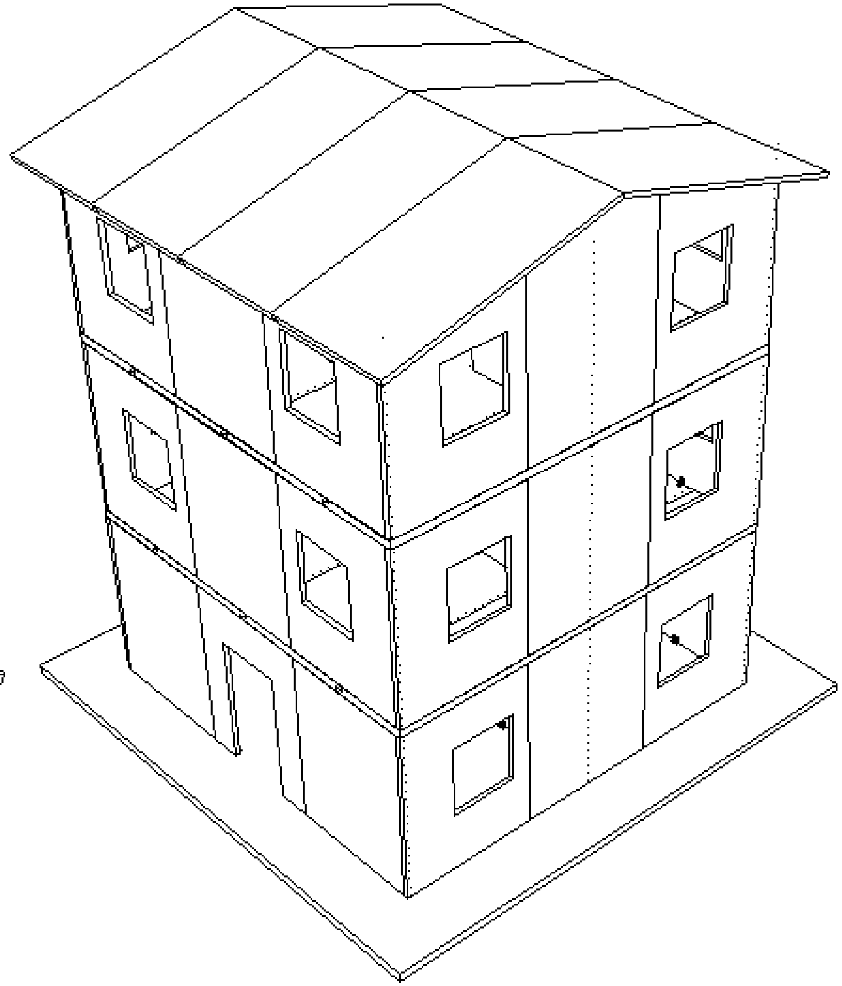


Xlam panel construction:



Xlam panel construction:





Xlam panel construction:

Xlam panel construction:

KW 42/11: Arbeiten am Erschließungskern

Xlam panel construction:

Detail of the wall-floor connection:

An example: Murray Grove, London UK

June 2007 - starting with project
April 2008 – starting with assembling on site
May 2008 - CLT construction erected within one month

Massivholz GmbH KLH®

Key facts for Developer

according to costs estimation and project plan prediction

- CLT cost ~ 30% more than comparable RC frame

  but …

- Programme CLT ~ 49 weeks

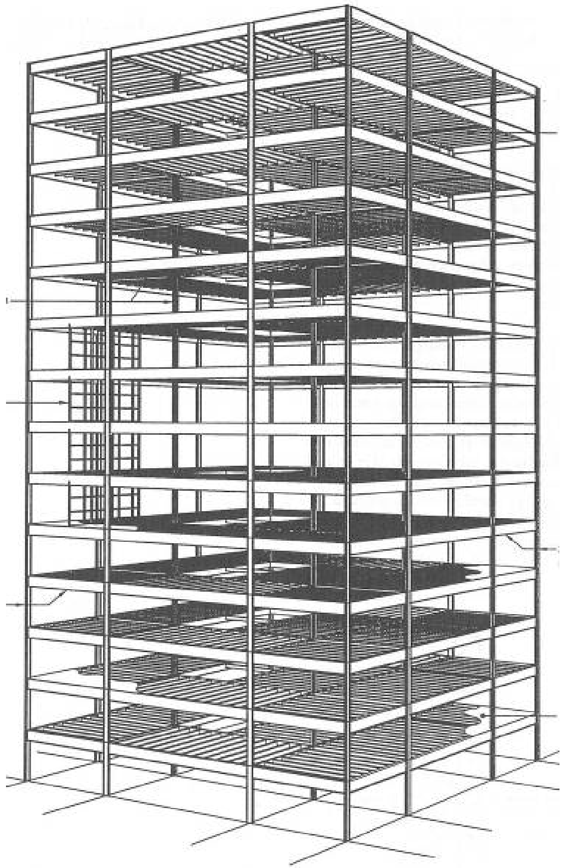
  RC frame ~ 66 weeks

  ~ 17 weeks less for a whole project

- Time savings mostly because CLT load bearing walls are also internal partition walls i.e. no stud/block or timber frame walls

Hybrid systems:

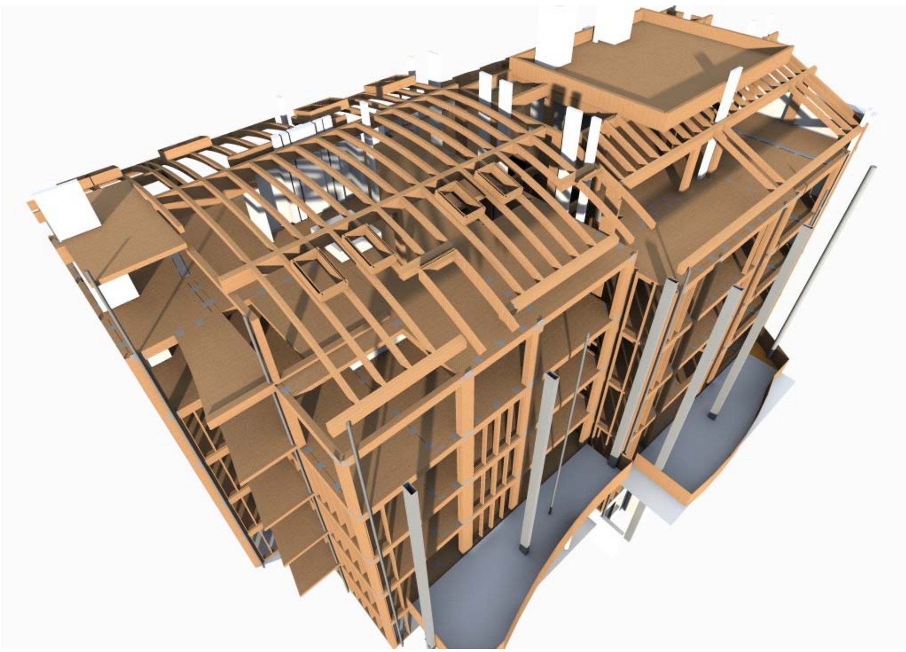
- Wood mainly used for gravity load resisting systems, other materials (steel and/or reinforced concrete) for lateral load resisting systems
- Suitable for open spaces
- Max: 10-15 storeys



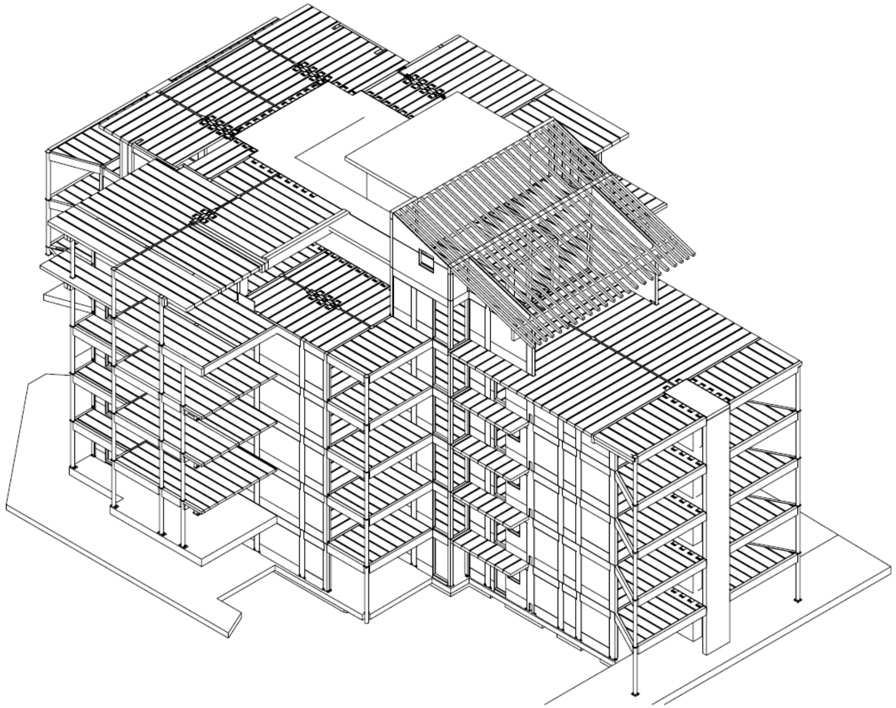
Example of hybrid systems:

2011 - ITALY

Trieste (TS)
6 storeys



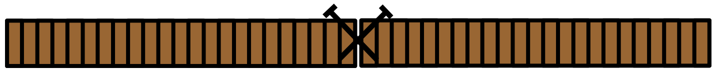
Caorle (VE)
6 storeys

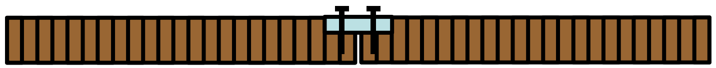


Glulam and r.c. hybrid system:

- **Glulam posts and beams for gravity loads**

- **Glulam beams used as floor panels connected with screws**



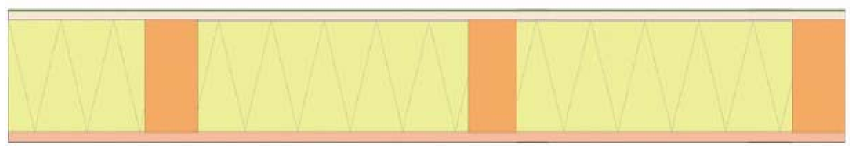


Glulam and r.c. hybrid system:

Glulam and r.c. hybrid system:

- **Internal reinforced concrete core for lift shaft and staircase to resist lateral loads**

- **Facades made of lightframe panels prefabricated offsite and connected to the glulam posts and beams**



Glulam and r.c. hybrid system:

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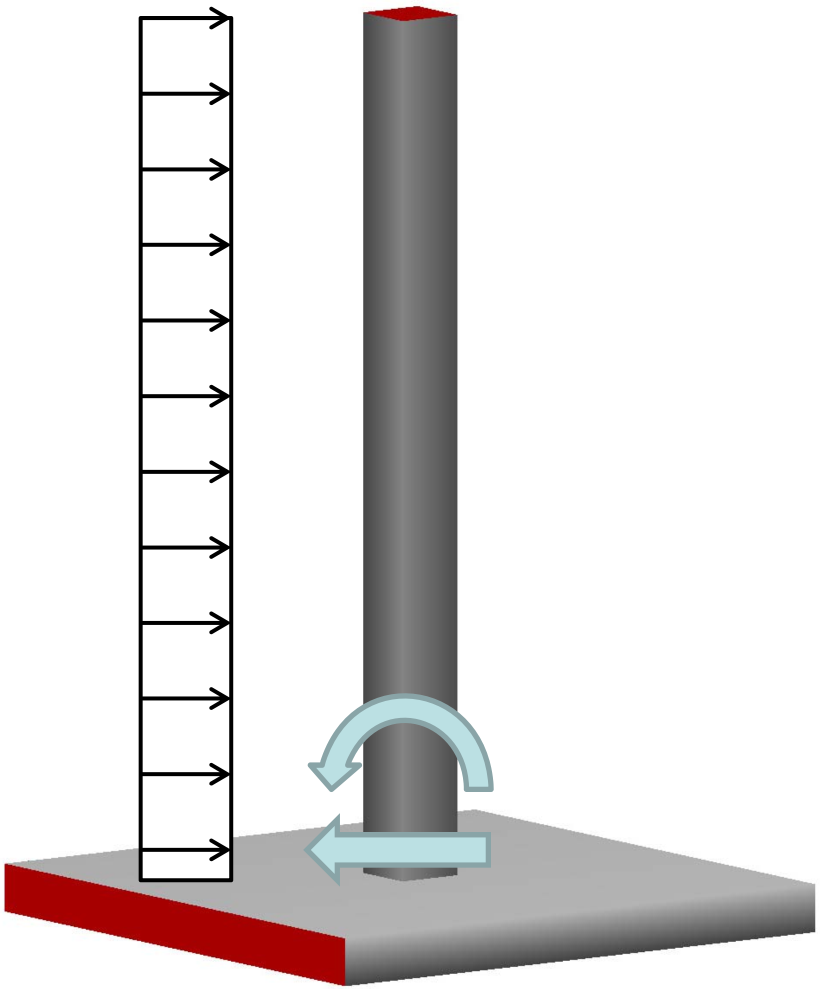
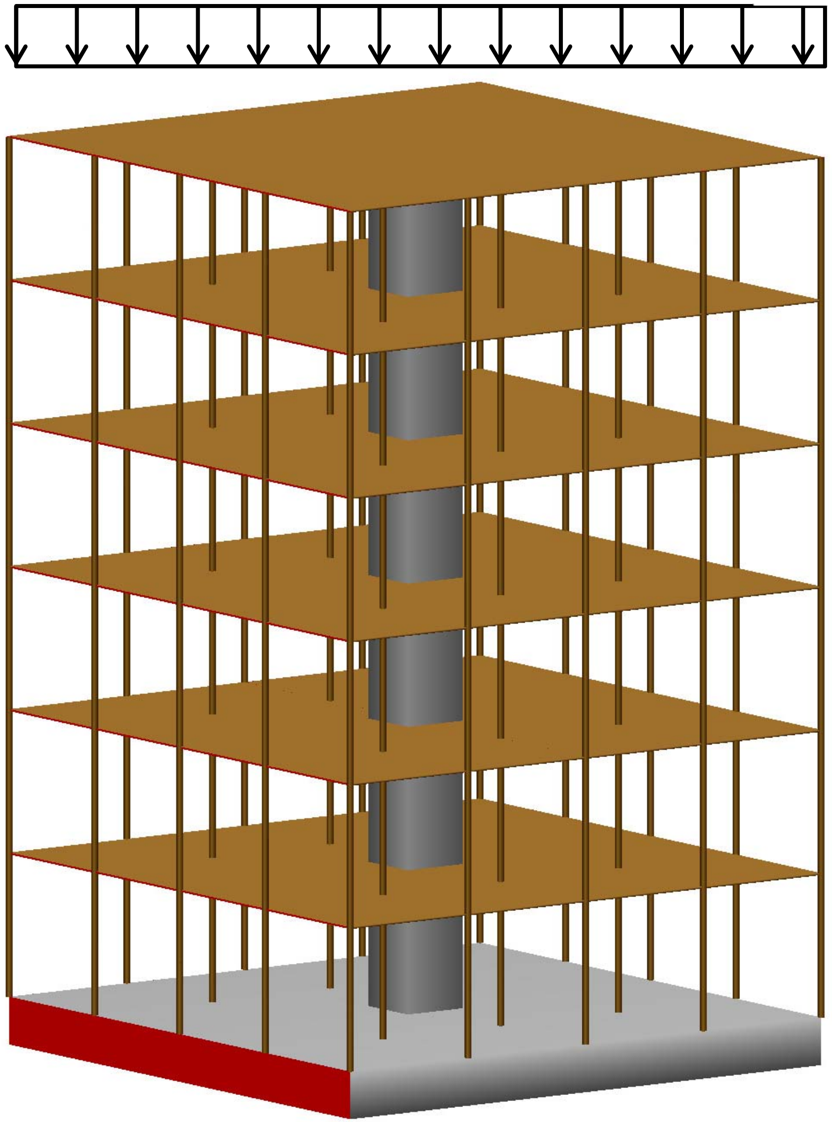
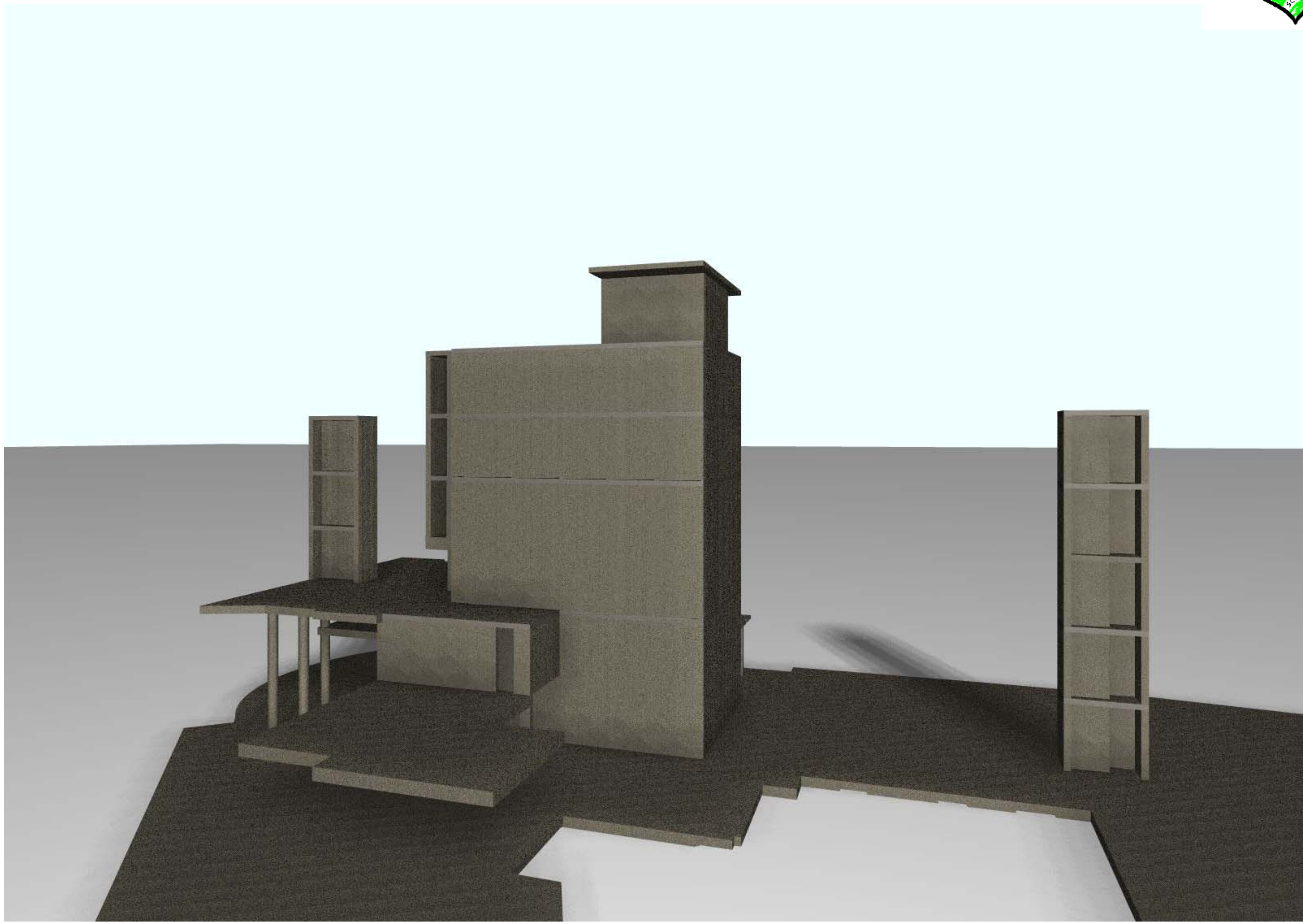




Erection sequence:



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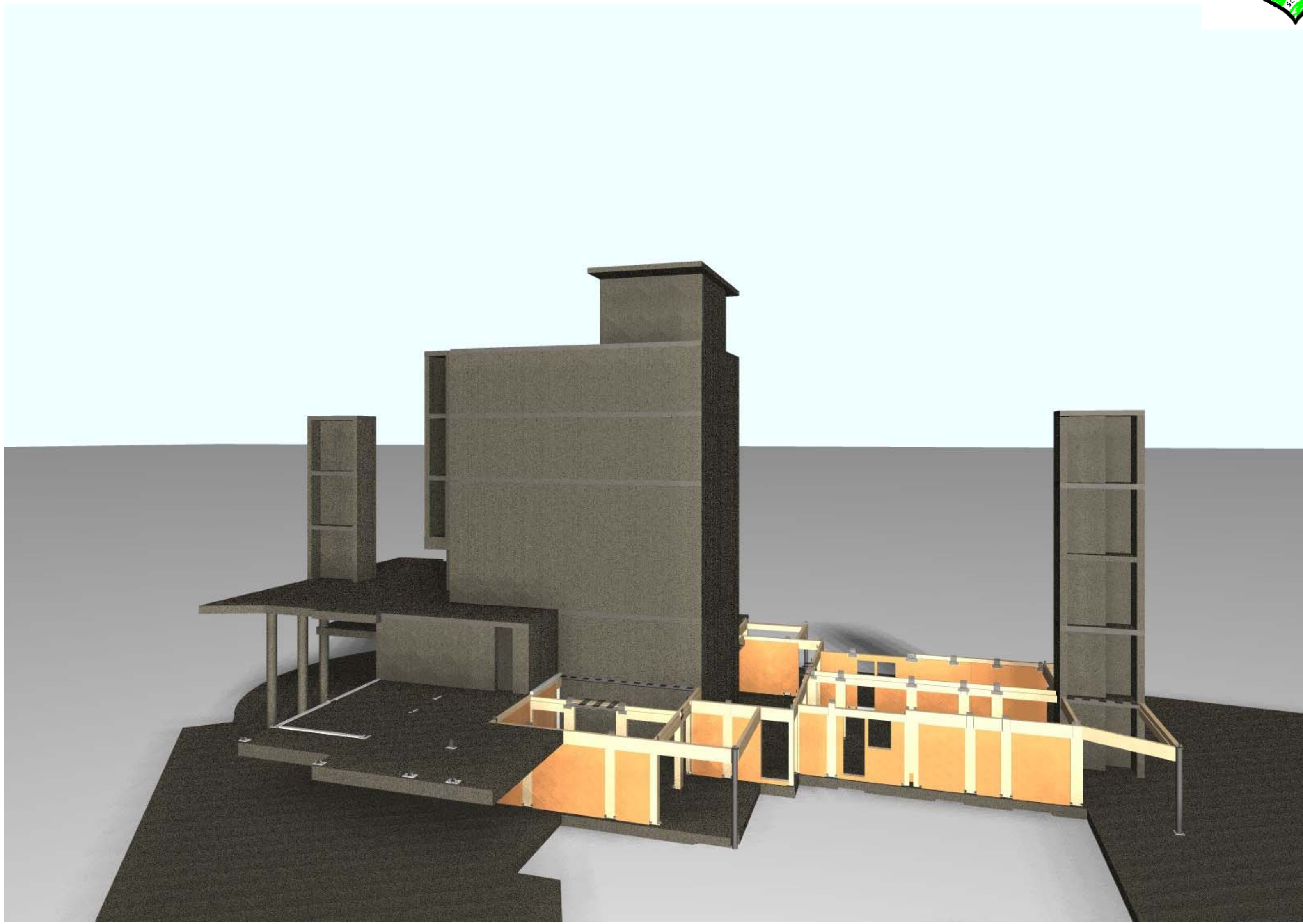

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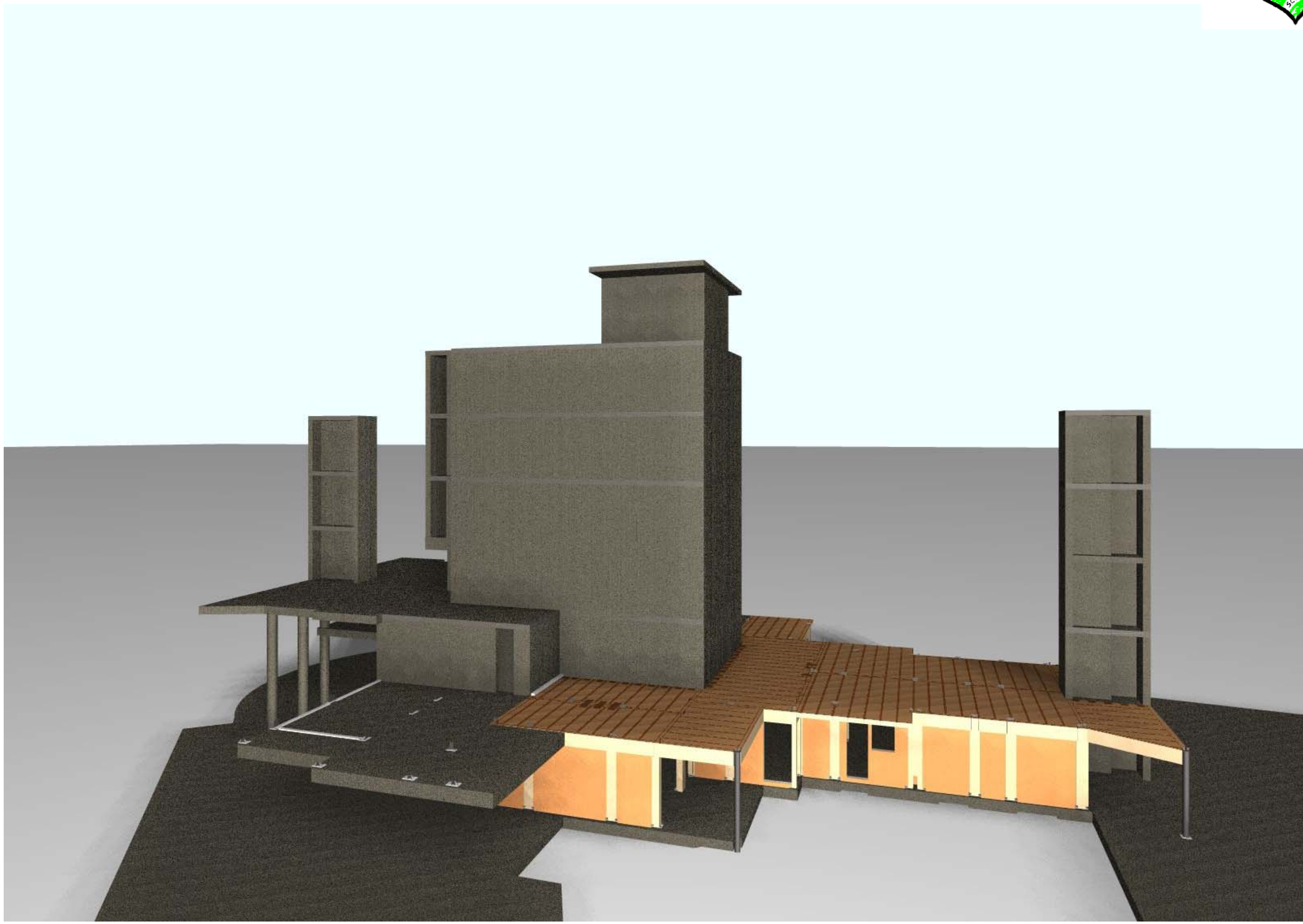

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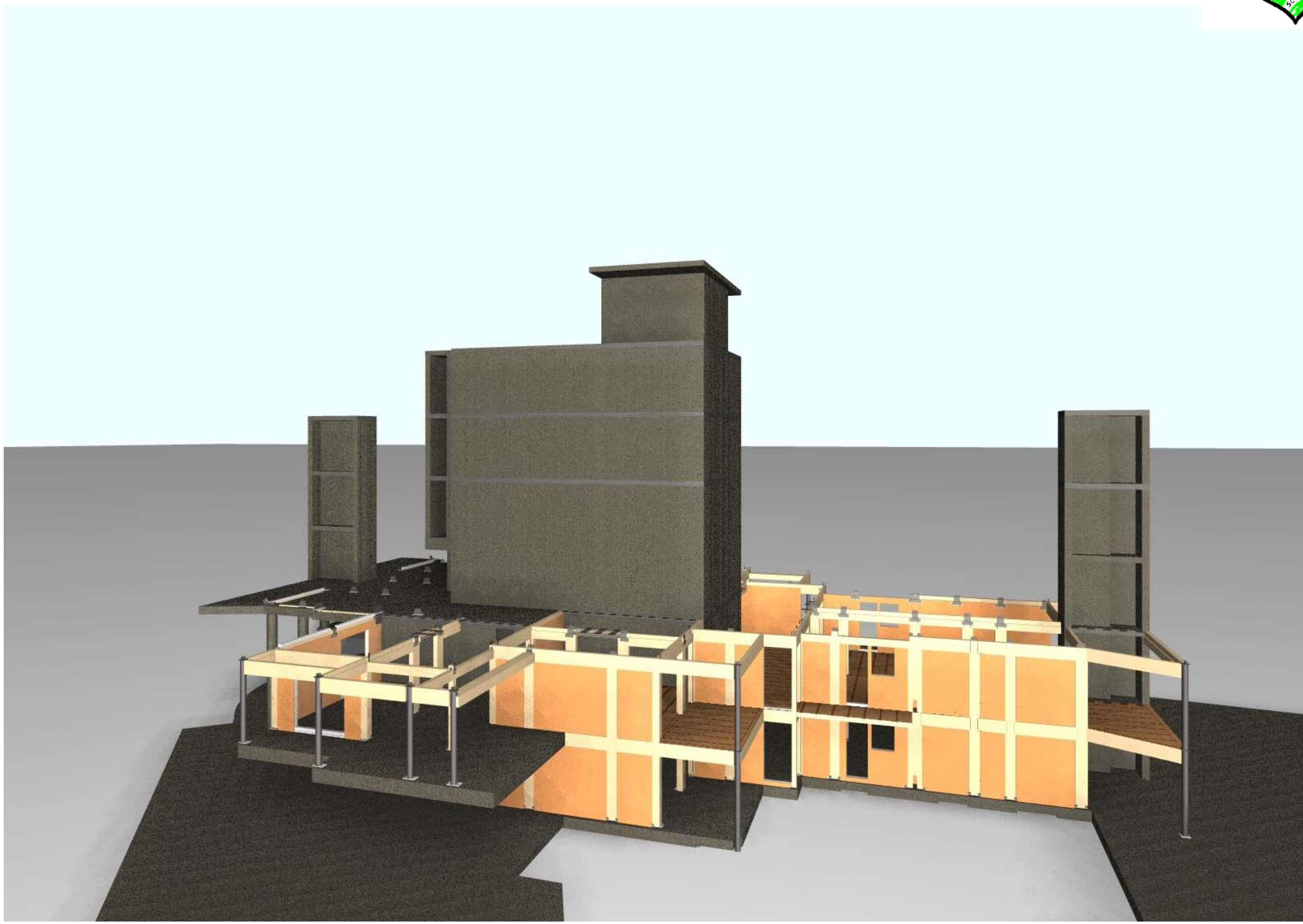

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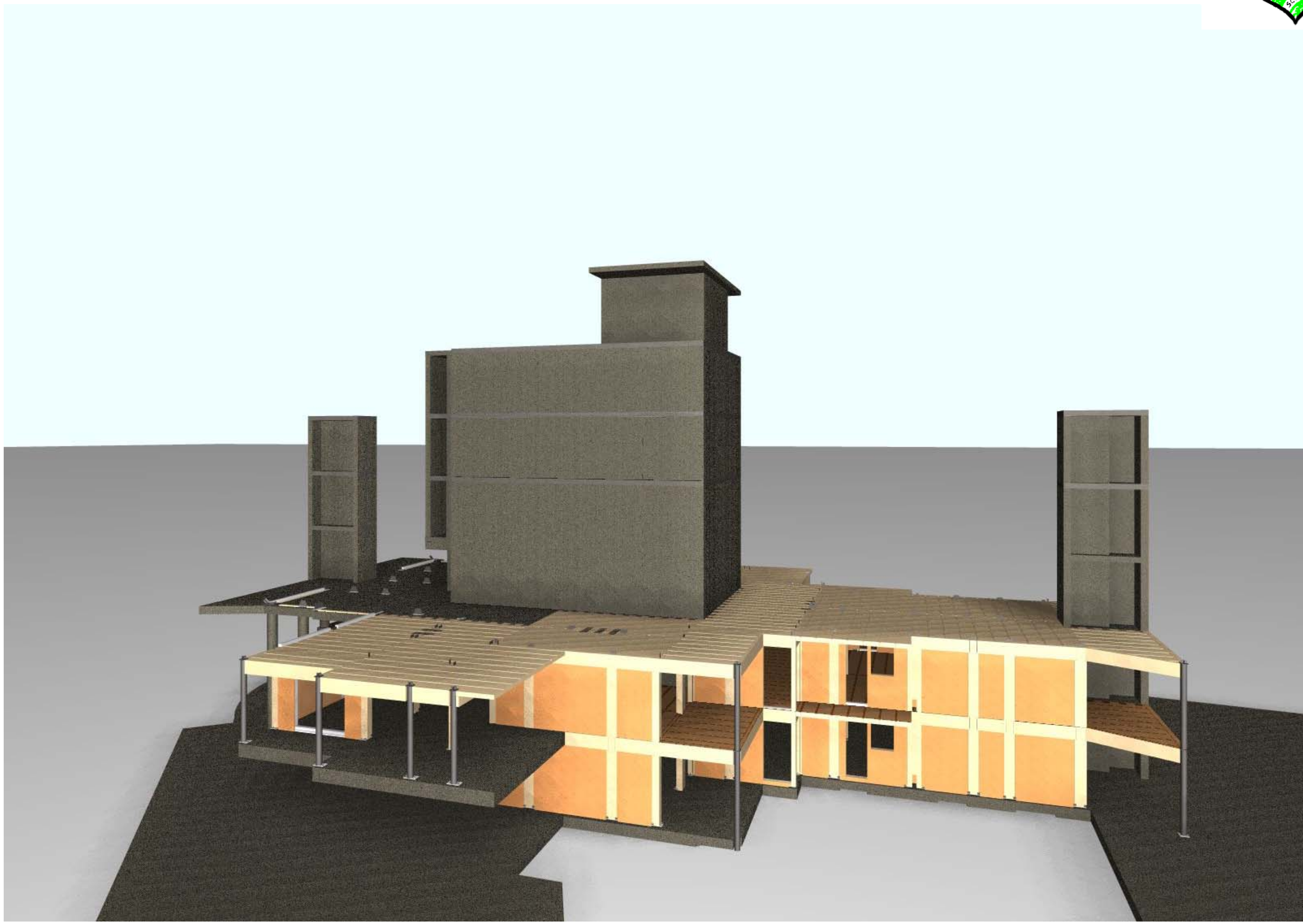

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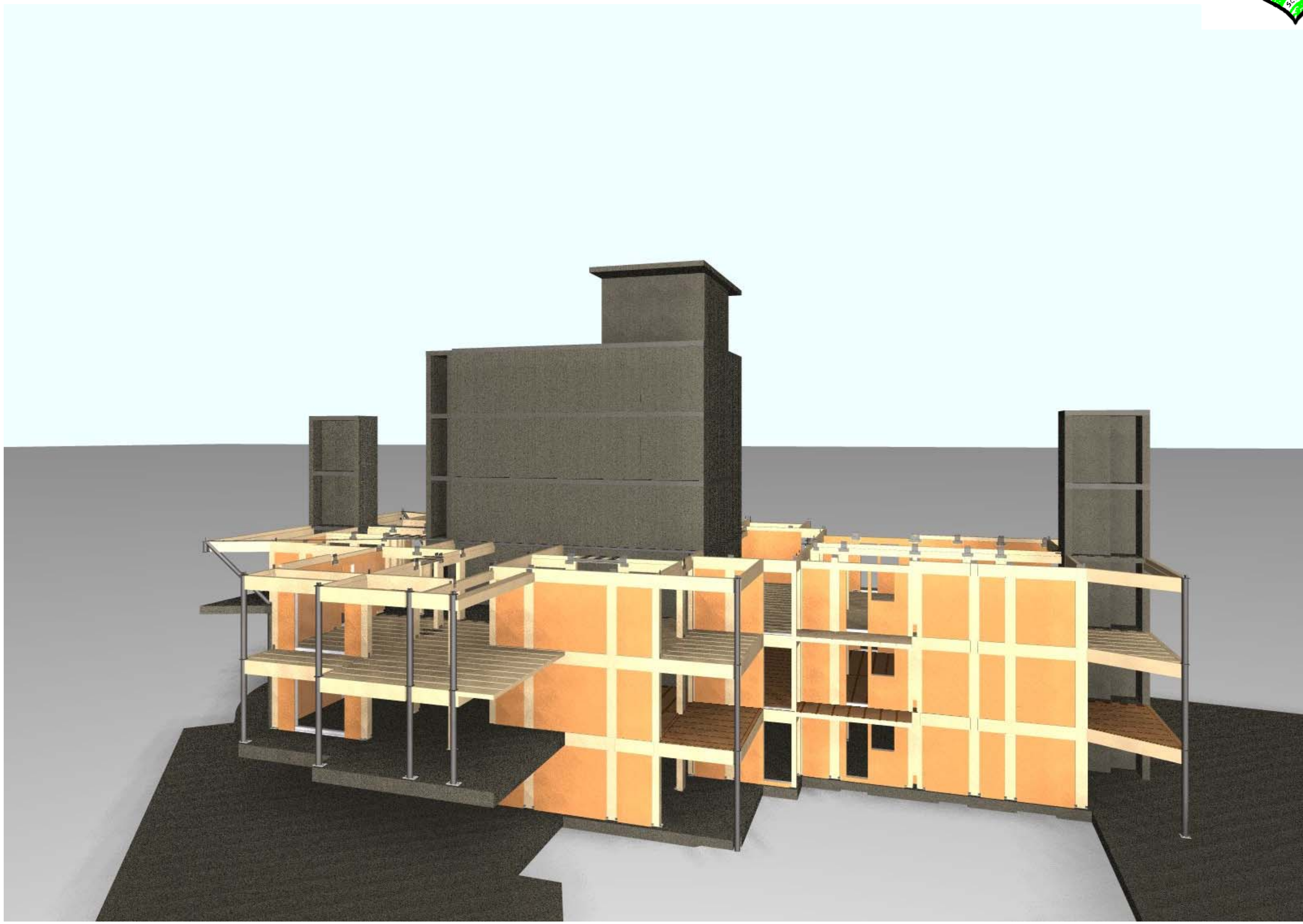

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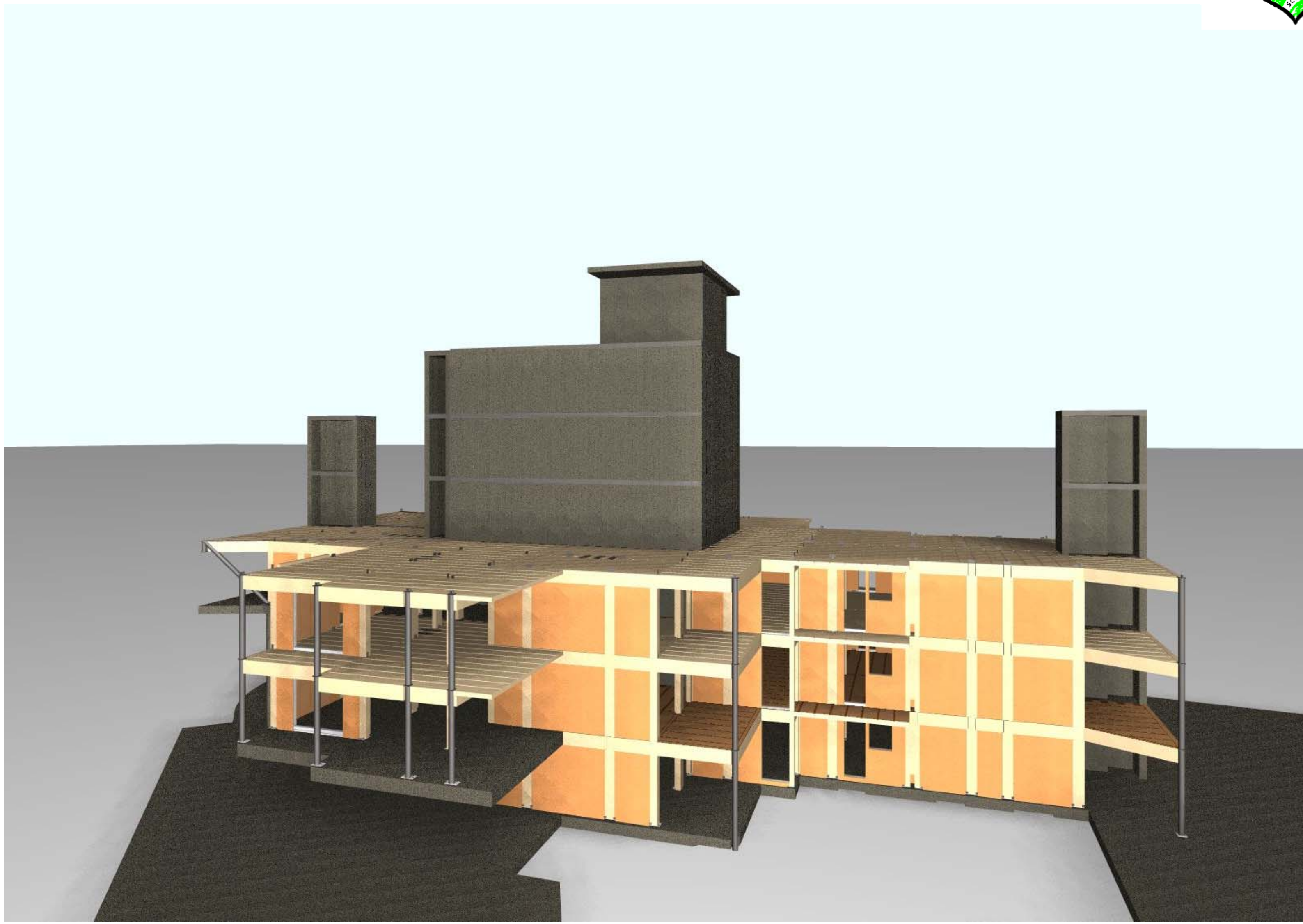

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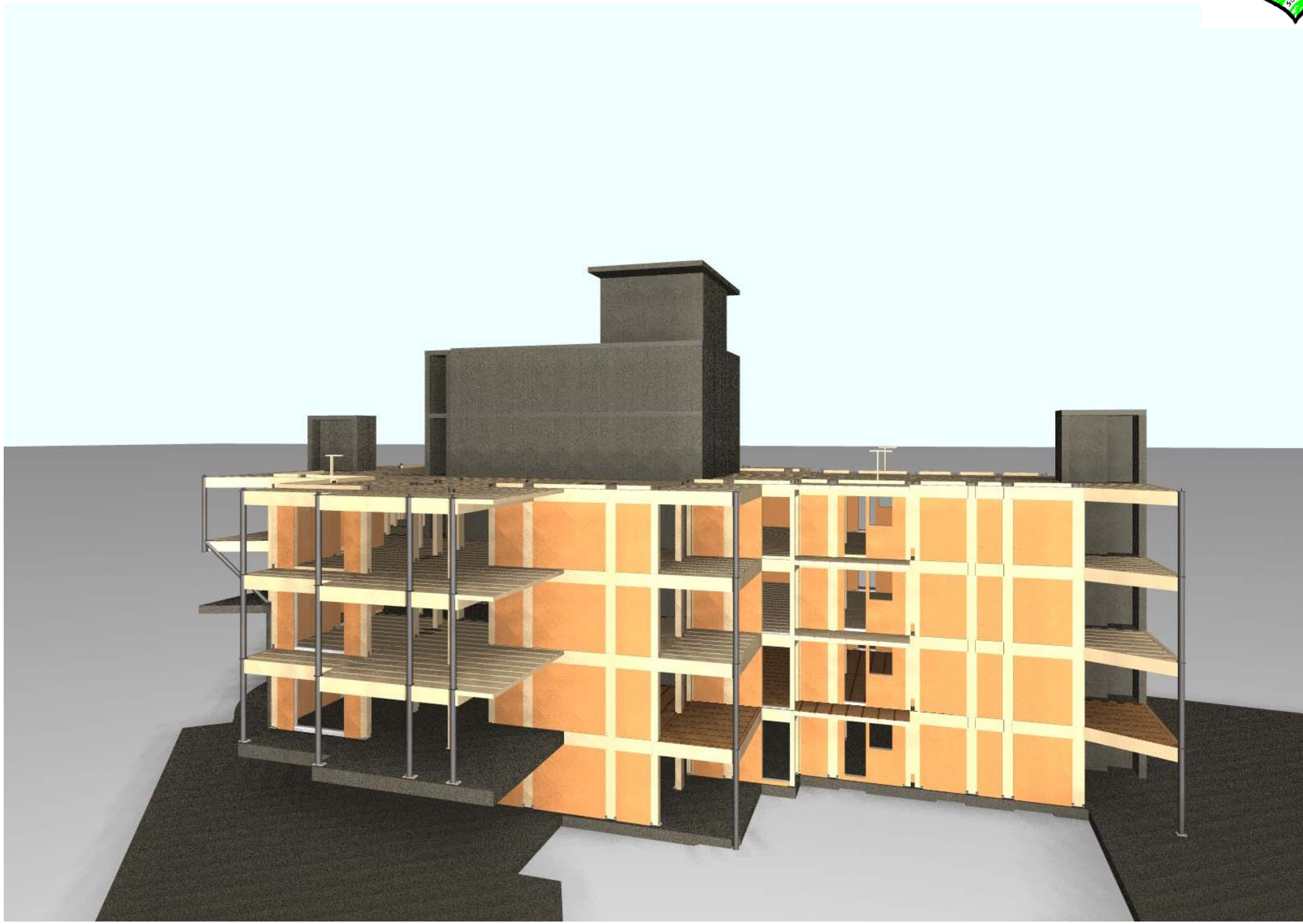

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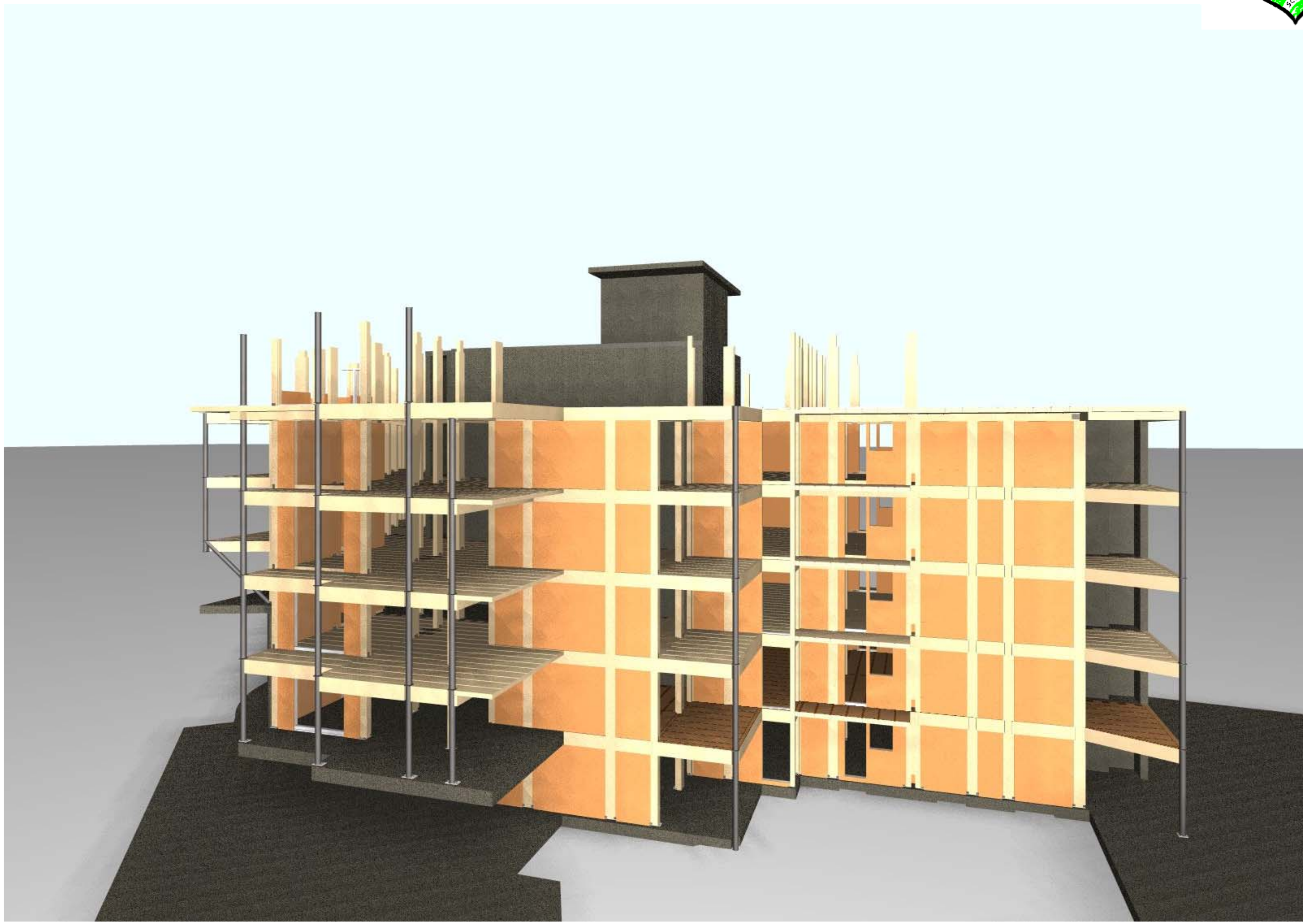


Erection sequence:

Erection sequence:

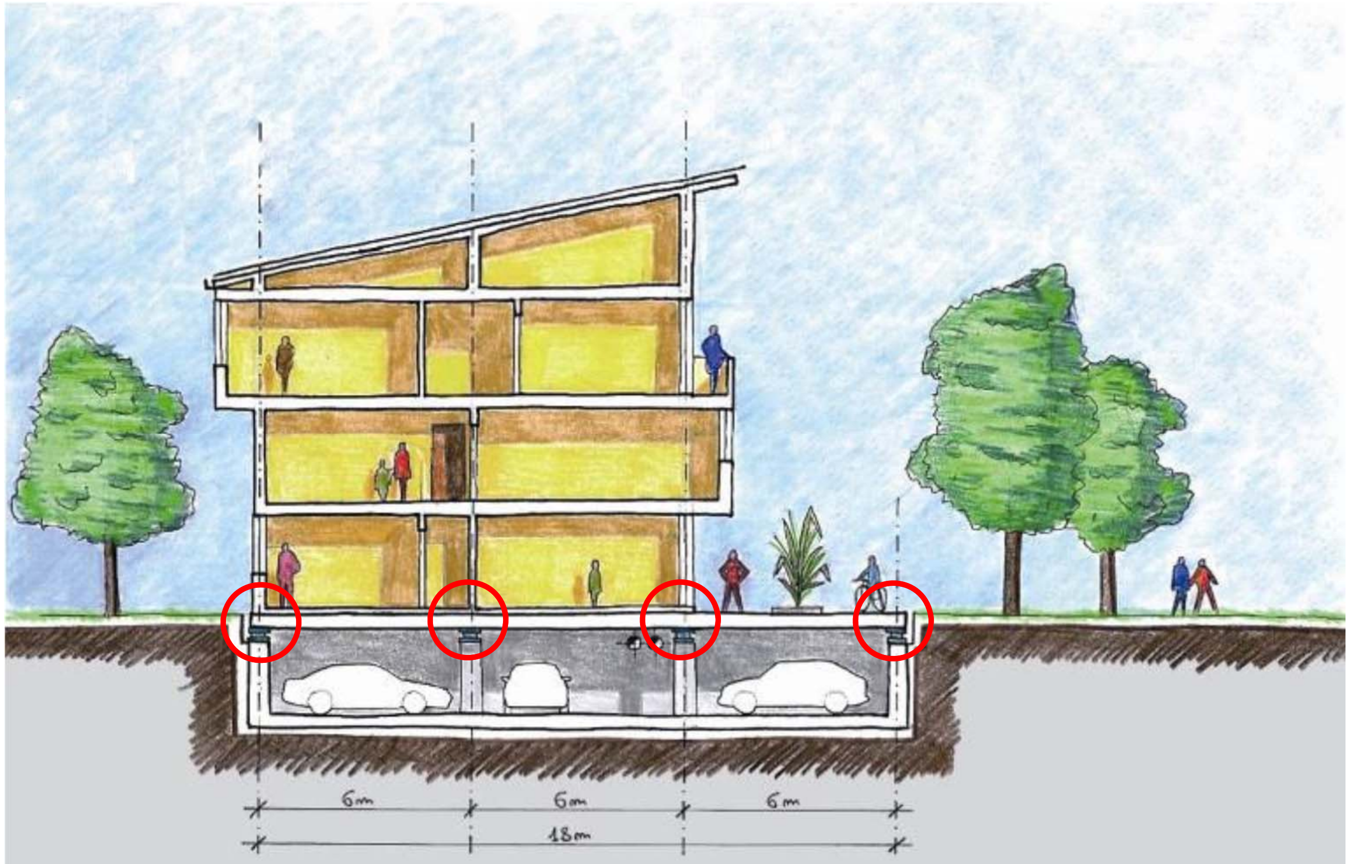
Construction times:

September 2011

November 2011

Use of passive base isolation:

- Timber building disconnected from foundations
- Suitable for any type of building
- Max: 5-7 storeys
- No damage due to earthquake



Use of passive base isolation:

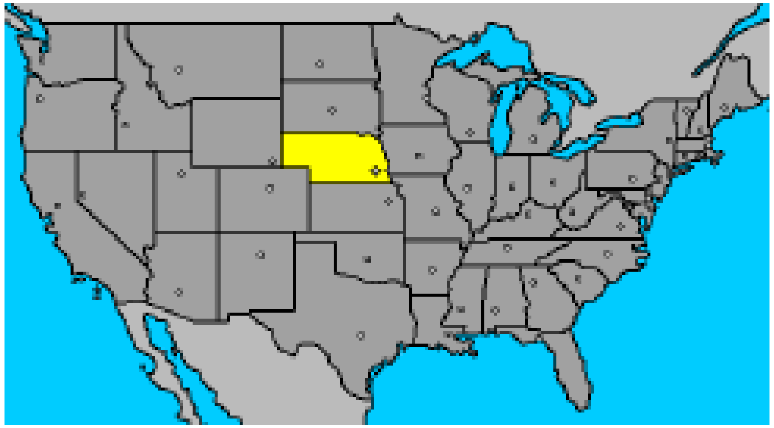
2009 – L'Aquila (Italy) – Progetto C.A.S.E. – after the earthquake which hit the city, 70 3-storey buildings with about 1850 flats for 6.000 people were built in about 80 days (25% with lighframe timber systems, 25% with crosslam panels, 50% made of reinforced concrete)

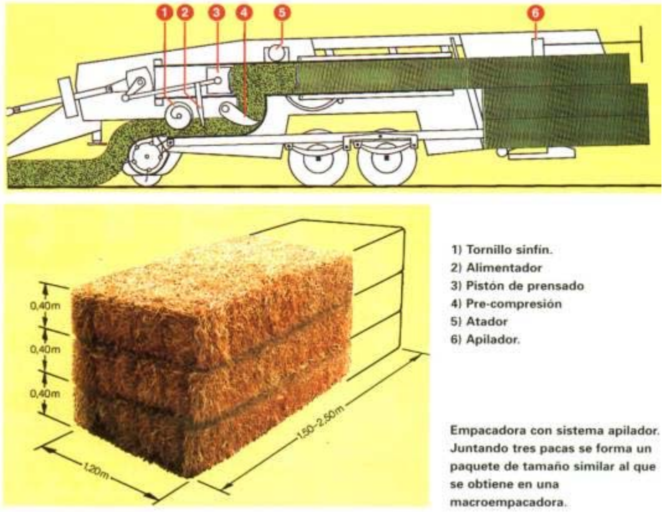
Use of timber and straw:

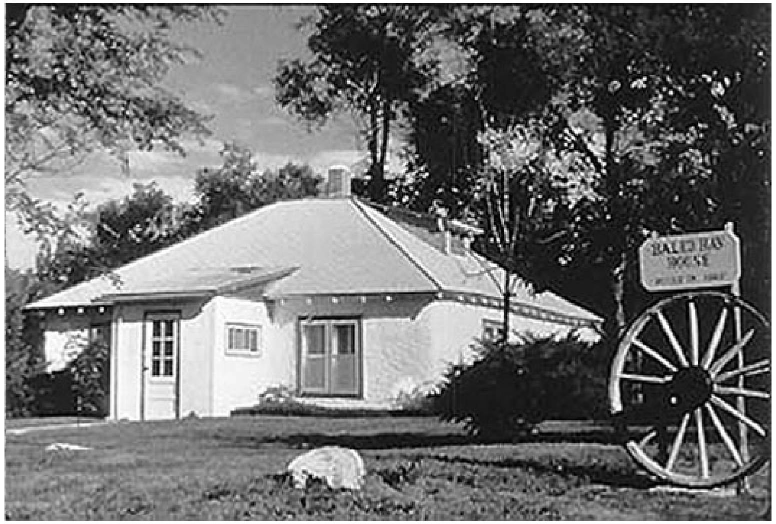
Timber and straw bale houses

Use of timber and straw:

First houses built in 1800 with the invention of the Nebraska packing machine







Burke House, Alliance, Nebraska 1903

Use of timber and straw:

Maison Feuillette

Montargis, Francia 1921

Burke House, Alliance, Nebraska 1903

Use of timber and straw:

Straw is not hay!

Hay is the grass lawn: it is green, humid and nutritious for animals

Straw is the dry part of the plant, between the rhizome and the ear, dry on the field and it is cut once mature

Types of straw:

Rye

Wheat

Barley

Rice

Use of timber and straw:

Properties of straw bales:

≈ 25 kg

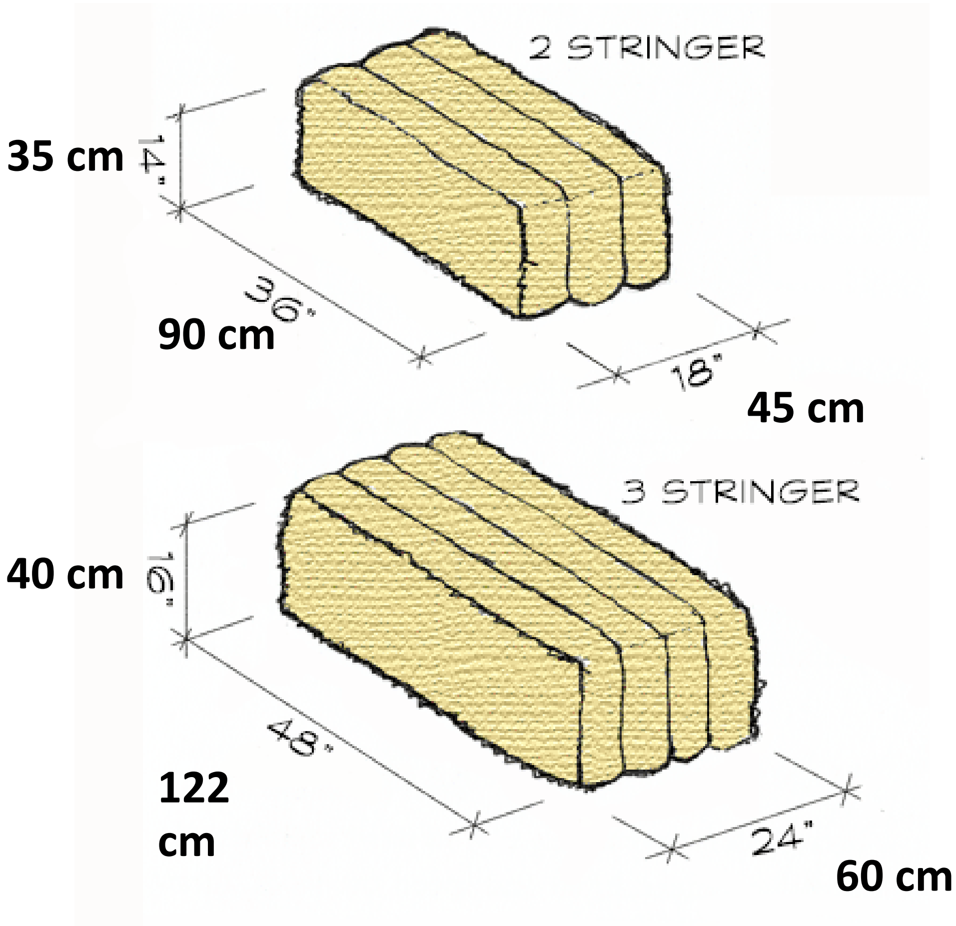


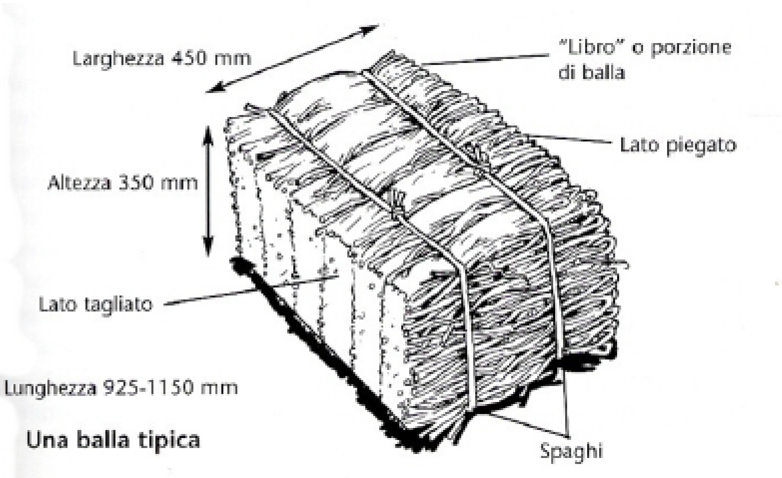
Figure 1 - Approximate dimensions of two and three string straw bales.

≈ 50 kg

Density 120-240 kg/m^3

Use of timber and straw:

Properties of straw bales:



Strings made of sisal, hemp, polypropylene or iron

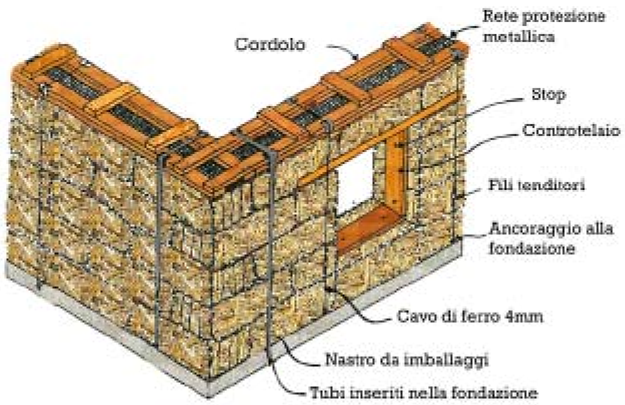
Max compression (ρ=120-240 kg/mc)

Moisture content less than 15%

Tied strings, placed at 100 mm from the edge to avoid extraction

Use of timber and straw:

Construction systems – Nebraska method



Straw bales are load-carrying walls for gravity loads

Staggered vertical joints - Fastened to wooden pegs

Walls prestressed with cables or belts

Walls cannot resist horizontal actions

SYSTEM NOT SUITABLE FOR EARTHQUAKE-PRONE REGIONS!

Use of timber and straw:

Construction systems – Greb method



Walls made of unbraced double timber lightframe

Filling with straw bales and either lime or raw earth plaster

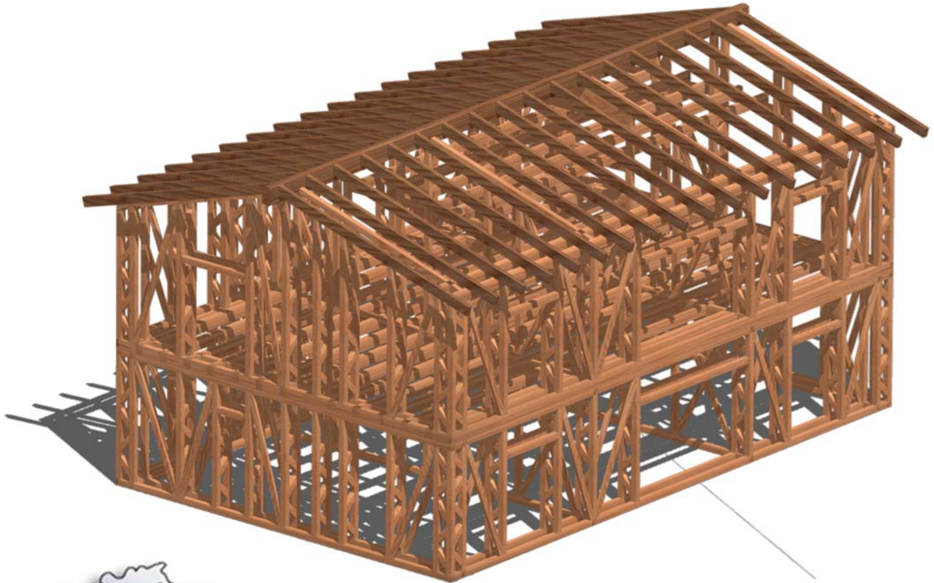
Timber and straw walls carry the gravity loads

Plaster braces the walls

SYSTEM NOT VERY SUITABLE FOR EARTHQUAKE-PRONE REGIONS!

Use of timber and straw:

Thermally isolated building using straw in S.Alfio (CT)

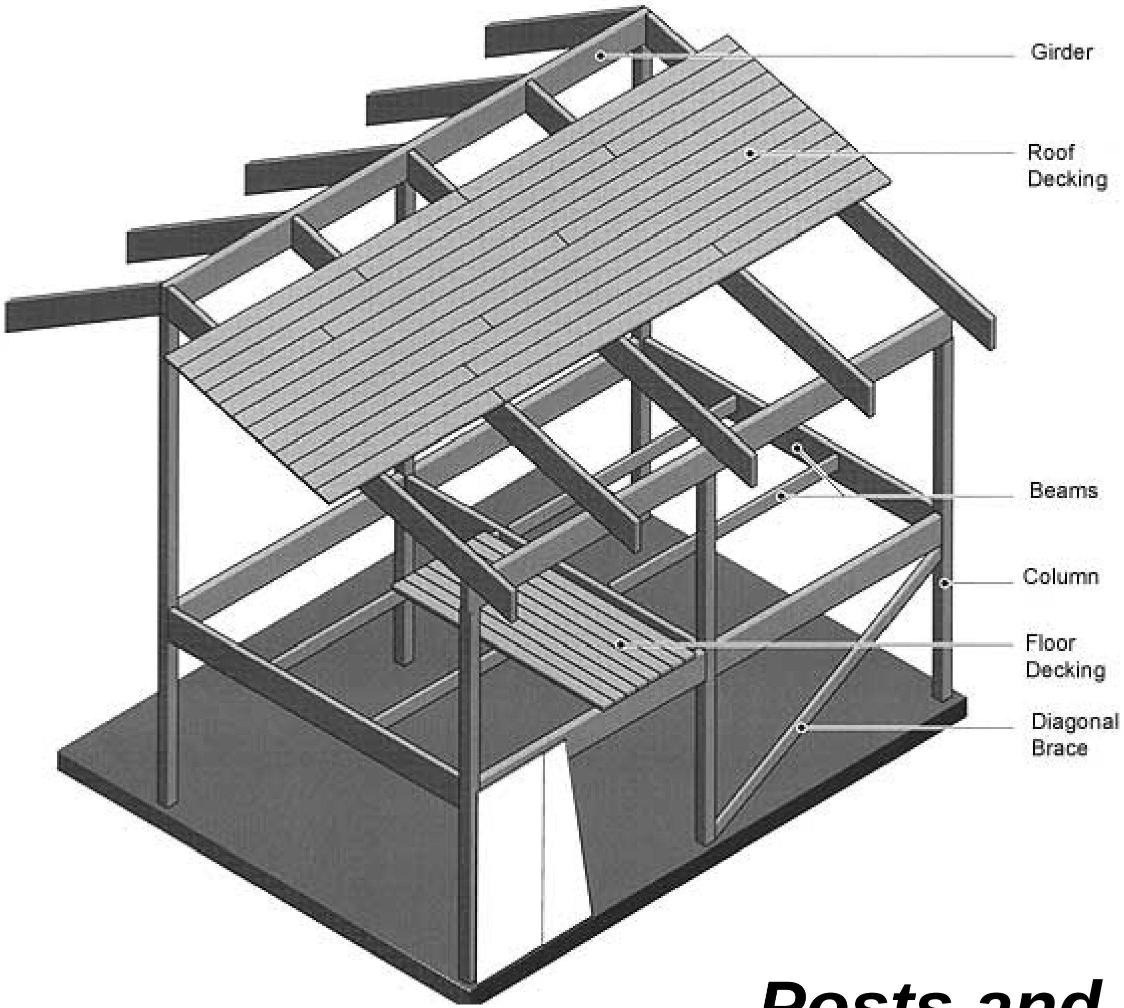


Two-storey building with 280 m^2

Built in 2011

Use of timber and straw:

Use of timber and straw:

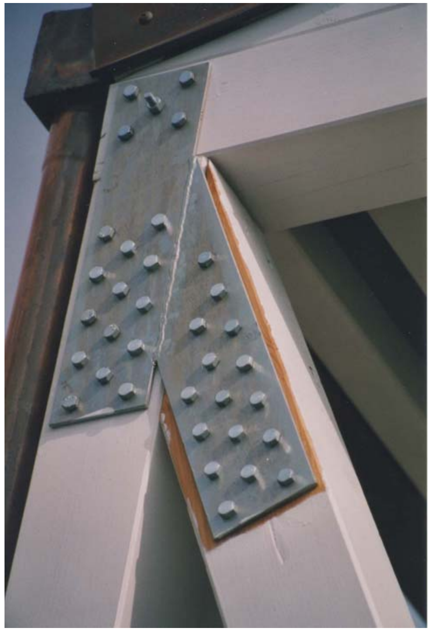


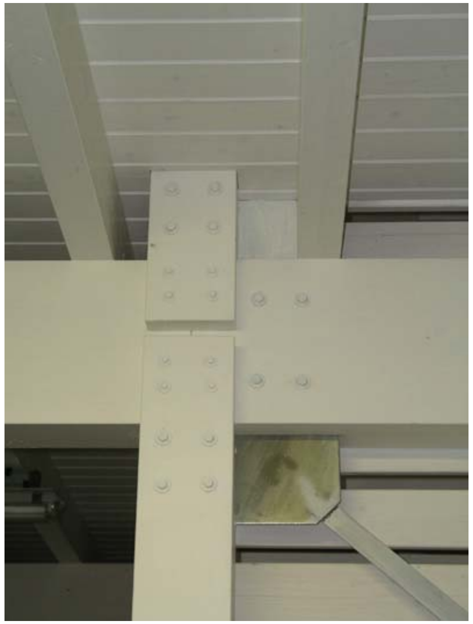
Posts and Beams

Use of timber and straw:

Vertical and horizontal bracings

Use of timber and straw:

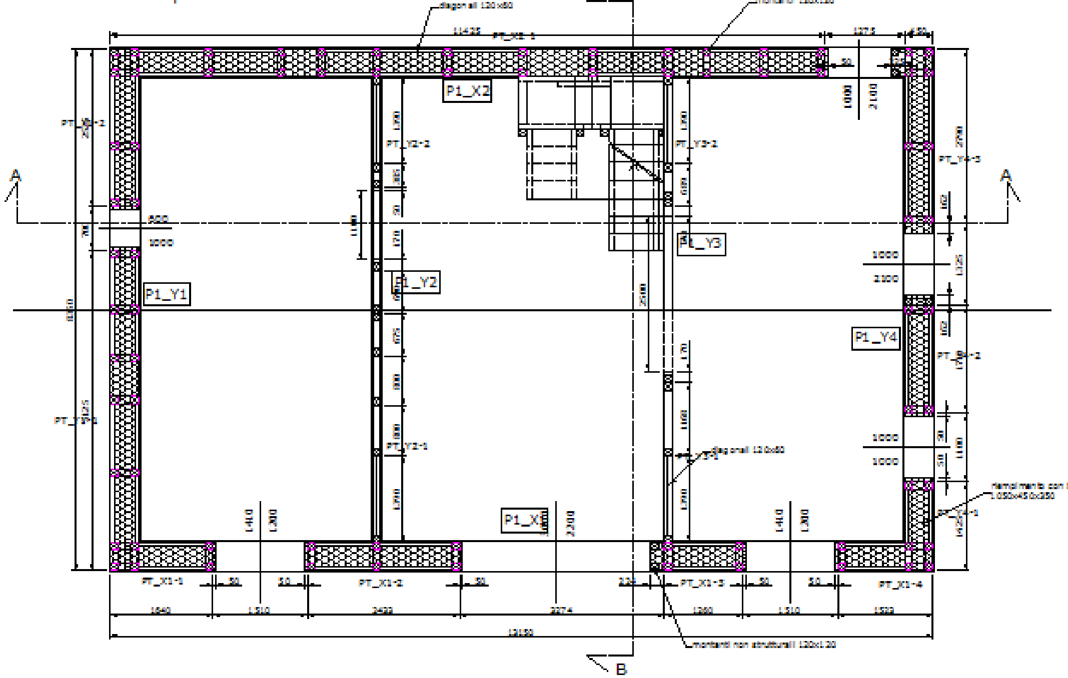




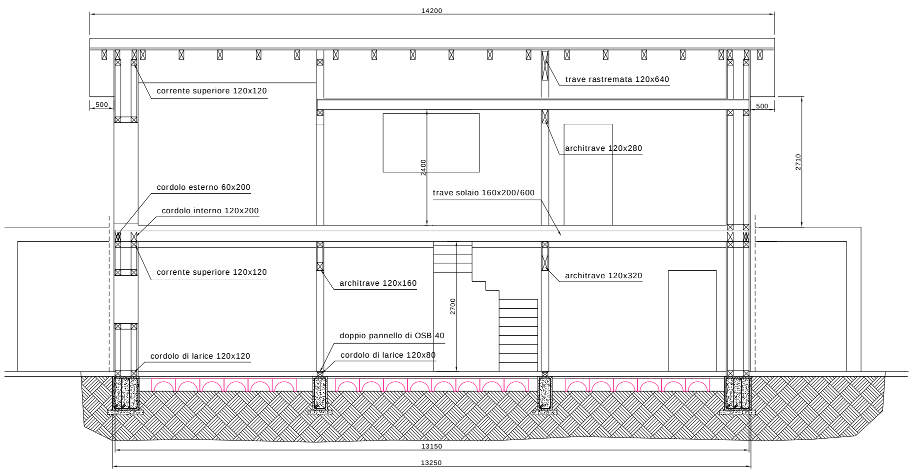
Posts and Beams

Use of timber and straw:

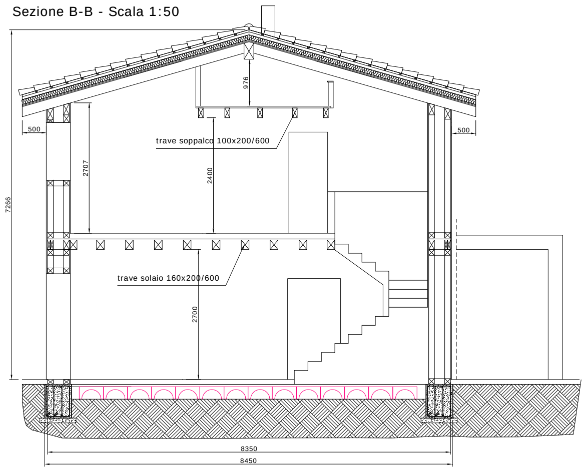
Pianta piano terra - Scala 1:50



Sezione A-A - Scala 1:50



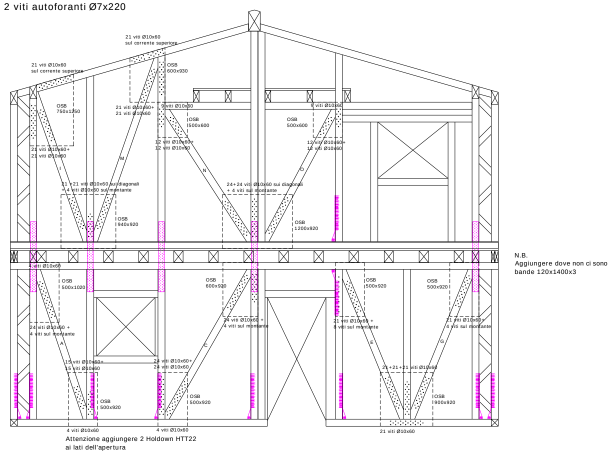
Sezione B-B - Scala 1:50



Use of timber and straw:

Prospetto parete PY4 - Scala 1:50

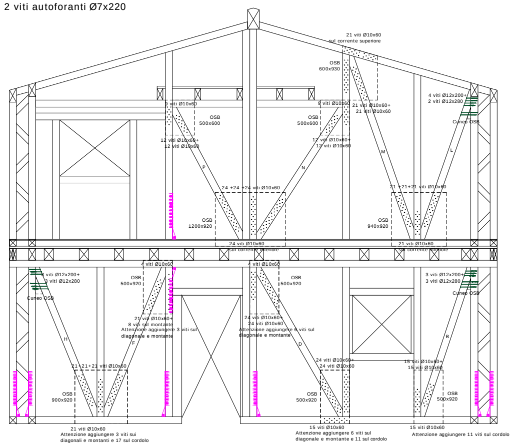
Collegamento OSB con montanti e diagonali:
viti Ø10x60 sui diagonali
viti Ø10x60 sui montanti
viti Ø10x60 sui cordoli o correnti
Collegamento col cordolo:
2 viti autoforanti Ø7x220



vista lato esterno

Prospetto parete PY4 - Scala 1:50

Collegamento OSB con montanti e diagonali:
viti Ø10x60 sui diagonali
viti Ø10x60 sui montanti
viti Ø10x60 sui cordoli o correnti
Collegamento col cordolo:
2 viti autoforanti Ø7x220

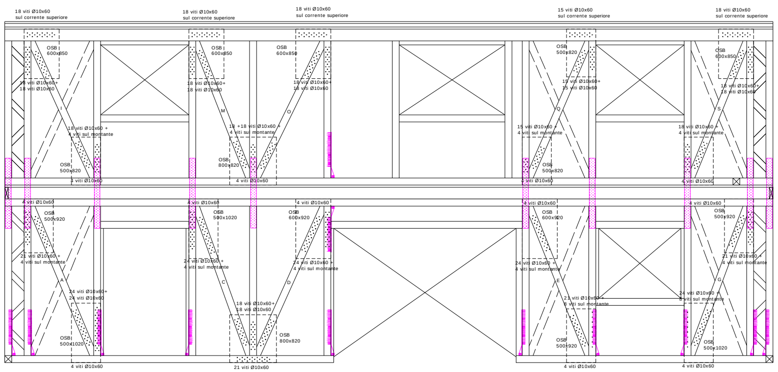


vista lato interno

Prospetto parete PX1 - Scala 1:50

Collegamento OSB con montanti e diagonali:
viti Ø10x60 sui diagonali
viti Ø10x60 sui montanti
viti Ø10x60 sui cordoli o correnti
Collegamento col cordolo:
2 viti autoforanti Ø7x220

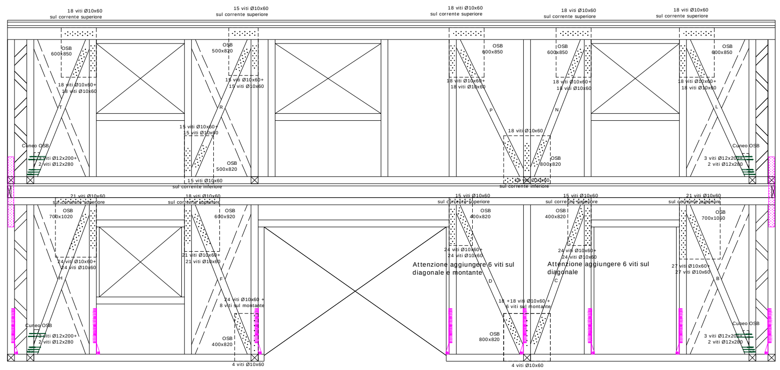
N.B.
Aggiungere dove non ci sono bande 120x1400x3



vista lato esterno

Prospetto parete PX1 - Scala 1:50

Collegamento OSB con montanti e diagonali:
viti Ø10x60 sui diagonali
viti Ø10x60 sui montanti
viti Ø10x60 sui cordoli o correnti
Collegamento col cordolo:
2 viti autoforanti Ø7x220

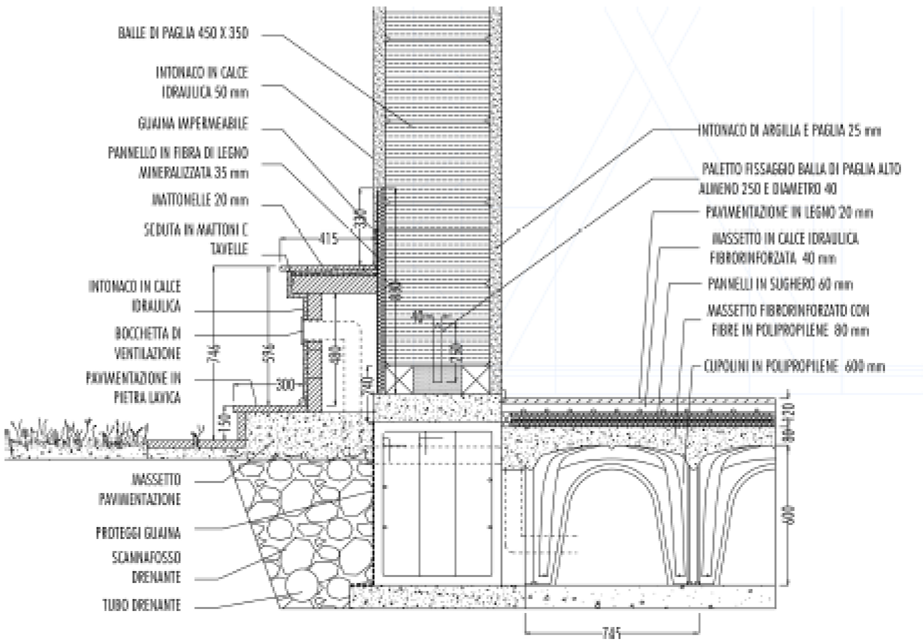


Attenzione aggiungere 6 viti sul diagonale

vista lato interno

Use of timber and straw:

Use of timber and straw:



Use of timber and straw:

Use of timber and straw:

Use of timber and straw:

Use of timber and straw:

Use of timber and straw:

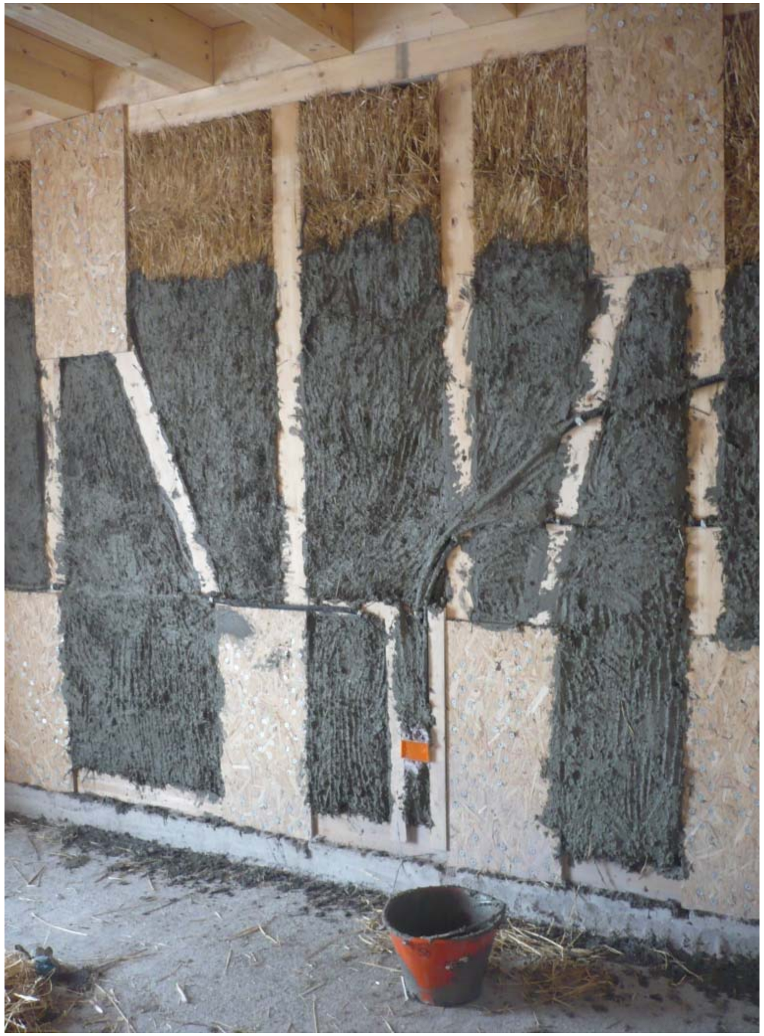
Use of timber and straw:

Use of timber and straw:

Preparation of raw earth plaster made of vulcanic sand and local clay

Use of timber and straw:

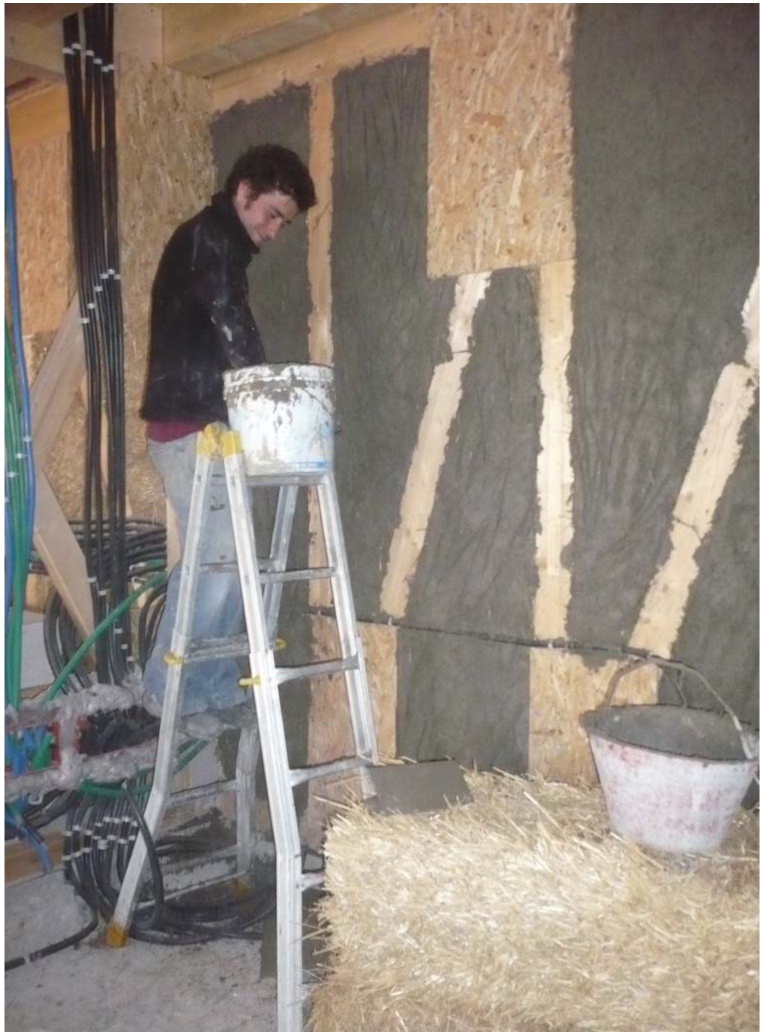
Raw earth plaster on straw and wood



Supporting ‘Canniccio’ (wattle) – raw earth plaster on the sides

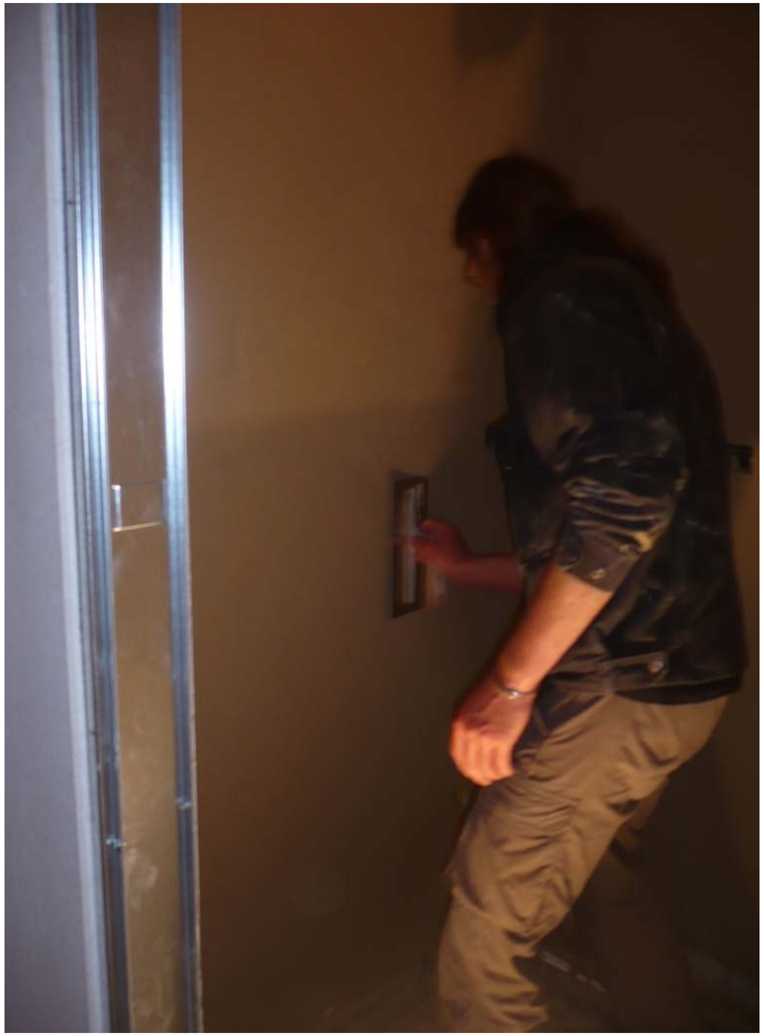
Use of timber and straw:

Raw earth plaster on straw **Plaster on wattle**



Use of timber and straw:

Pre-mixed plaster made of raw earth



Zero kilometres timber buildings:

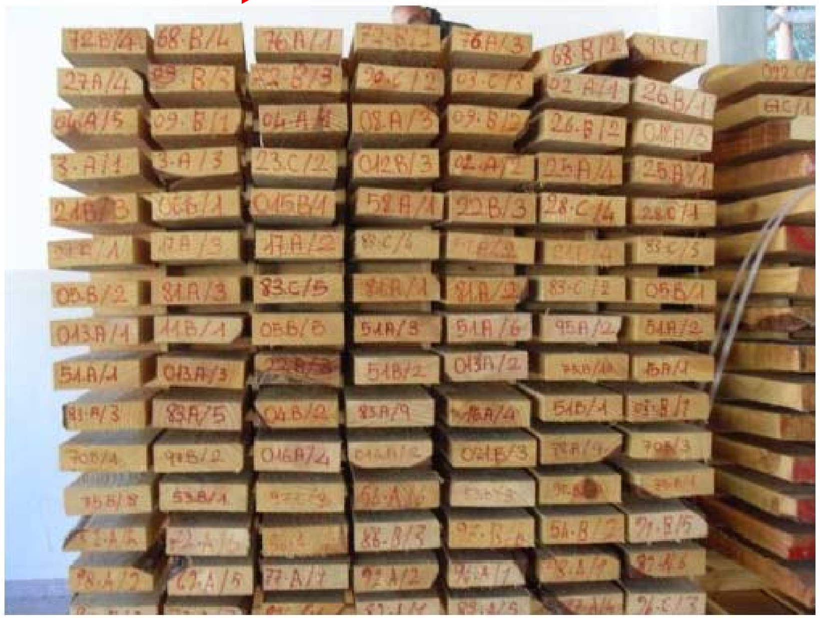
- **Most of the timber** currently used in Italy is **imported from** Austria and Germany
- In Italy there are **extensive forests** hardly used for timber production nowadays (although they were used in the past!)
- **Why not use locally grown timber to construct zero kilometer buildings rather then importing it from far away and burning many tons of CO_2** during transportation?

The short procurement chain of timber:

• **Sustainable forest management: trees** are **fallen and re-planted** in perpetuity so as **to ensure a preservation** or even an increase **of the forested areas** over time.

The short procurement chain of timber:

- The **logs** are **transported in local sawmills and cut into boards**



The short procurement chain of timber:

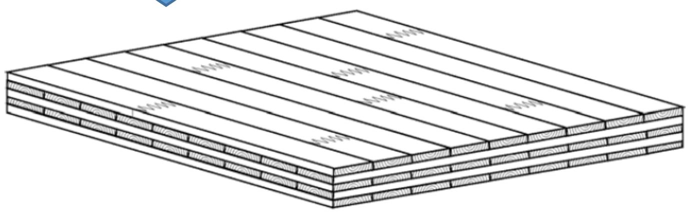
• The **production waste** (branches, bark, sawdust, etc.), NOT THE BEST PART OF THE TREE, can then be **used as biomass** for the production of energy

The short procurement chain of timber:

• The **boards are** (visually or machine) **graded** according to national (UNI 11035, DIN 4074) and European (EN) regulations

The short procurement chain of timber:

• The **boards** are then **used within prefabricated structural components** (e.g. ‘xlam’ panels) **produced in a local transformation centre**



The short procurement chain of timber:

• The **structural components** (e.g. 'xlam' panels) are **used to construct residential and public buildings**

The short procurement chain of timber:

Environmental, economical and social advantages:

• **Increase in value of the forests due to the use of wood in modern structural components** rather than (only) as firewood.

• **Possibility to increase the forested area with:**
- **significant environmental benefits (CO_2 reduction)**
- **landscaping improvement**
- **possible touristic development**
- **landslide hazard reduction**

• The short procurement chain of timber can contribute to an **economic recovery of areas often underdeveloped**, **offering jobs in the forestry and construction sectors**, and **preventing depopulation** of these areas (**social benefit**)

The first results in Sardinia, Italy:

Prototype of Xlam panel made of maritime pine boards (inner and outer layers)

Prototype of Xlam panel made of Eucalyptus boards (outer layers) and maritime pine boards (inner layer)

What is needed to start this program?

• **Assessment of the timber volume** that can be produced in a certain region **via a sustainable forestry practice (collaboration with the school of Forestry)**

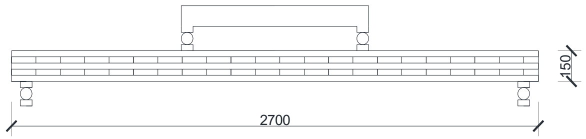
• **Choice of the** most suitable **wood species** for use in construction (e.g. maritime pine, Eucaliptus, what else?)

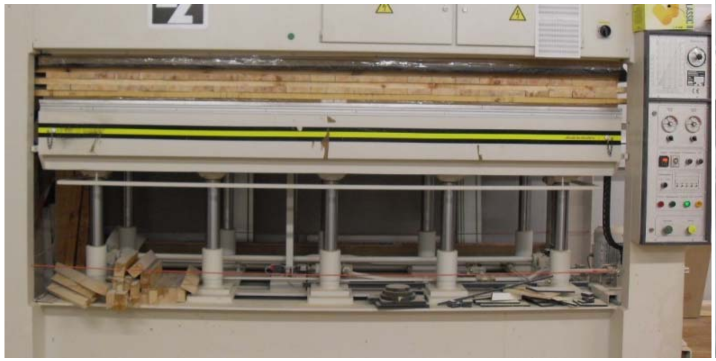
• **Determination of** visual and/or machine **grading rules by testing some thousands of wood boards**

What is needed to start this program?

- Production of Xlam panels made of local wood

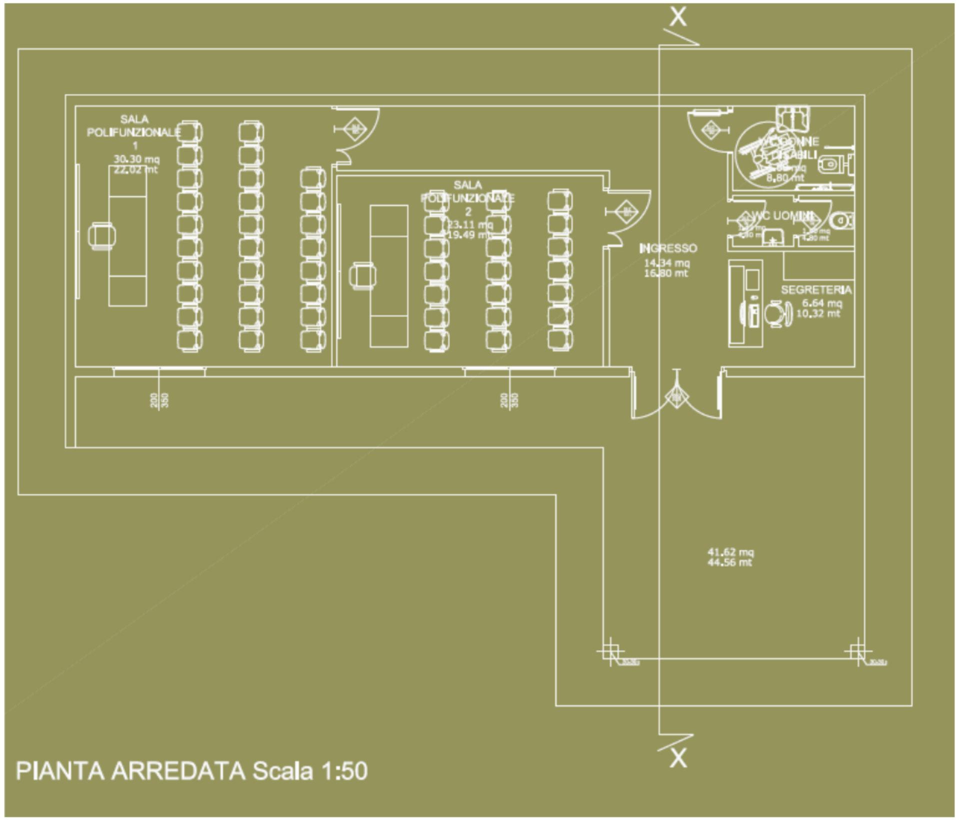
- Tests to destruction of the panels to determine their mechanical properties





What is needed to start this program?

- **Construction of a small case study building made of local wood**



Thank you very much!

massimo.fragiacomo@univaq.it