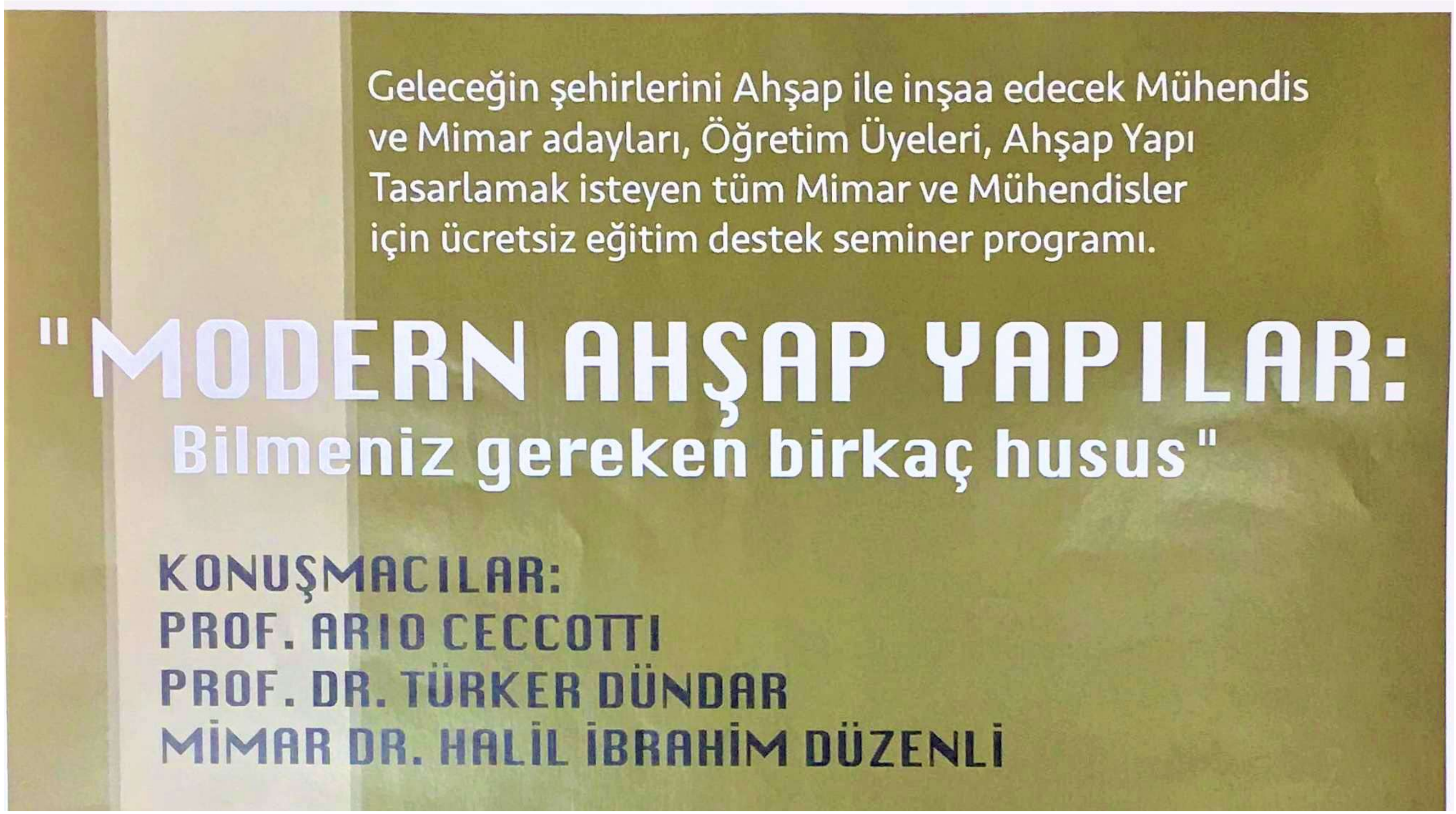


Timber engineering, few things to know (III)

Ario Ceccotti *Boğaziçi University*

List of content

- ***The material.***

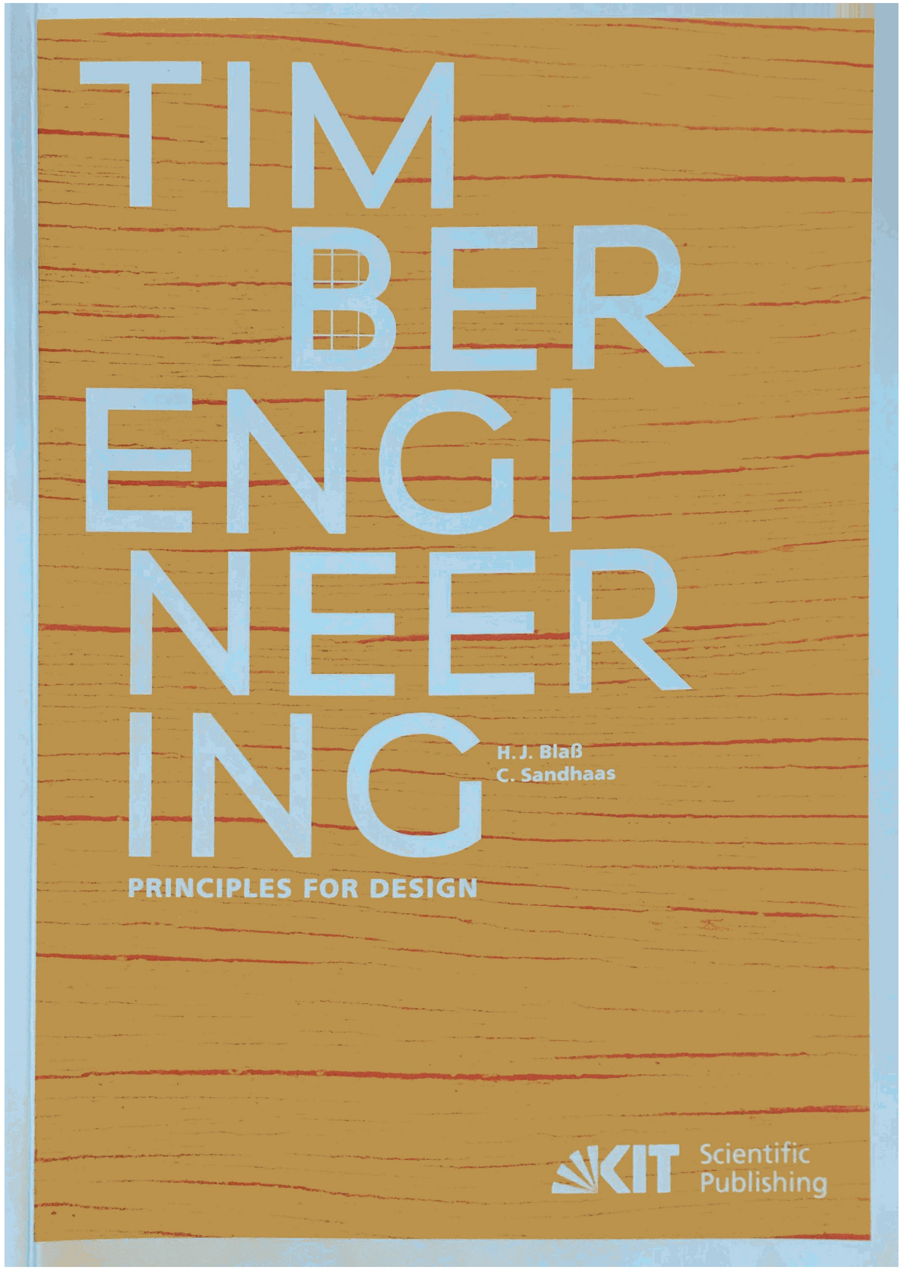
Structural wood: technology and physical-mechanical properties of wood products derived from wood for use in load-bearing structures.

- ***The connections***

Joints between elements, glued and mechanical. Materials, devices and their properties.

- ***The buildings.***

The main construction types. Frame and partition systems. Behavior to seismic actions and to fire.



Hans J. Blass
Carmen Sandhaas

KIT Karlsruhe Institute of Technology
Germany

https://publikationen.bibliothek.kit.edu/1000069616

Cristina Benedetti

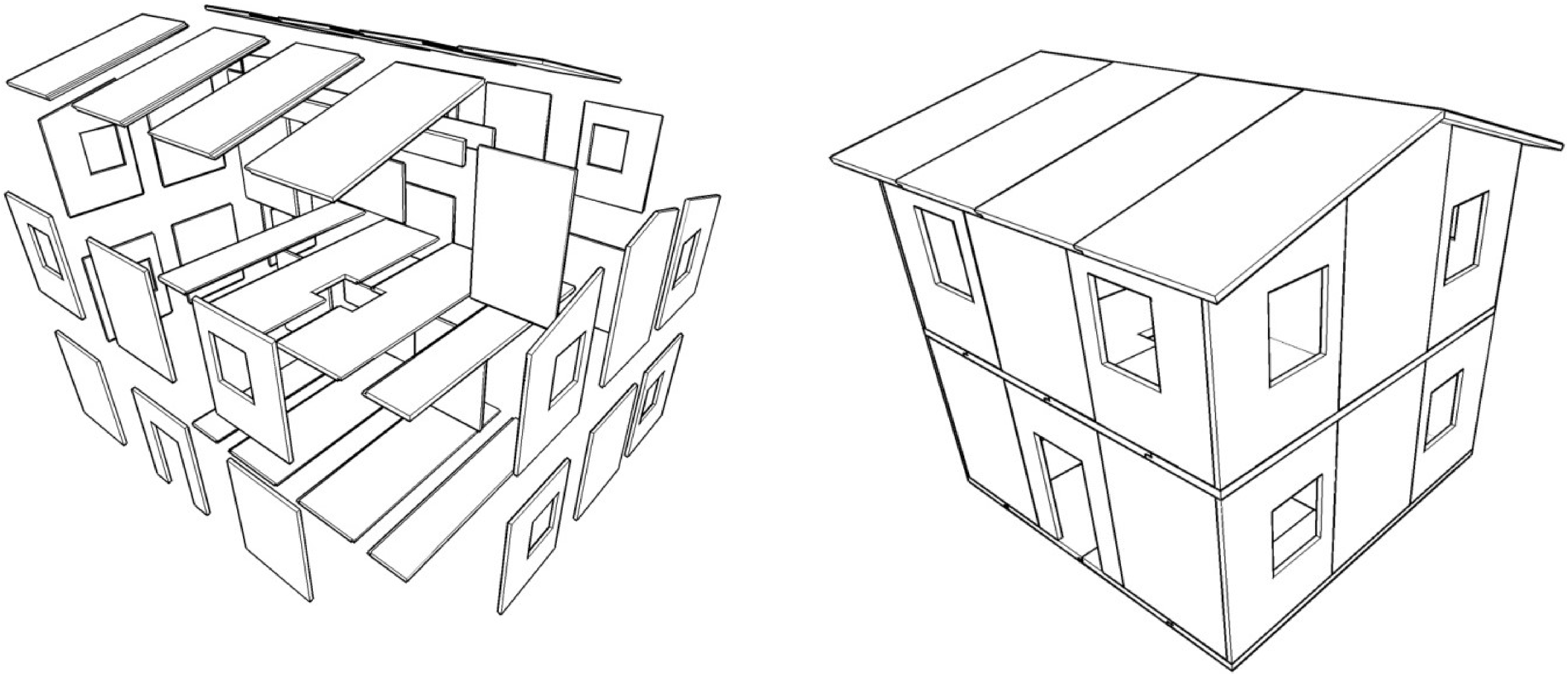
University of Bolzano
Italy

https://bupress.unibz.it/it/timber-buildings.html for these lectures notes, please write to:

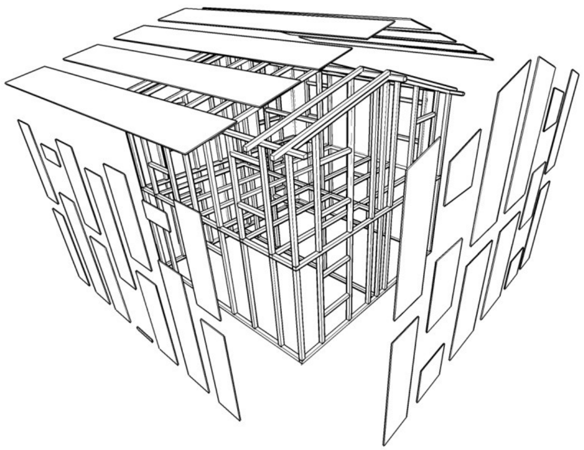
Celalettin Akça mcakca@gmail.com

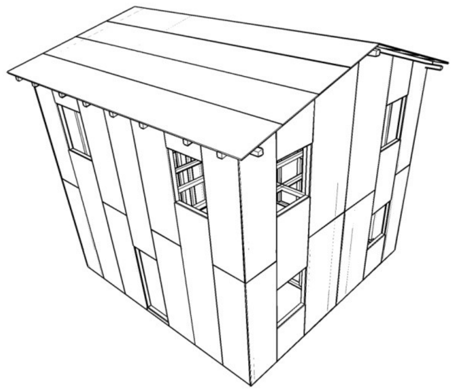
Traditional Platform Timber Framed Construction:

CLT Cross Laminated Timber



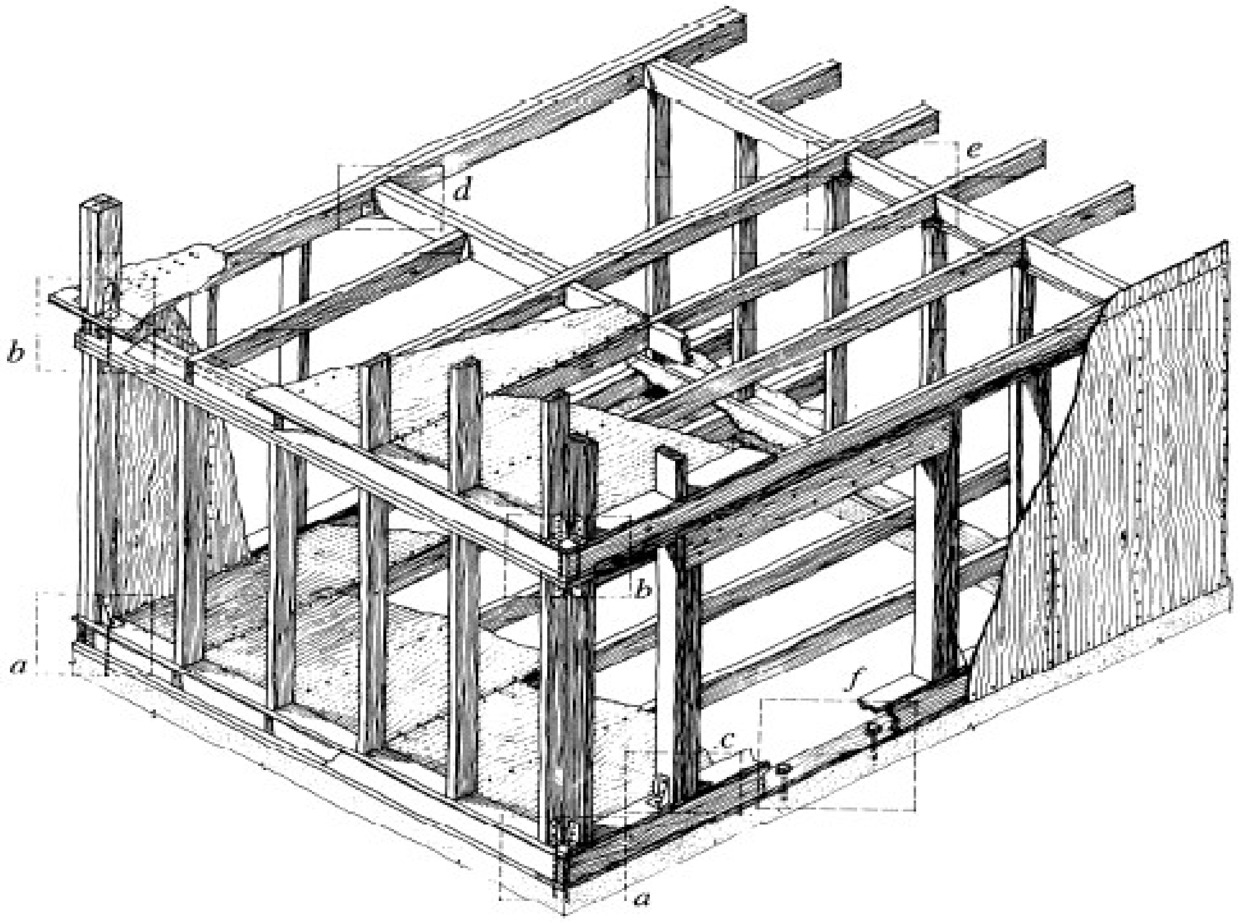
TF

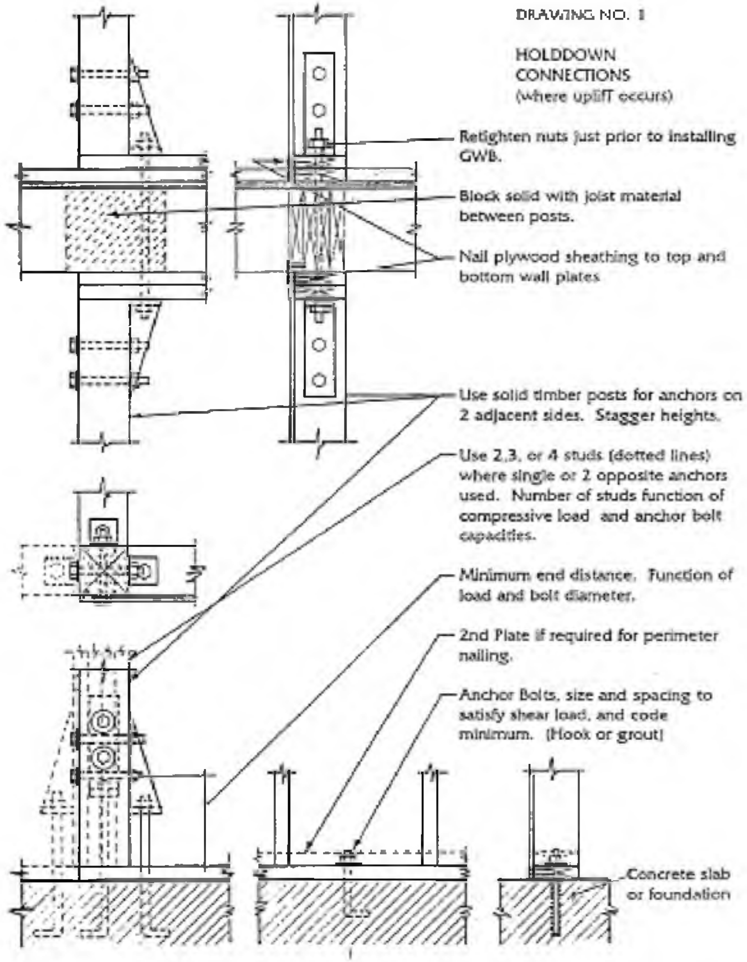






Timber Frame construction (platform)





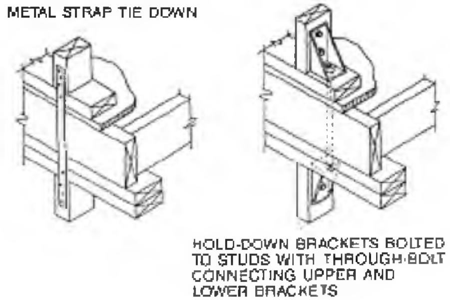
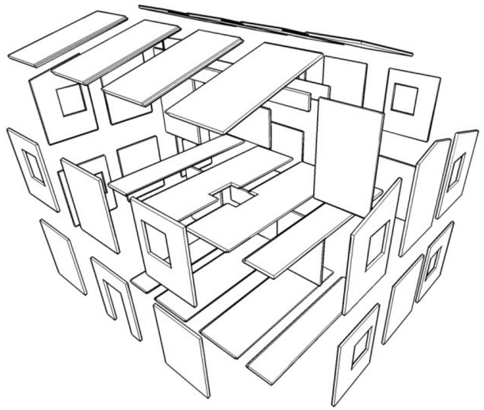
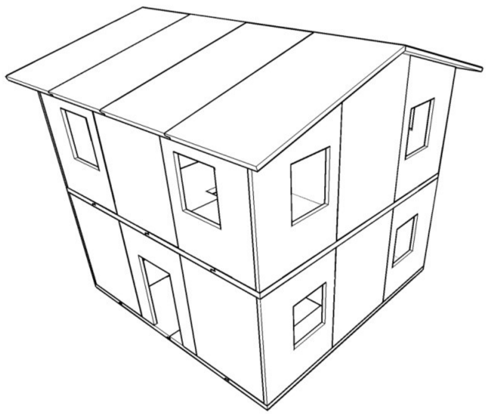


Fig. 3.8 The anchoring of uplift forces is handled with metal straps or hold-down bolts (SECBC 1997).

Anchoring details in a multi-storey house case (SECBC 1997)

CLT



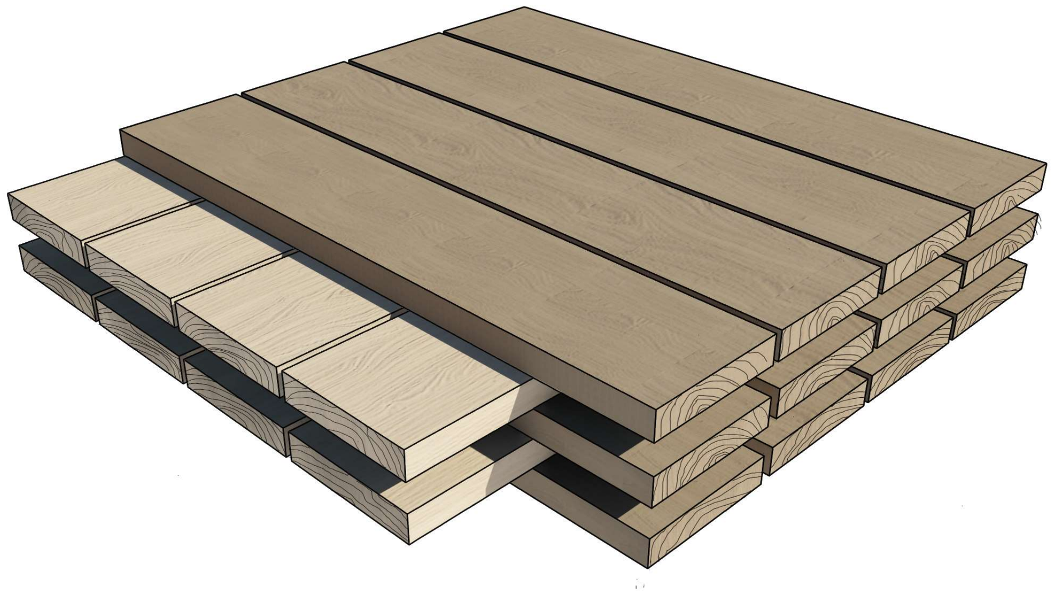


CLT

in plane

stabilized and

self-reinforced structural wood



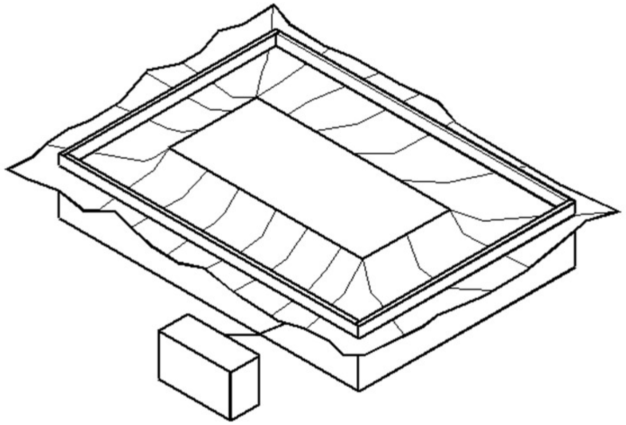
it comes in panels:

from small:

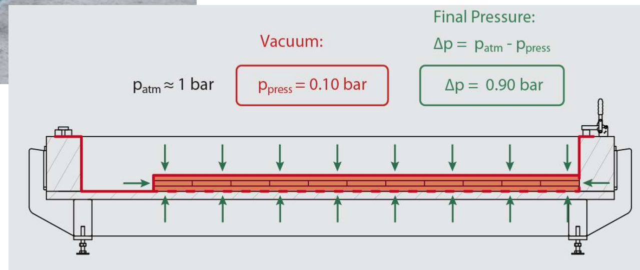
to large ones

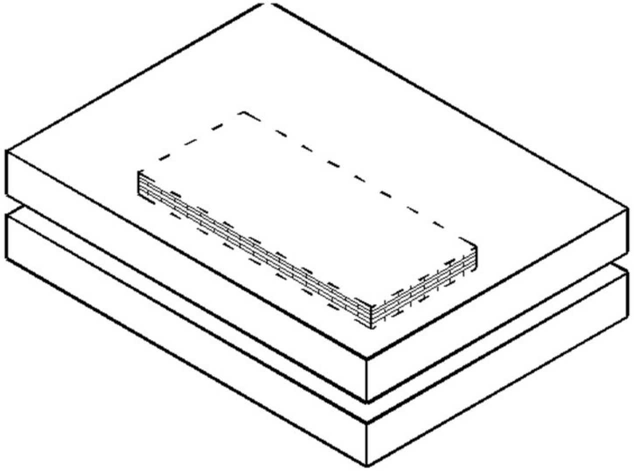
even pre-cut...

Production:



Vacuum press:





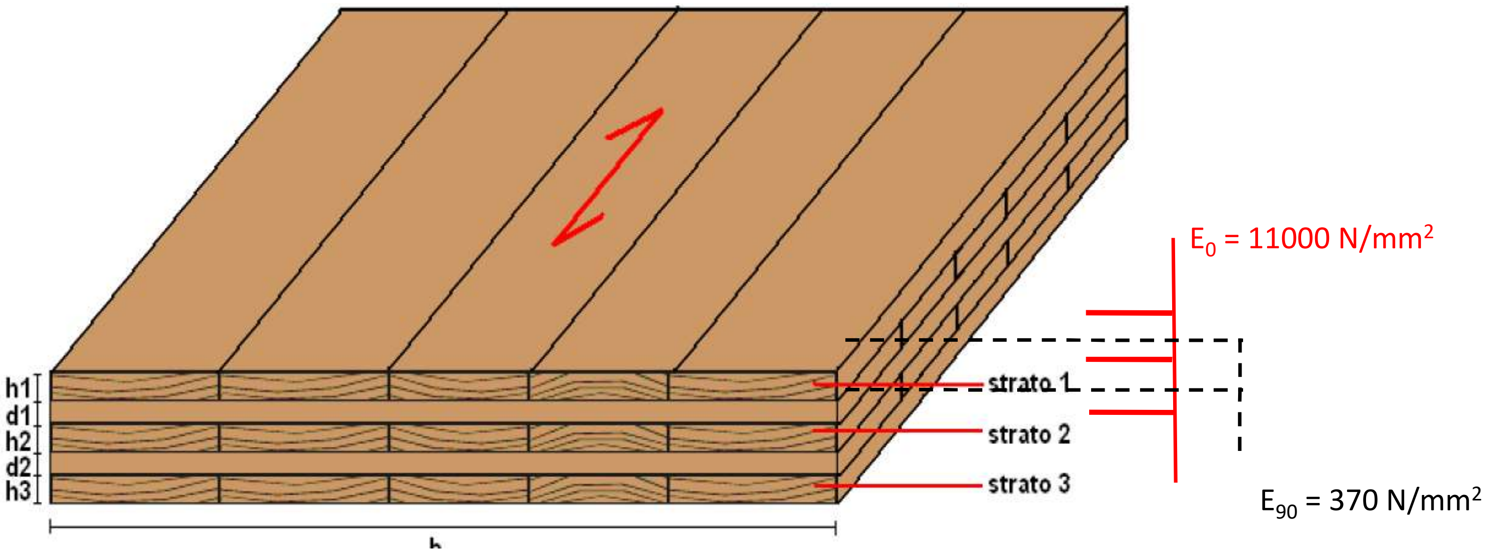
Mechanical press:


70
80

CLT

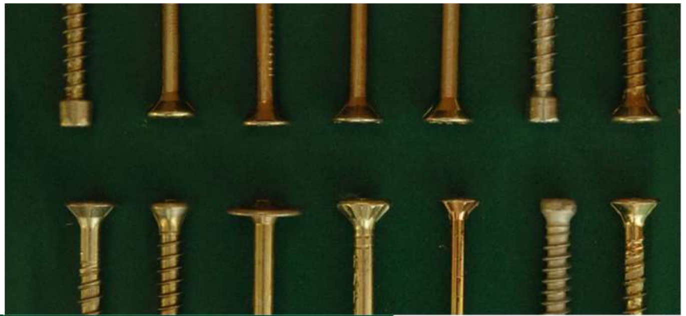
Dimensioni massime	13,50 x 3,50 m
λ	0,13 W/mK
Umidità	12 % (+/- 2%)
Protezione antincendio	carbonizzazione: 0,67 mm/min
Densità grezza	4.5 - 5 kN/m³
Tipo legno	abete rosso classe C24

- from 3 to 9 ply
- from 51 to 360 mm

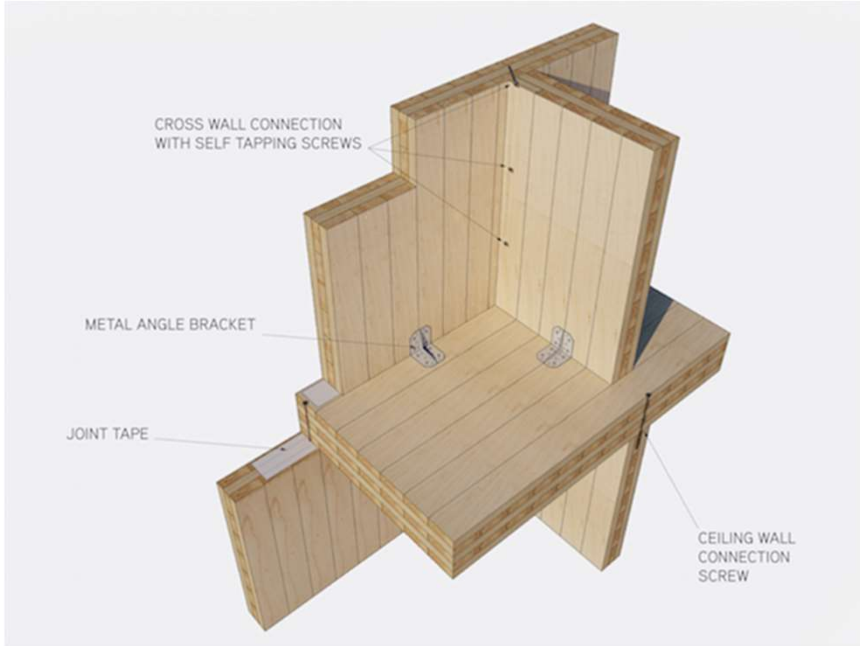


New millennium

- Self-tapping screws:



Uibel, Blaß –
Determining Spacings and Distances for Screws by Experimental and Numerical Studies



...very effectively connected panels!

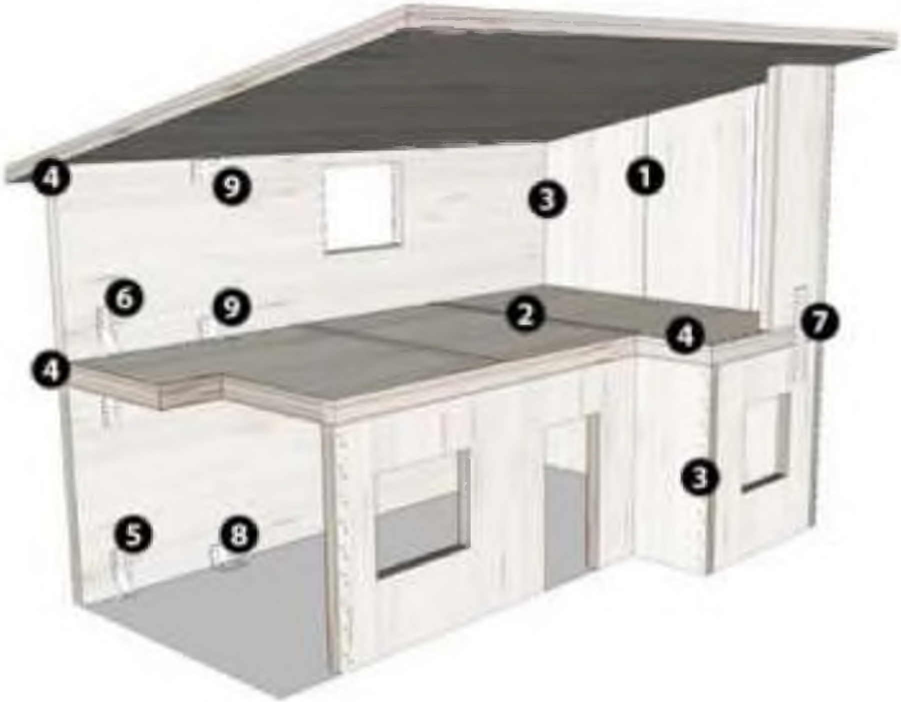


Figure 13: Points where design of connections must be undertaken:

- screws

1 wall-wall
2 floor-floor
3 wall-corner wall
4 floor-wall

- hold-downs

5 wall-foundation
6 wall-floor/floor-wall

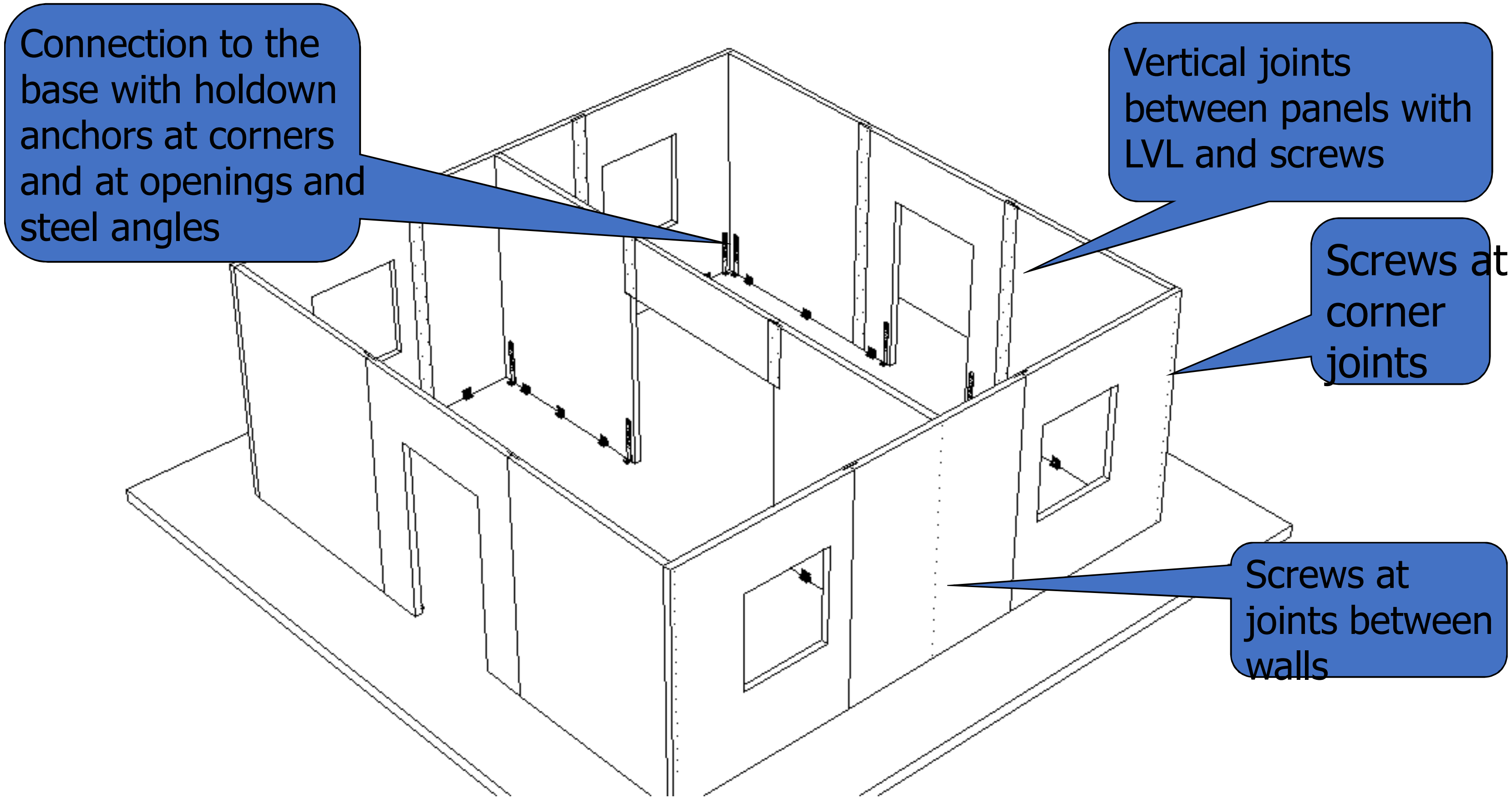
- steel straps

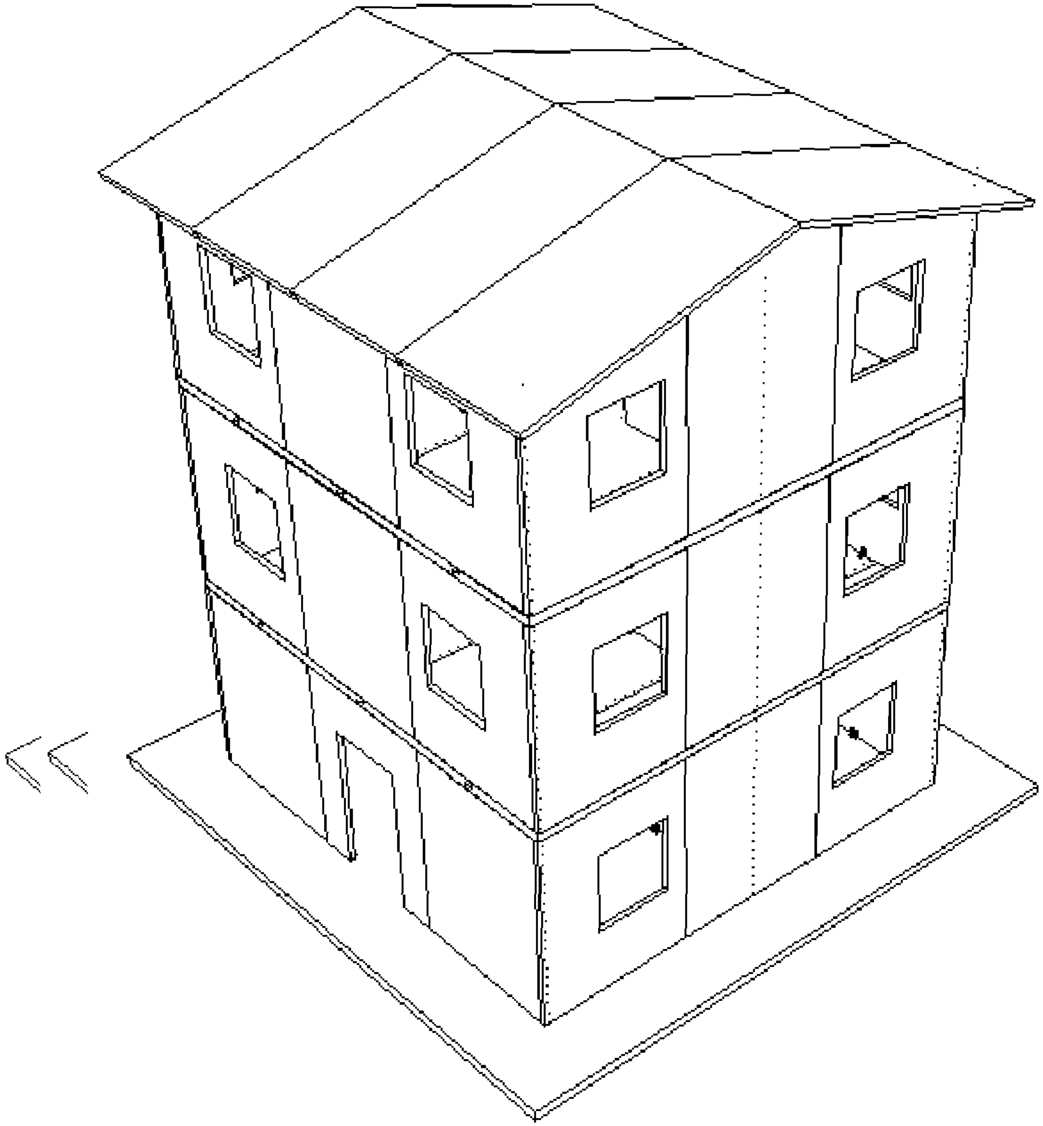
7 wall-wall

- steel angles

8 wall-foundations
9 wall-floor/ wall-wall (in vertical)

rothoblaas


Connection to the base with holdown anchors at corners and at openings and steel angles
Vertical joints between panels with LVL and screws
Screws at corner joints
Screws at joints between walls



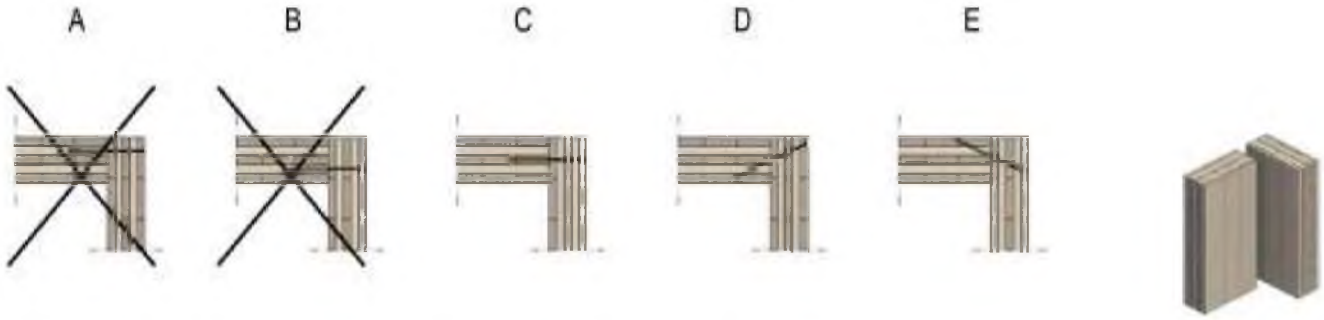


Figure 14a: details for screw insertion in wall to wall connections.
To be avoided: A, B; Recommended but very difficult: C; Recommended: D,E.

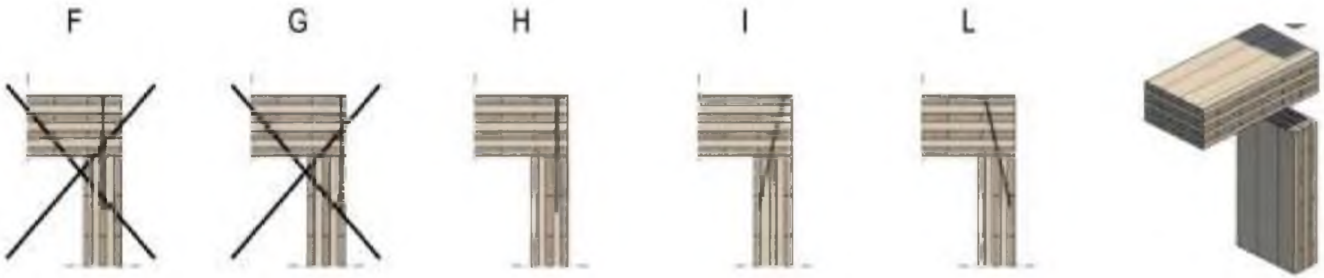
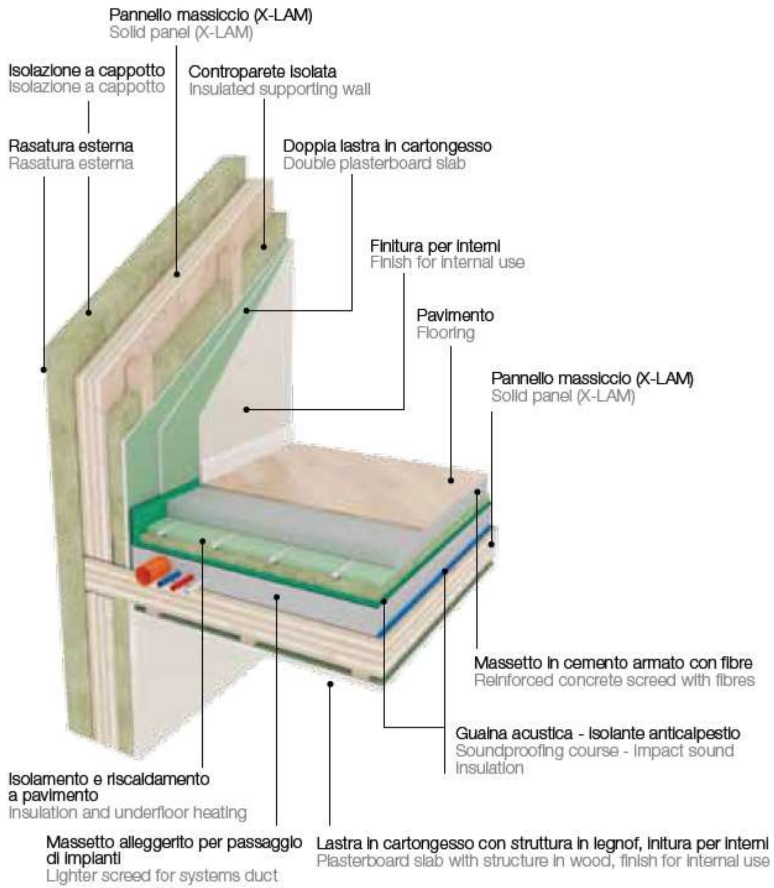
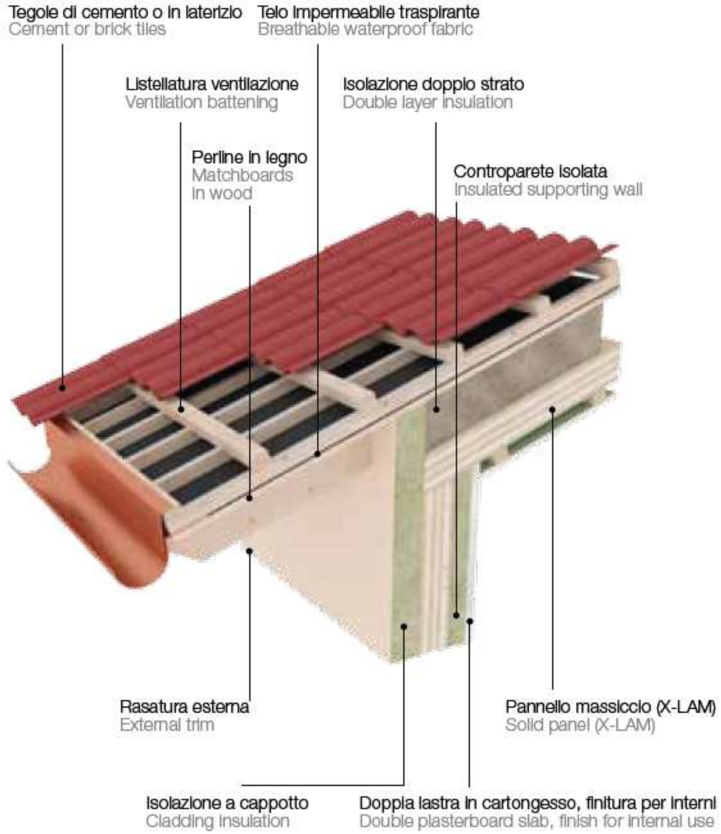


Figure 14b: details for screw insertion in wall to floor connections.
To be avoided: F, G; Recommended but very difficult: H; Recommended: I,L.

RASOM Holz&Ko

Wall and floor composition

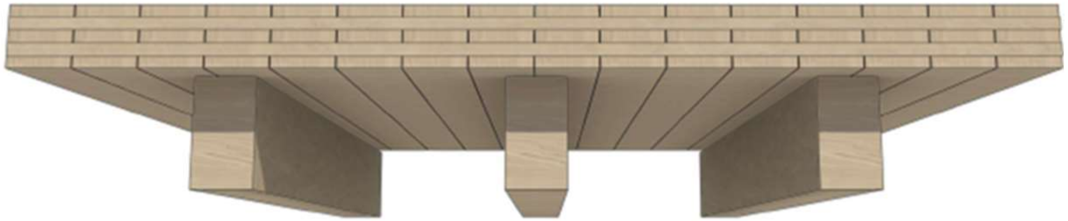




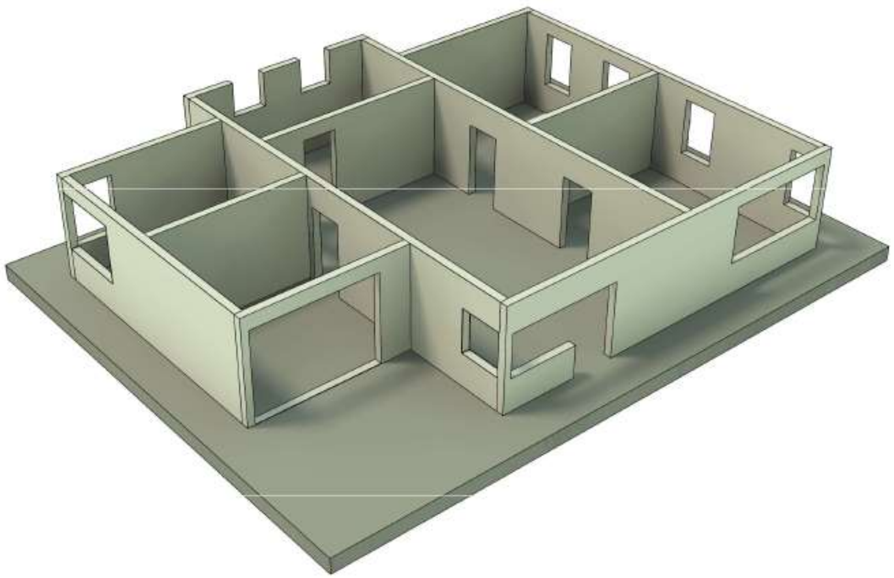
Wall and floor composition

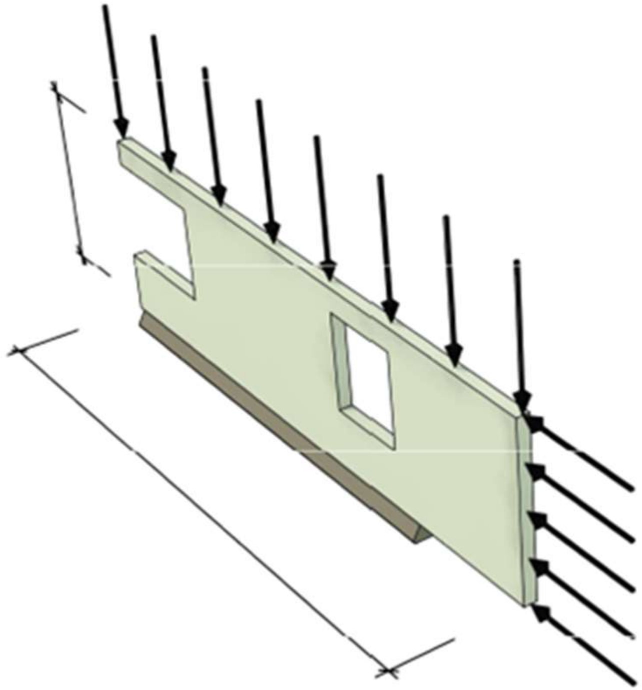
Technological installations

CLT panels are intended to be used as floors…

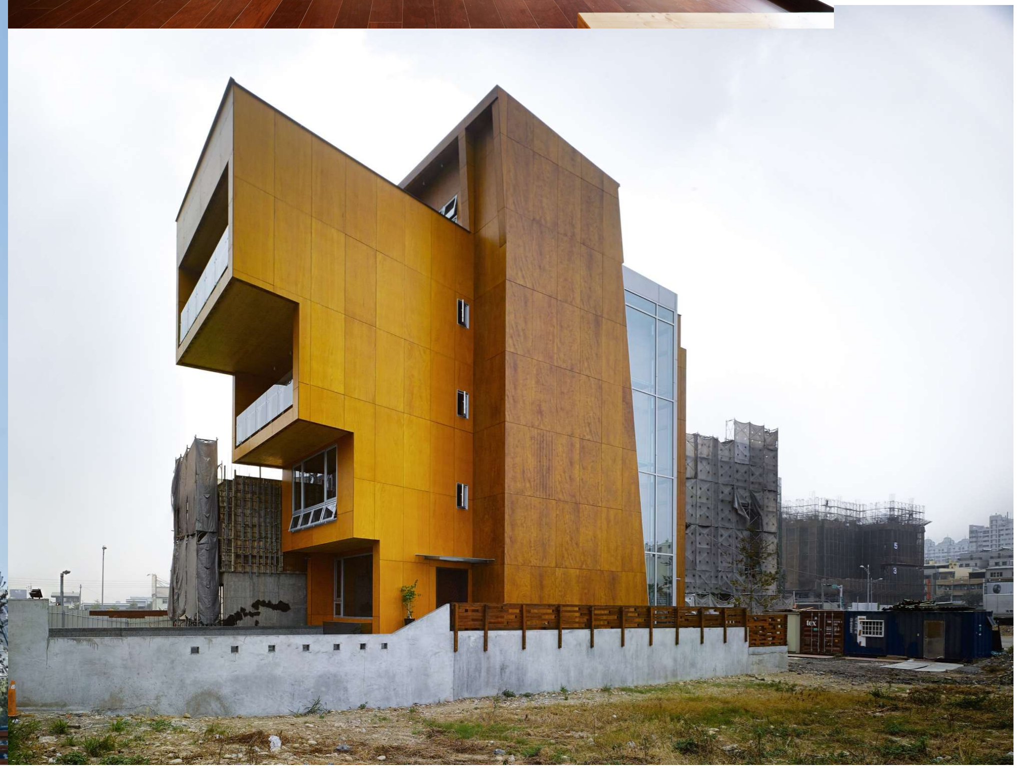


or walls and beams…





Woodtek HQ, Taiwan



some “European” examples of CLT buildings

Italy, year 2000

Castelrotto: the first **7 storey** cross-lam building in Europe has been built in year 2000 in Italy, Trentino-Alto Adige region (Rasom WT, CLT supplier KLH).

2008 - STADTHAUS MURRAY GROVE

Architect: Waugh Thistleton | CLT Supplier & Installer: KLH UK

9 weeks CLT construction

4 Skilled Labourers

1 Supervisor

architects Waugh Thistleton

architects Waugh Thistleton

C M Y K Nxxx,2012-06-05,D,001,Bs-4C,E1

Science Times

N D1

TUESDAY, JUNE 5, 2012

The New York Times

Wood That Reaches New Heights

Building With Engineered Timber

The Graphite Apartments, a nine-story residential tower in London, is one of the tallest timber buildings in the world. It is constructed of factory-made solid-wood wall and floor panels called **cross-laminated timber**, or CLT.

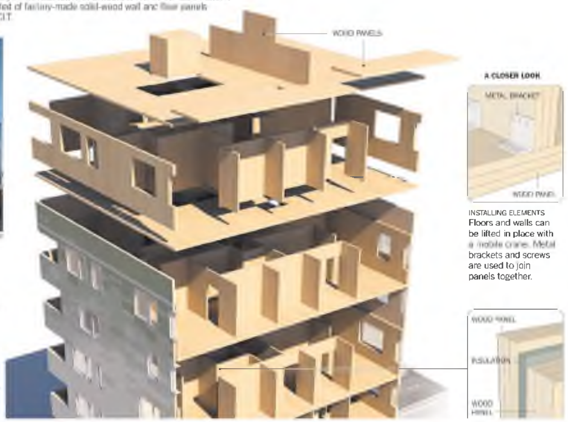
PHOTOGRAPH BY WILL PRYCE

THE BUILDING BLOCKS

The panels, made of three or five layers, are up to 6 inches thick and 30 feet long. But thicker and bigger panels can be made.

Cross section of a cross-laminated timber panel

LAYERS OF WOOD BOARDS GLUED TOGETHER



INSTALLING ELEMENTS
Floors and walls can be lifted in place with a mobile crane. Metal brackets and screws are used to join panels together.

By HENRY FOUNTAIN

LONDON — Among the many apartment buildings in the London borough of Hackney, the nine-story structure on the corner of Provost Street and Murray Grove stands out, its exterior a mix of white and gray tiles rather than the usual brick.

But it's what's underneath this cladding that makes the 29-unit building truly different. From the second floor up, it is constructed entirely of wood, making it one of the tallest wooden residential buildings in the world.

It was built three years ago using laminated spruce panels, up to half a foot thick and 30 feet long, that were fabricated to precise specifications in Austria, shipped across the English Channel and bolted together on site to form the exterior and interior walls, floors and roof. Even the stairwells and elevator shafts are made from these solid panels, called cross-laminated timber, which resemble supersize plywood.

Developed in Europe in the 1990s, cross-laminated timber, or CLT, is among the latest in a long line of "engineered" wood products that are strong and rigid enough to replace steel and concrete as structural elements in bigger buildings. Already popular in Europe, CLT is only beginning to catch on in North

Honeycomb

CLT Structure

Rotated

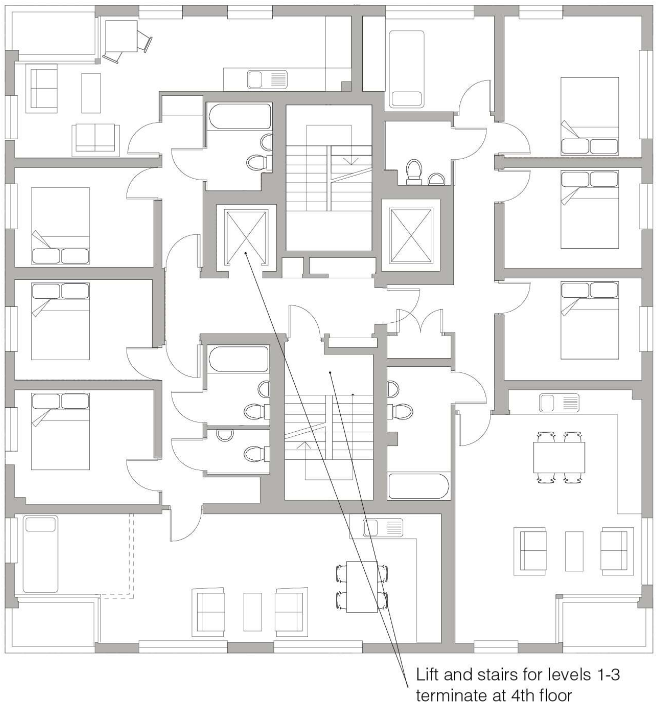
Plans

Load-bearing

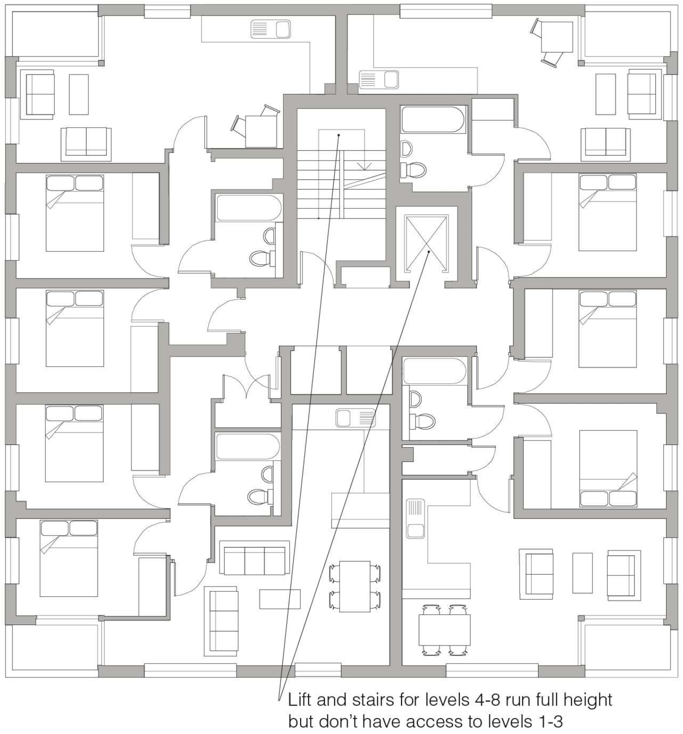
walls, floors, cores

The CLT structure comfortably achieved the required fire resistance. The structural engineer allowed for charring to achieve **60-minutes** fire resistance and achieved **90-minutes** fire resistance by adding plasterboard.

Third floor plan (apartments for tenants of Metropolitan Housing Trust)



Fifth floor plan (apartments for private owners)



architects Waugh Thistleton

C.A.S.E. l'Aquila (IT), the 2009 big quake in Central Italy

2010 - OPEN ACADEMY NORWICH GROVE

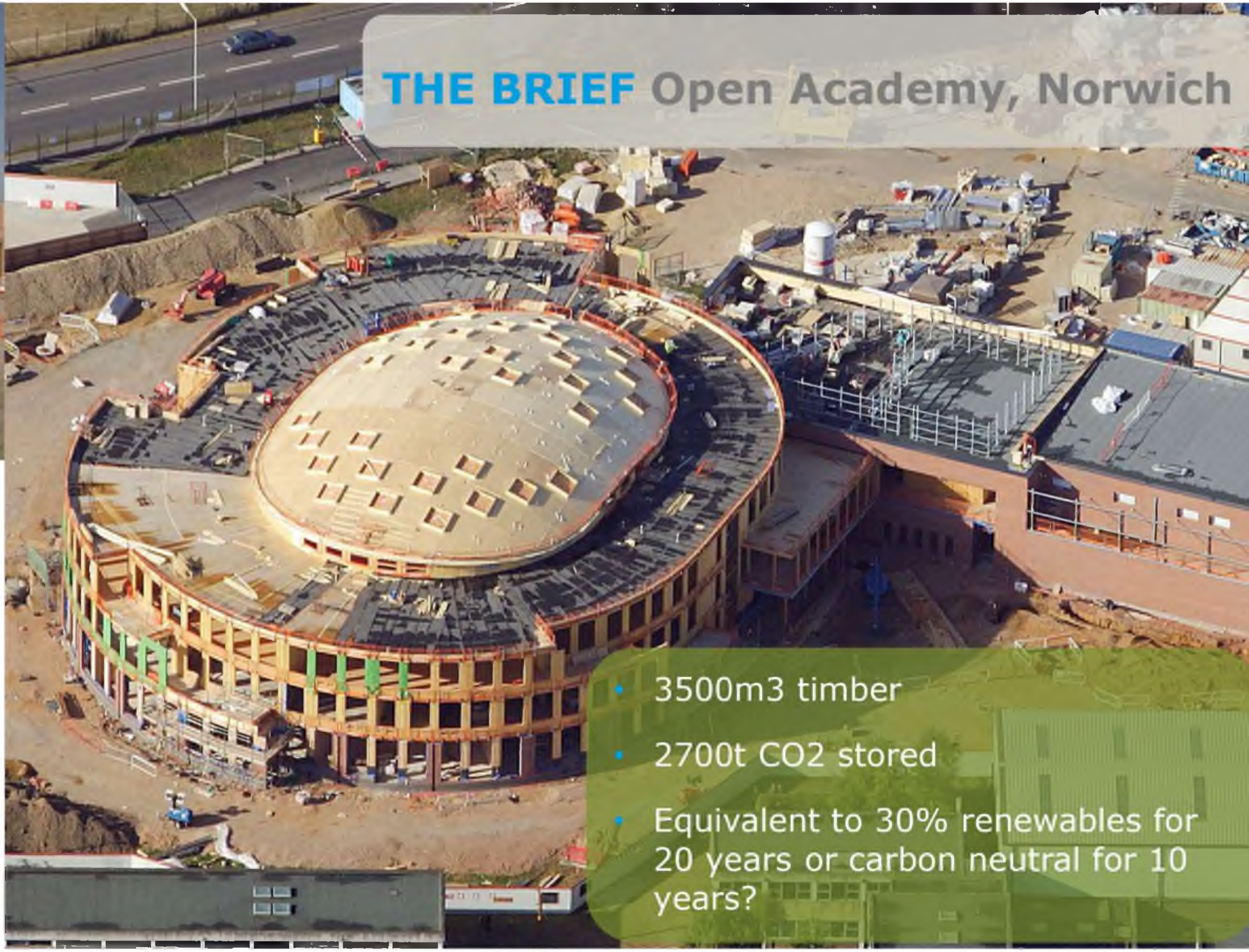
Architect: Sheppard Robson | CLT Supplier & Installer: KLH

16 weeks CLT construction

8 Skilled Labourers

1 Supervisor

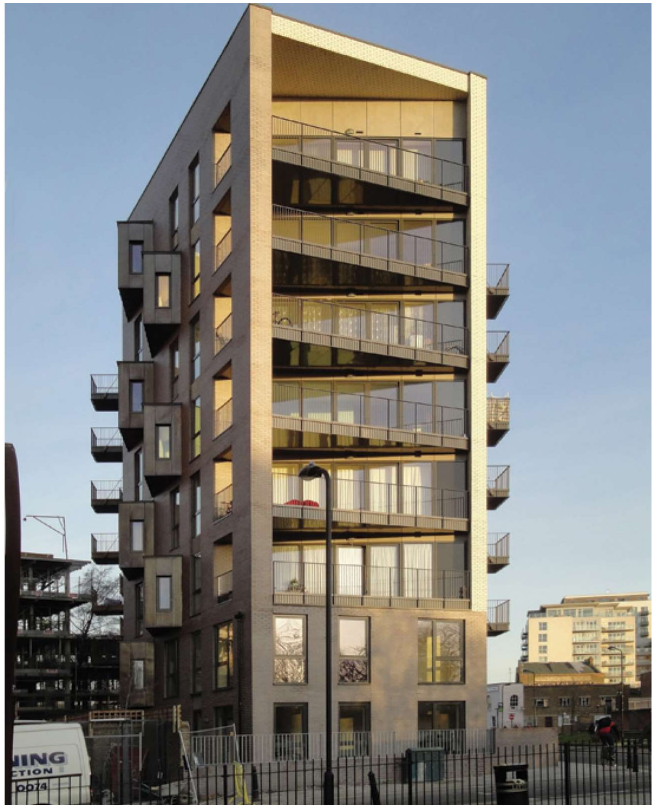
THE BRIEF Open Academy, Norwich



- 3500m3 timber
- 2700t CO_2 stored
- Equivalent to 30% renewables for 20 years or carbon neutral for 10 years?

RAMBØLL

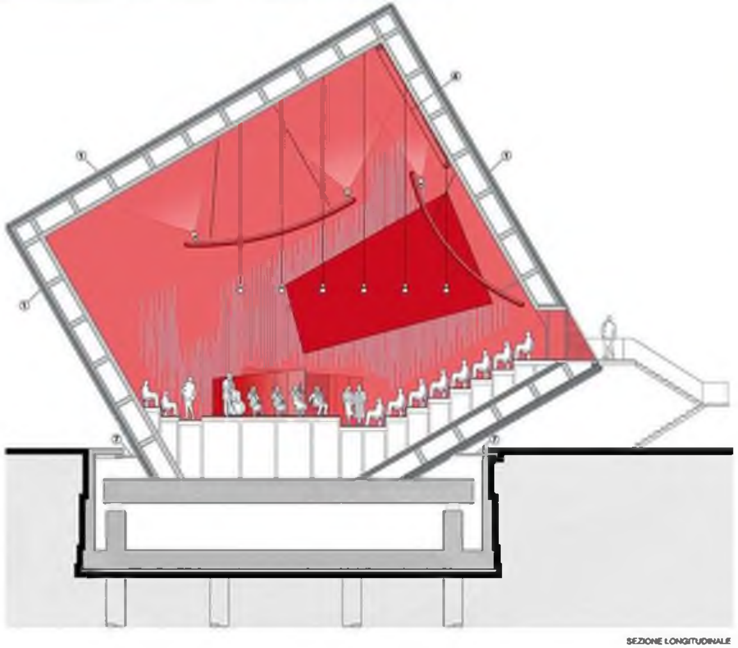
Bridport House in London

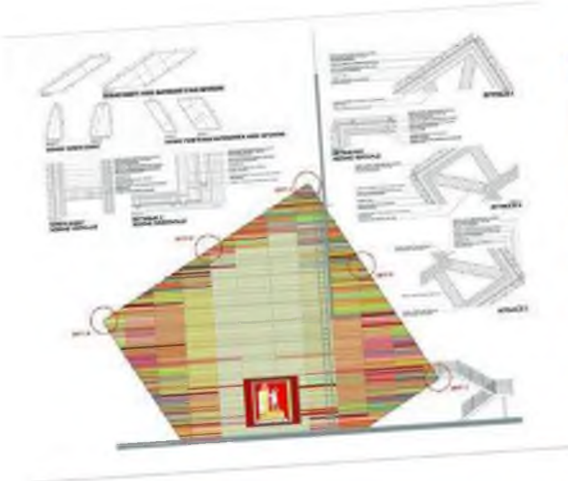


When Bridport House in London was constructed in 2011, it was the largest contemporary timberbuilt apartment block in the world. The CLT construction was completed in 12 weeks, by four skilled laborers and one supervisor.

Karakusevic Carson Architects

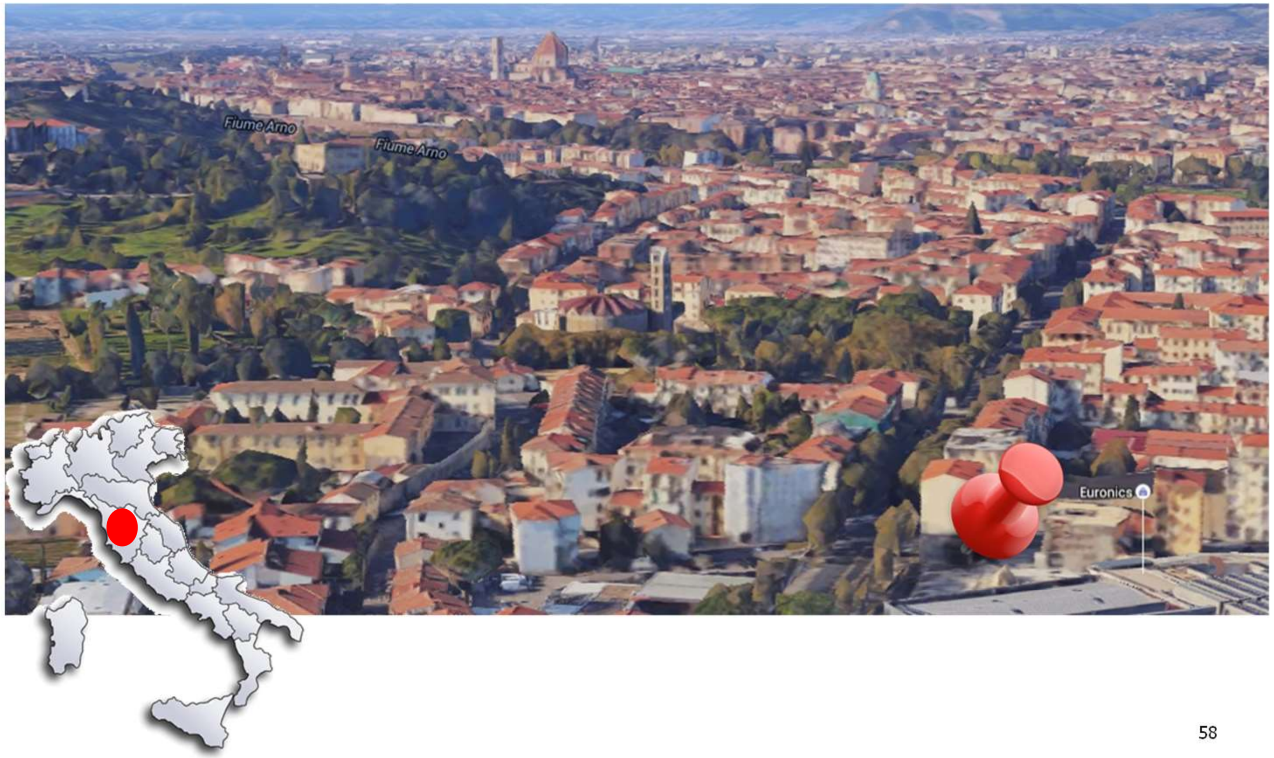
Auditorium de l’Aquila (Italy), arch. Renzo Piano


SEZIONE LONGITUDINALE

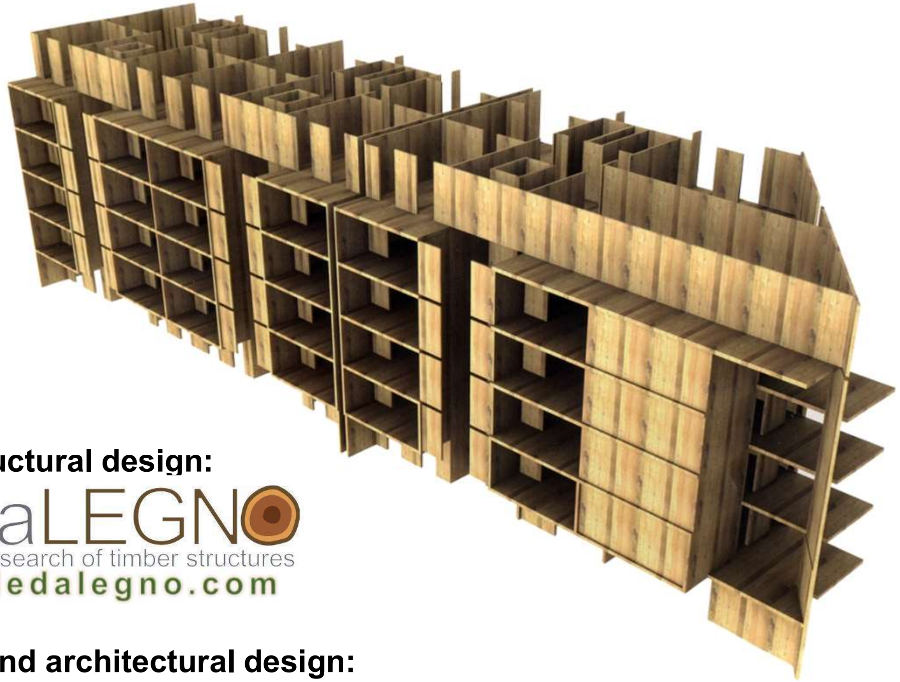


6 Storey residential CLT Buildings in Florence

Located near the historical city center of Florence.



6 Storey residential CLT Buildings in Florence



CLT Structural design:

dedaLEGNO
design & research of timber structures
www.dedalegno.com

Owner and architectural design:

CASA SPA

SOCIAL HOUSING
COMPANY OF
FLORENCE

Builder:

CAMPIGLI LEGNAMI
LEGNO E INGEGNO

6 Storey residential CLT Buildings in Florence

6 storey CLT & 1RC+3CLT storey
public residential building

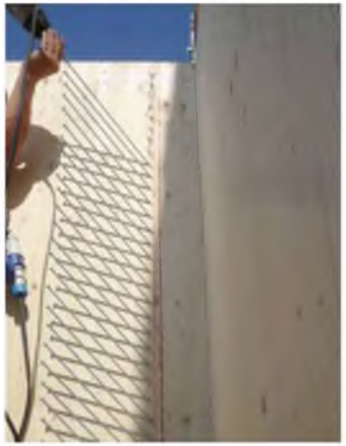
39+6=45 apartments

6 Storey residential CLT Buildings in Florence

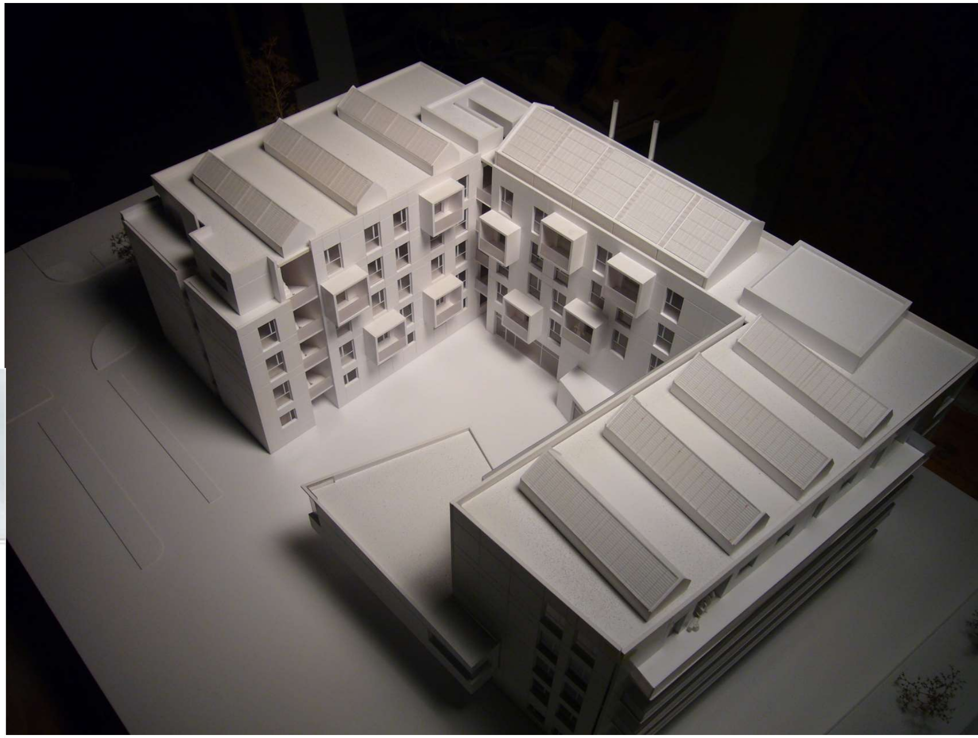
6 storey building construction time: 4.5 months

Via Cenni, in Milano, Italy (arch. F. Rossi-Prodi)


Progetto: Prof. Arch. Fabrizio Rossi Prodi - MILANO - VIA CENNI



Opera Universitaria Trento, Italy (arch. M. Scartezzini)



OPERA UNIVERSITARIA
PROVINCIA AUTONOMA DI TRENTO


OMIS


essepi
XXL


XXL
XXL
XXL


essepi
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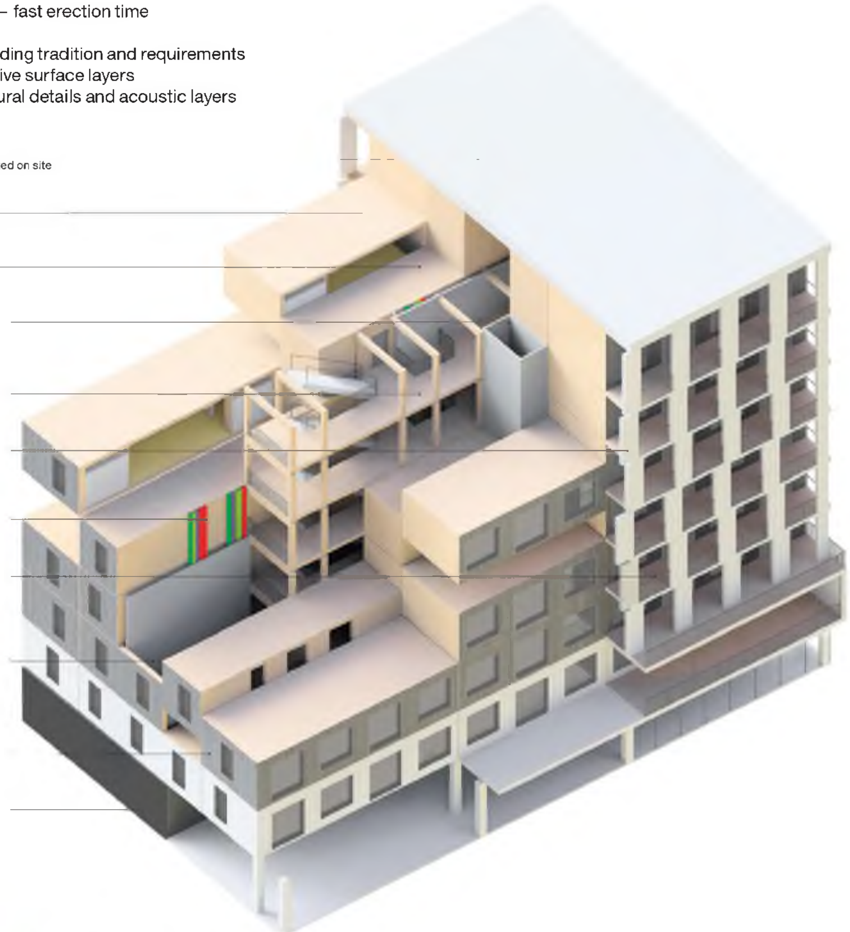
XXL
SISTEMI X-LAM

Stora Enso modular building system

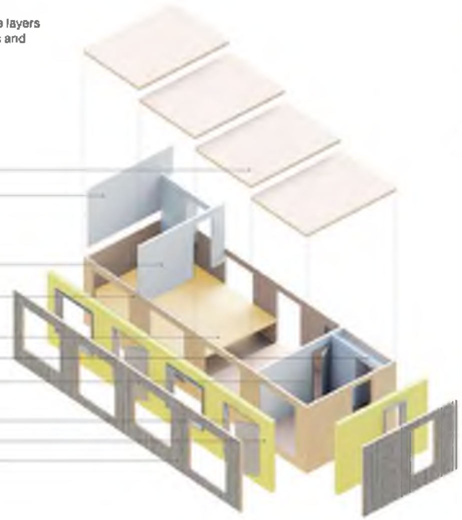
2.1 Anatomy of a modular building

- Ready-made modules and optimised details — fast erection time
- Stiff and rigid central core
- The system can be localised to meet local building tradition and requirements
- Fire safety with massive wood and fire protective surface layers
- Acoustic performance with engineered structural details and acoustic layers



2.2 Anatomy of a modular element

- Prefabricated in factory conditions
- Finished surfaces, pre-fitted technical installations and pre-installed fixtures and fittings
- Basic modules:
  - room module (living room, bedroom, dining room, workspace)
  - technical module (kitchen, bathroom, toilet)
- Fire safety with massive wood and fire protective surface layers
- Acoustic performance with engineered structural details and acoustic layers



FORTÉ
VICTORIA HARBOUR
MELBOURNE

- **Scale:** 9 stories, 23 apartments
- **Build Period:**
  Start on site: February 2012
  Begin CLT installation: June 2012
  CLT structure complete: Aug 2012
  Practical completion: December 2012
- **Architect:** Lend Lease
- **CLT supplier:** KLH

Lend Lease

SHIPPING A BUILDING FROM EUROPE TO AUSTRALIA

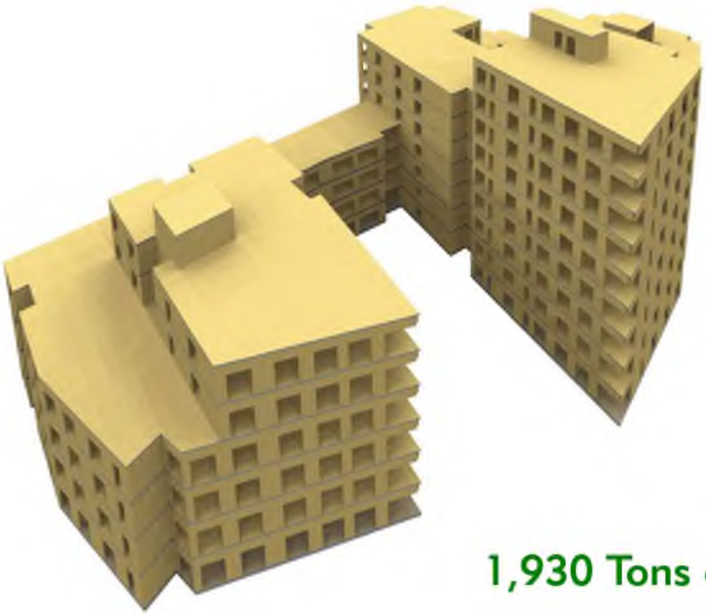
KLH Factory

Koper Slovenia

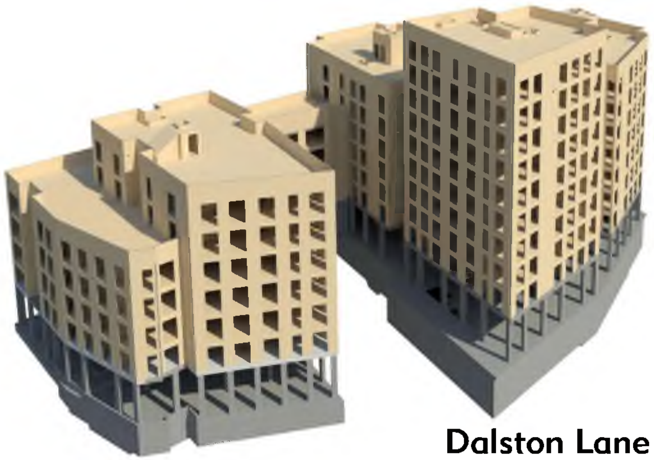
Suez canal

Port Melbourne
– Australian Customs

Shed at Victoria Harbour
– LL IKEA



1,930 Tons of timber



architects Waugh Thistleton

Dalston Lane
2015


theB1M
COURTESY OF WAUGH THISTLETON

Banyan Wharf, London, Uk

B&K STRUCTURES

OPTIMISED HYBRID SOLUTIONS

Finland,
8 floors
OOPEAA architects

Paris, St. Denis, France
Bureau d’etudes Arpente
CLT supplier KLH

COMBLES


Catania, Italy, Scuola Empedocle, Costyedil Timber Wood

Dante O. Benini & Partners | Architects

Milano, university degli studi Milano – Bicocca
15 floors







Amsterdam, team V architectuur

21 floors

…recently, Arup was selected to develop 'HAUT', a project in development which — at 21 floors — would become the highest wooden residential building in the world

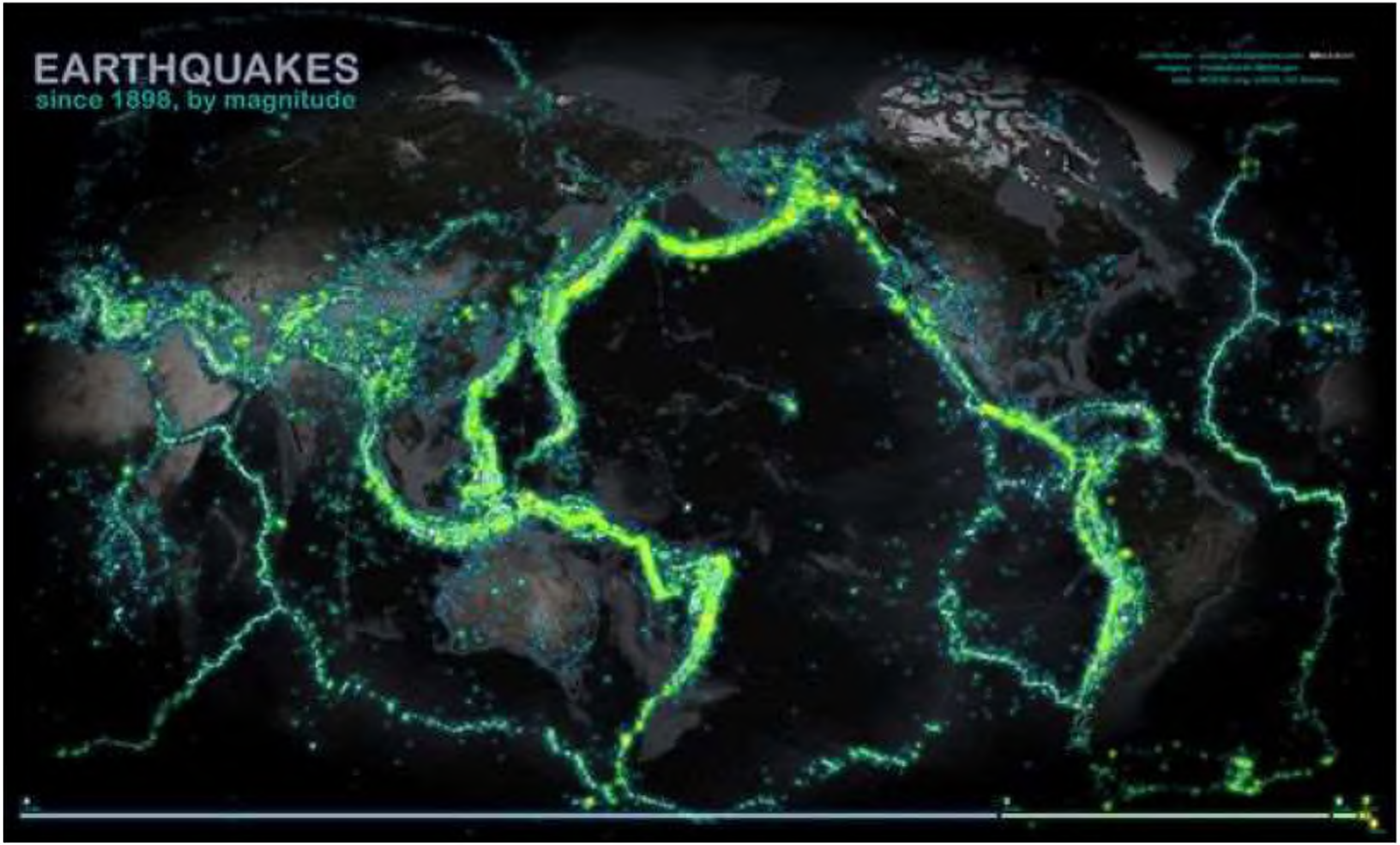
Stockolm, Anders-Berensson architects

40 storeys CLT buiding

In 2016 PLP Architecture proposes London's first wooden skyscraper

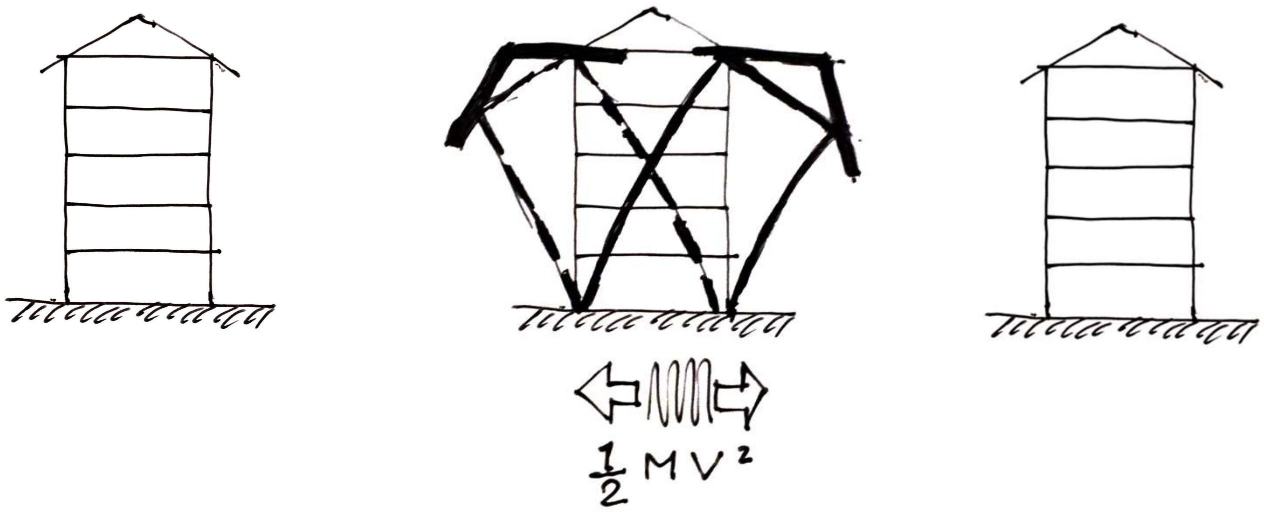
80 storey, 300 metre high timber building !

"London's first timber skyscraper could be a step closer to reality as city engineers are finalizing their evaluation of a conceptual plans for an 80-storey, 300-meter high wooden building integrated within the Barbican" (***Homeland Security News Wire*** April 2017)


EARTHQUAKES
since 1898, by magnitude

So, how come?

before | during | after the quake

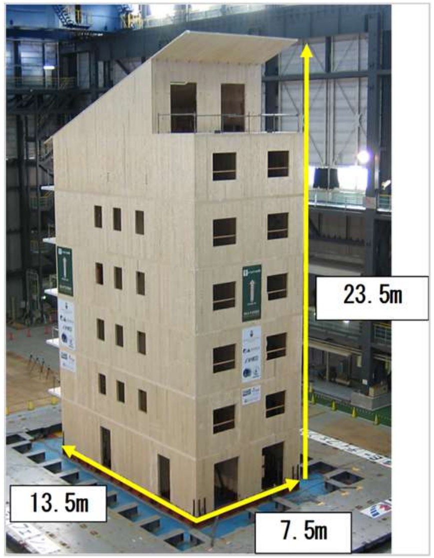


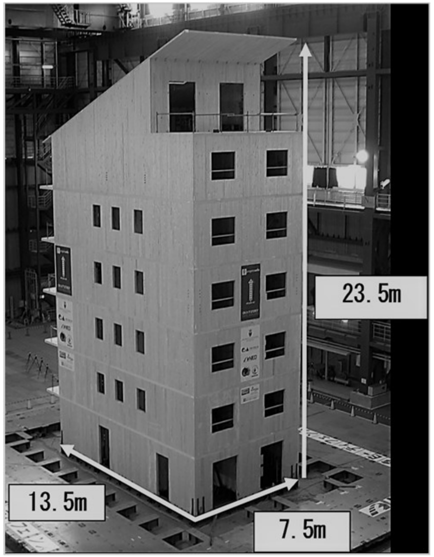
A - the building weight is modest
compared to a similar-shape reinforced building (≈ 1/3 ÷ 1/4)

B - the total energy input at the base of the building is dissipated
within the structure prior its collapse

A

a wood structure is ligther than an “equivalent” reinforced concrete structure





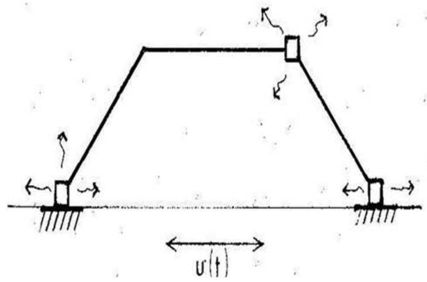
e.g.

- A, Wood structure self weight: 120 tons
- B, Reinforced concrete structure self weight: 600 tons
- C, Additional permanent weight + service load: 150 tons

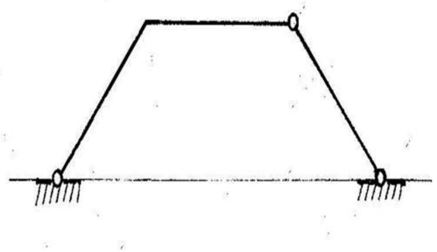
- **ratio B+C/A+C ≈ 3**

B

the total energy input at the base of the building is dissipated



before the quake

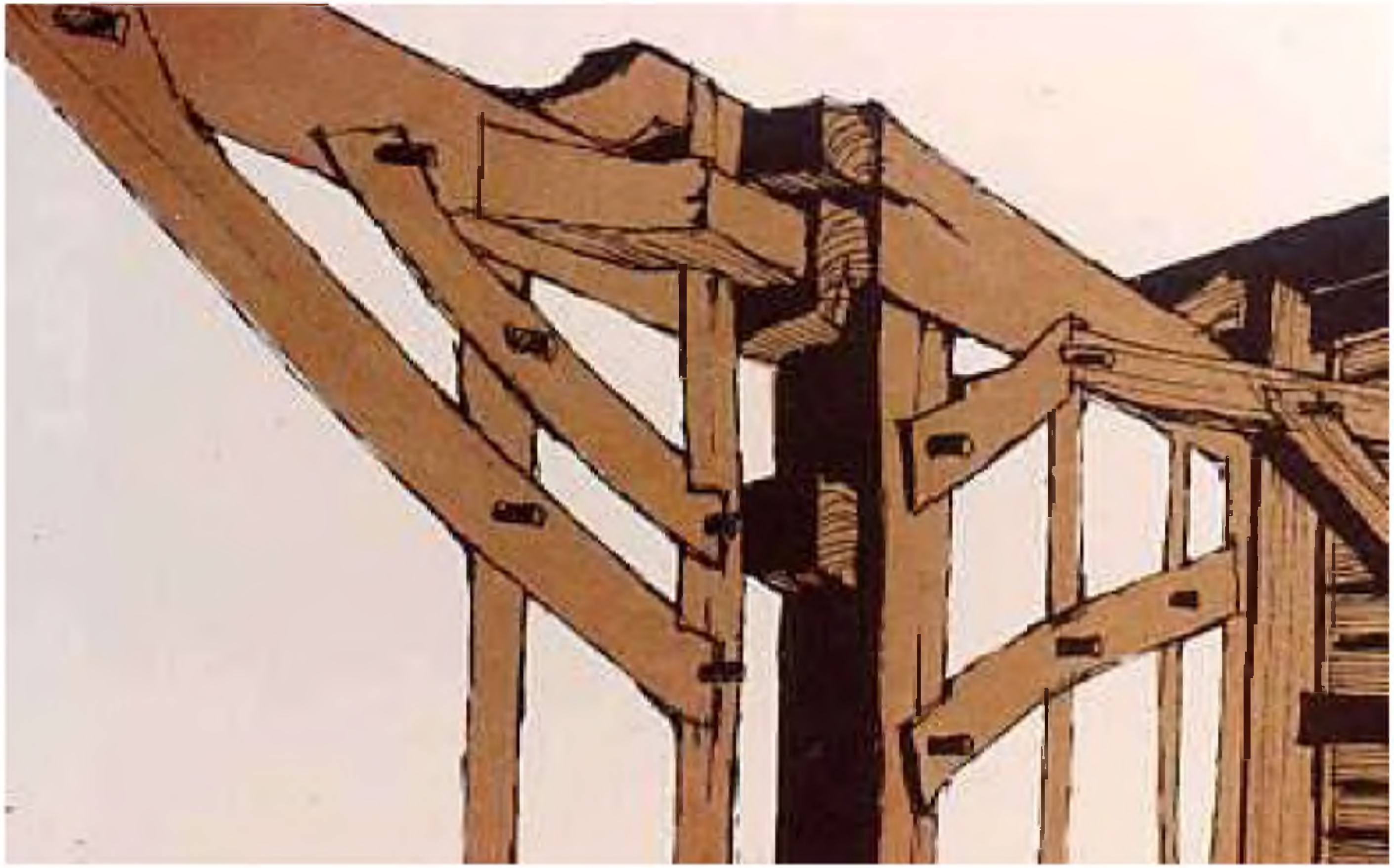


after the quake…

e.g.

- by plastic deformations within mechanical connections…

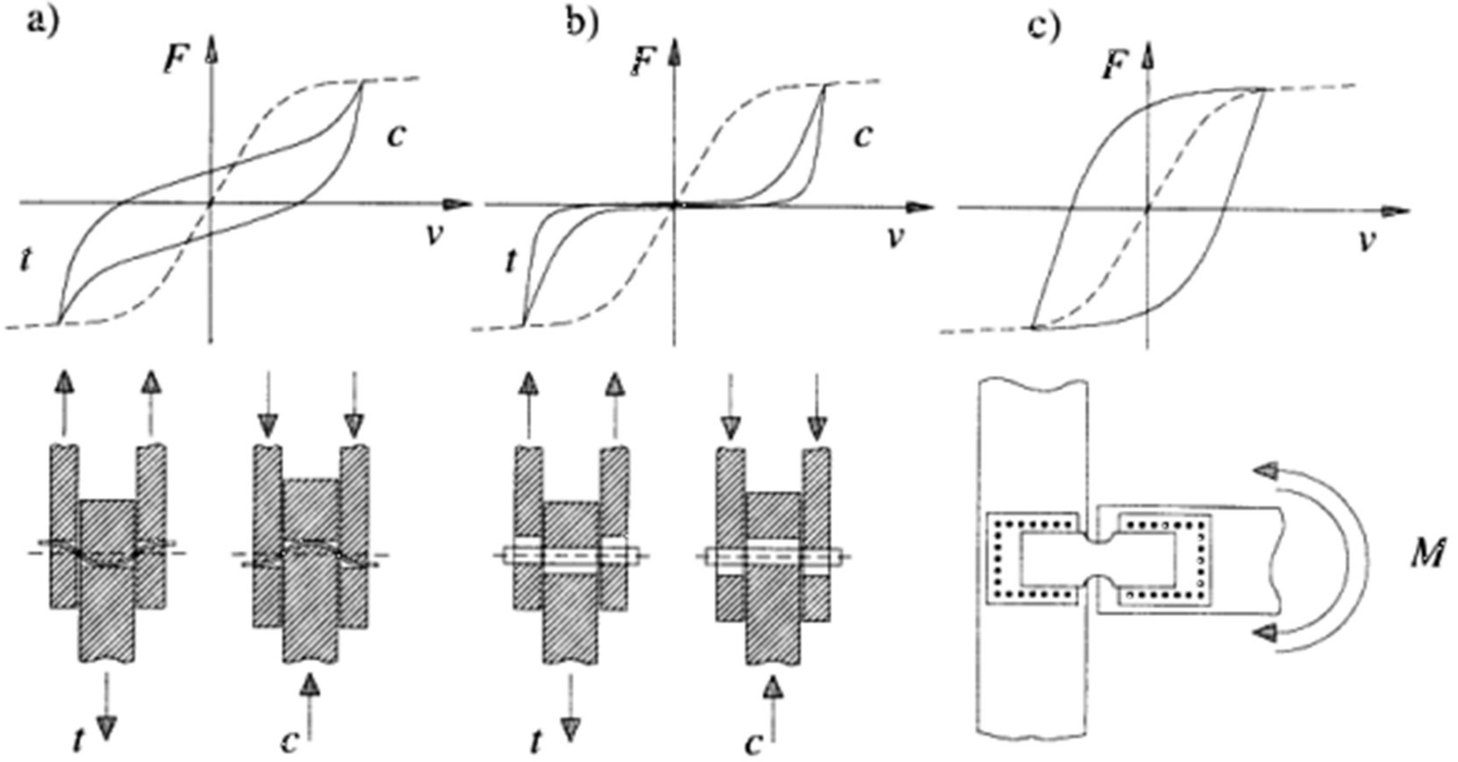
energy is dissipated
e.g.
by friction within elements…



energy is dissipated

e.g.

by plastic deformation of mechanical connections …



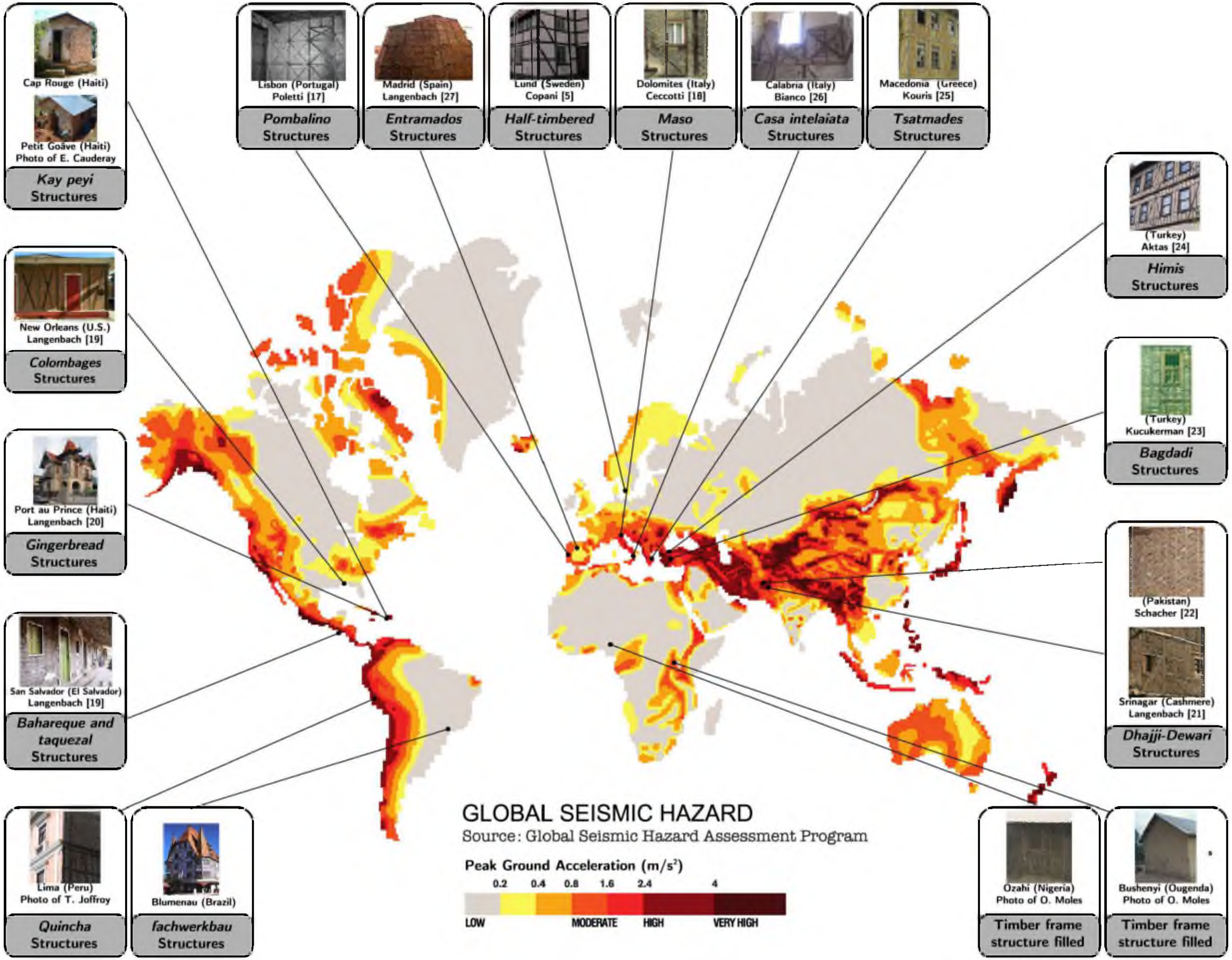
NB: the area of the "hysteresis" cycles measures the quantity of dissipated energy

wood has been successfully used for high-rise buildings in very high intensity seismic zones

Experience from the past…

Japan

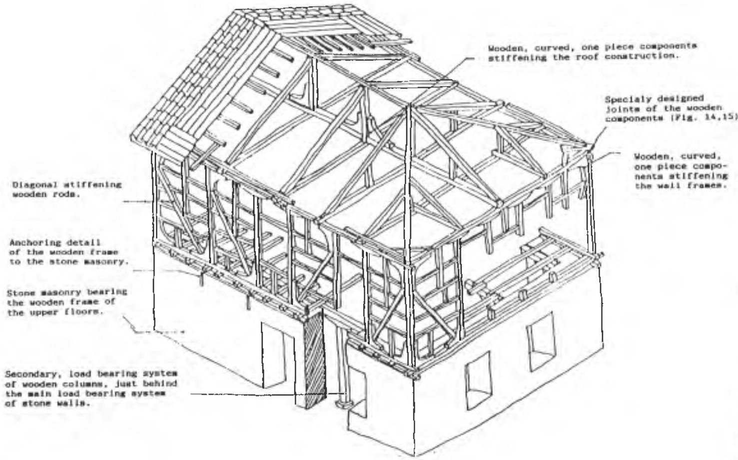
China



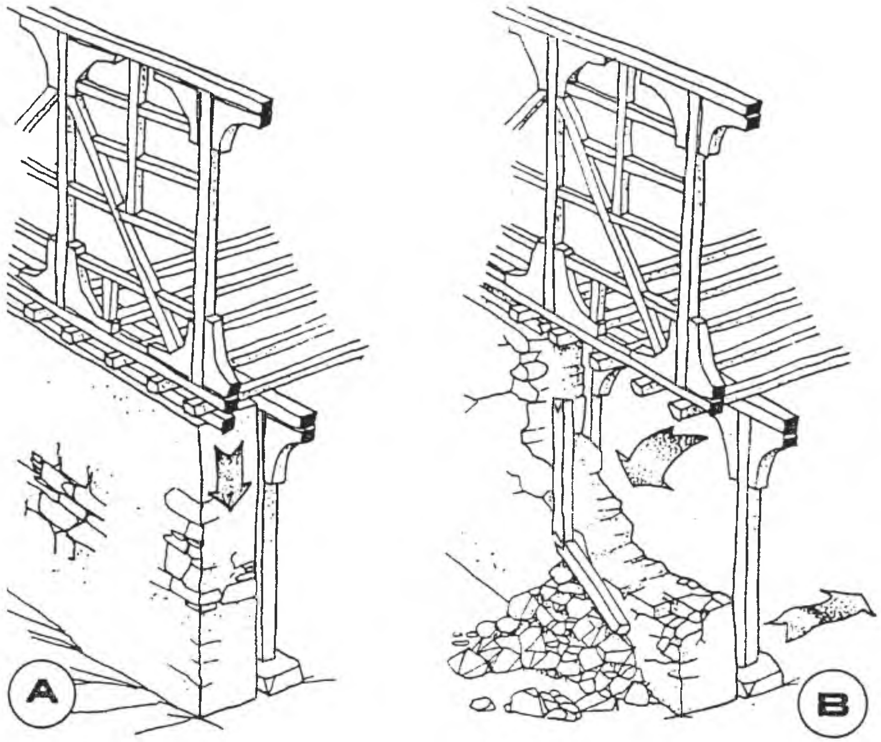
Cap Rouge (Haiti)
Petit Goâve (Haiti)
Photo of E. Cauderay
Kay peyi
Structures
Lisbon (Portugal)
Poletti [17]
Pombalino
Structures
Madrid (Spain)
Langenbach [27]
Entramados
Structures
Lund (Sweden)
Copani [5]
Half-timbered
Structures
Dolomites (Italy)
Ceccotti [18]
Maso
Structures
Calabria (Italy)
Bianco [26]
Casa intelaiata
Structures
Macedonia (Greece)
Kouris [25]
Tsatmades
Structures
(Turkey)
Aktas [24]
Himis
Structures
New Orleans (U.S.)
Langenbach [19]
Colombages
Structures
(Turkey)
Kucukerman [23]
Bagdadi
Structures
Port au Prince (Haiti)
Langenbach [20]
Gingerbread
Structures
(Pakistan)
Schacher [22]
San Salvador (El Salvador)
Langenbach [19]
Bahareque and
taquezal
Structures
Srinagar (Cashmere)
Langenbach [21]
Dhajji-Dewari
Structures
GLOBAL SEISMIC HAZARD
Source: Global Seismic Hazard Assessment Program
Peak Ground Acceleration (m/s²)
0.2
0.4
0.8
1.6
2.4
4
LOW
MODERATE
HIGH
VERY HIGH
Lima (Peru)
Photo of T. Joffroy
Quincha
Structures
Blumenau (Brazil)
fachwerkbau
Structures
Ozahi (Nigeria)
Photo of O. Moles
Timber frame
structure filled
Bushenyi (Ougenda)
Photo of O. Moles
Timber frame
structure filled


(photo: Langenbach, R.)

Portugal



Wooden, curved, one piece components stiffening the roof construction.
Specialy designed joints of the wooden components (Fig. 14,15)
Wooden, curved, one piece components stiffening the wall frames.
Diagonal stiffening wooden rods.
Anchoring detail of the wooden frame to the stone masonry.
Stone masonry bearing the wooden frame of the upper floors.
Secondary, load bearing system of wooden columns, just behind the main load bearing system of stone walls.



A
B

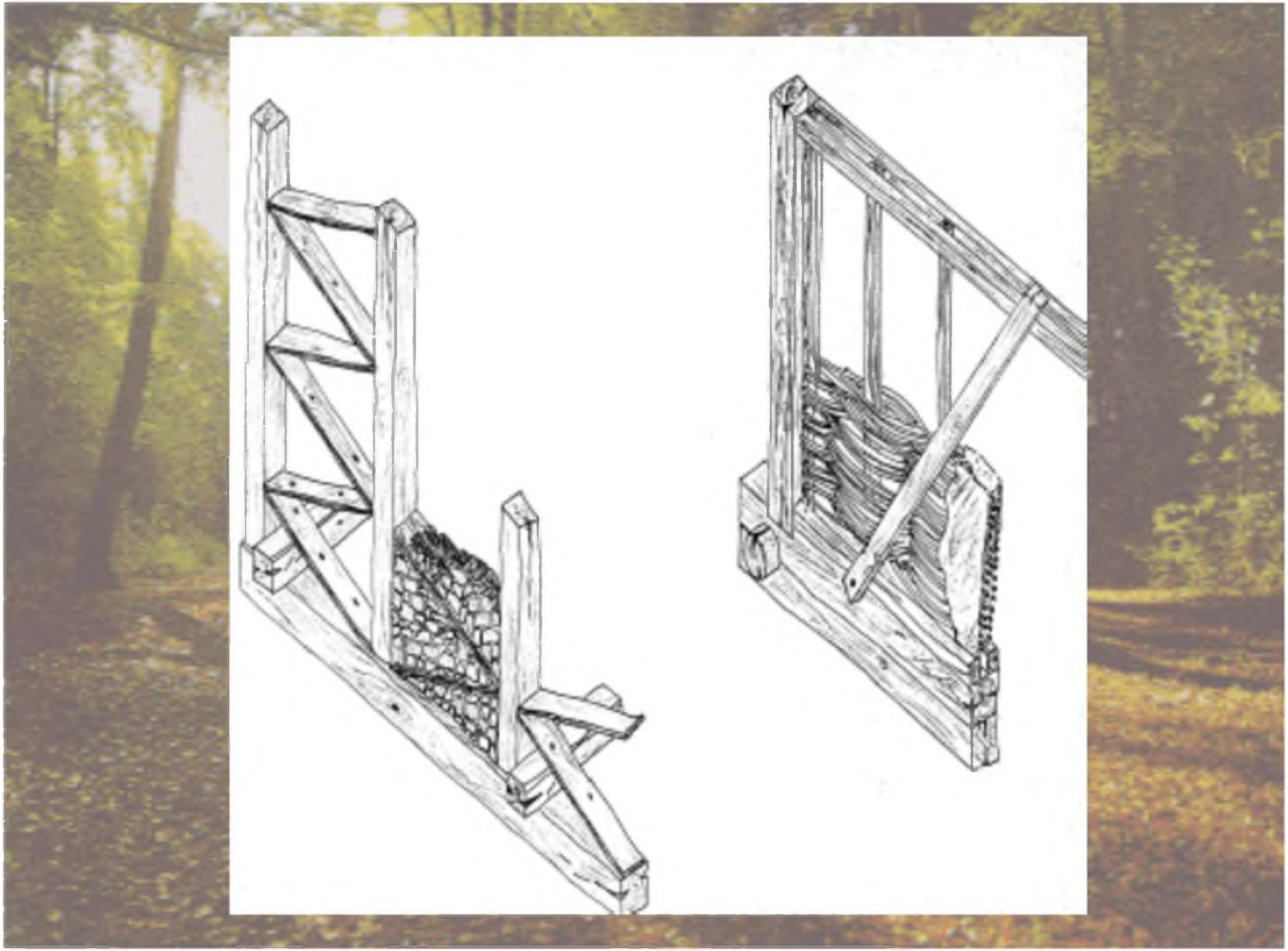
Turkey

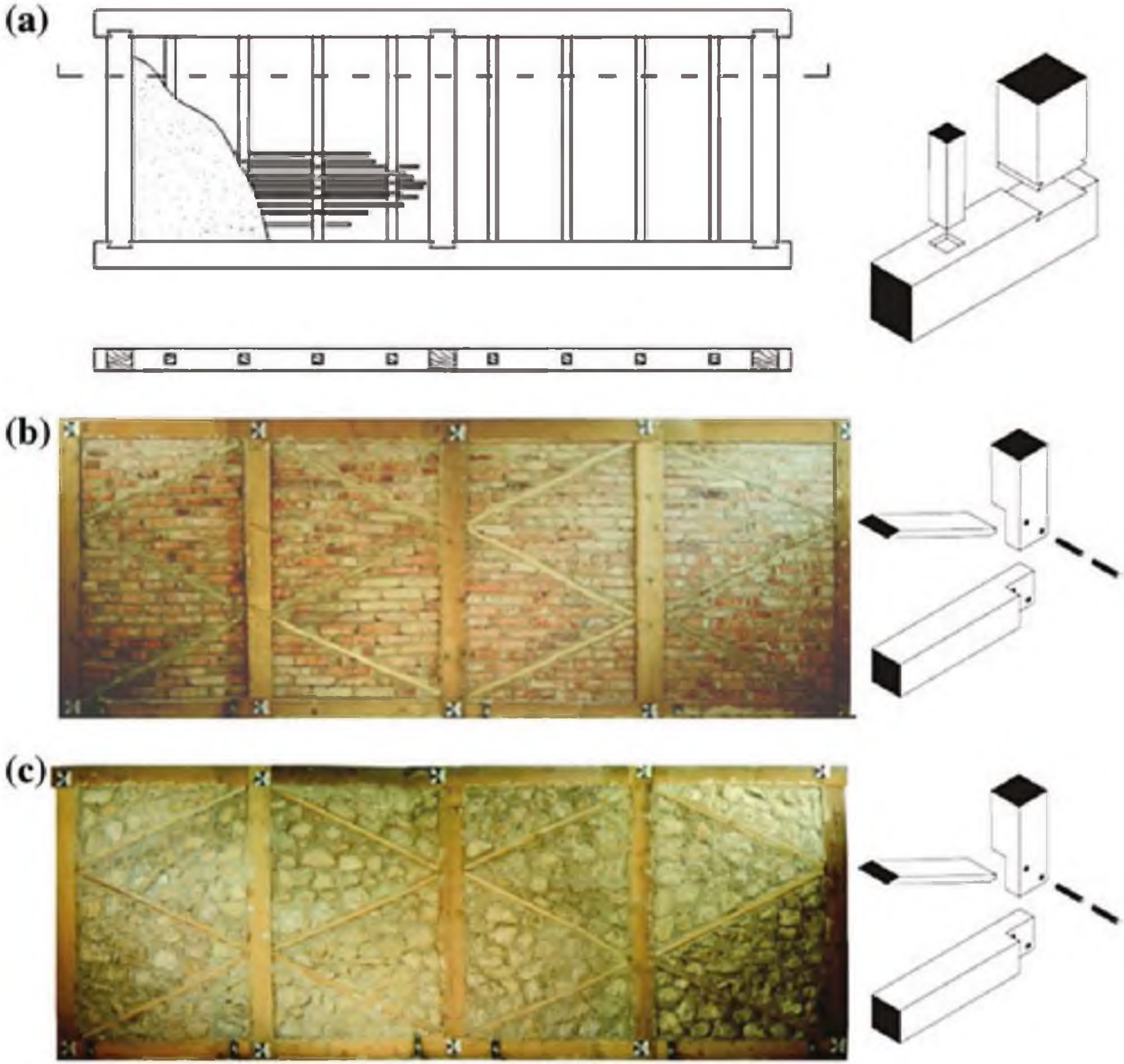
(photo: Diskaya, H.)

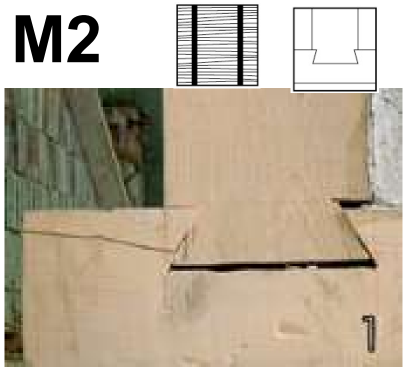
By courtesy of R. Langenbach

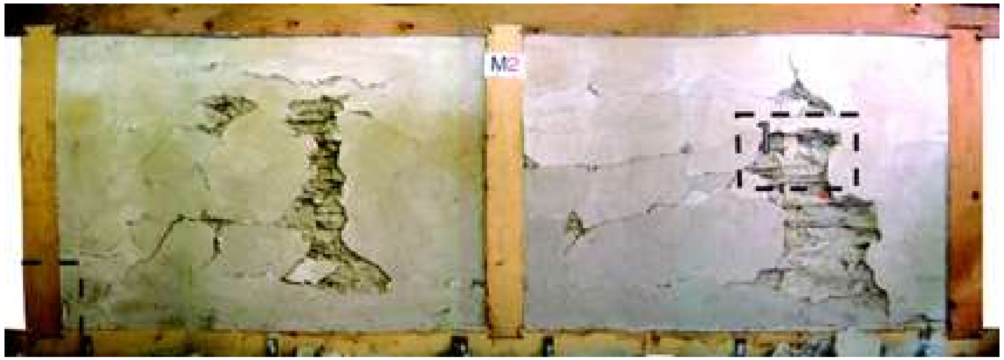
By courtesy of R. Langenbach

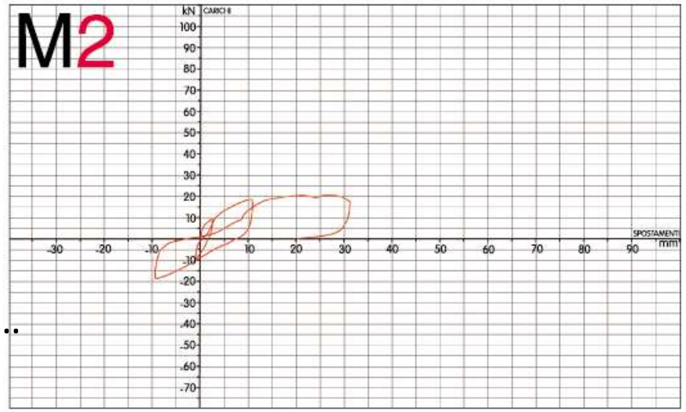
Dolomites houses, Northern Italy



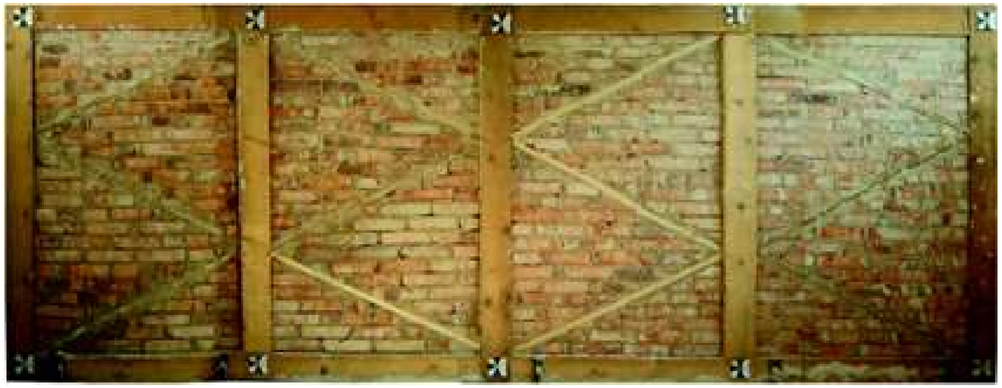

(a)
(b)
(c)

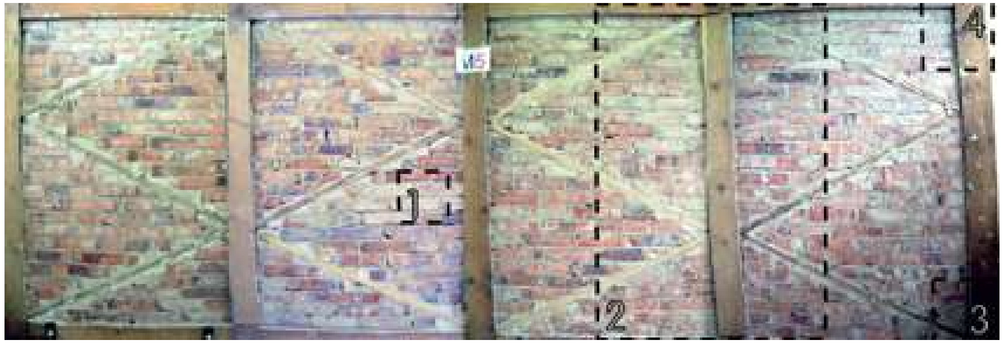




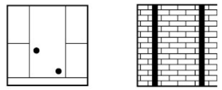


Laboratory tests on Dolomites houses walls…




M5
1
2
3
4

M5



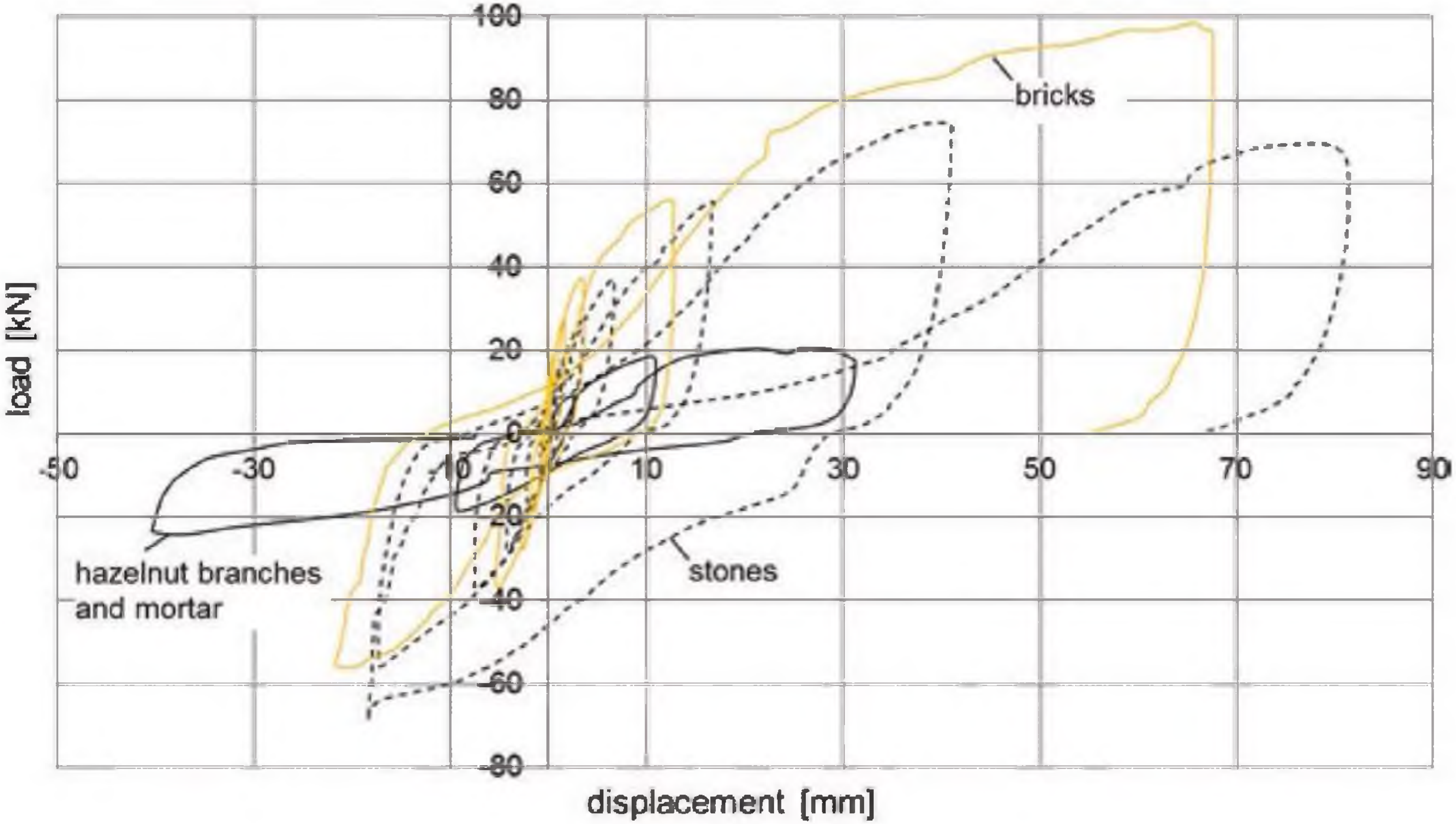

1


2


3


15x15
4


M5
kN
CARICHI
SPOSTAMENTI
mm
100
90
80
70
60
50
40
30
20
10
-10
-20
-30
-40
-50
-60
-70
-30
-20
-10
10
20
30
40
50
60
70
80
90



load [kN]
displacement [mm]
bricks
stones
hazelnut branches and mortar
100
80
60
40
20
0
-20
-40
-60
-80
-50
-30
-10
10
30
50
70
90

numerical tests on Dolomites houses walls…

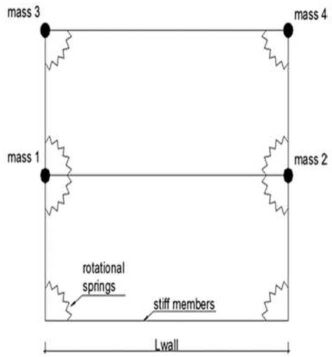


Fig. 9.6 2D model of traditional timber frame

Building Vulnerability **can be evaluated in a quantitively way**

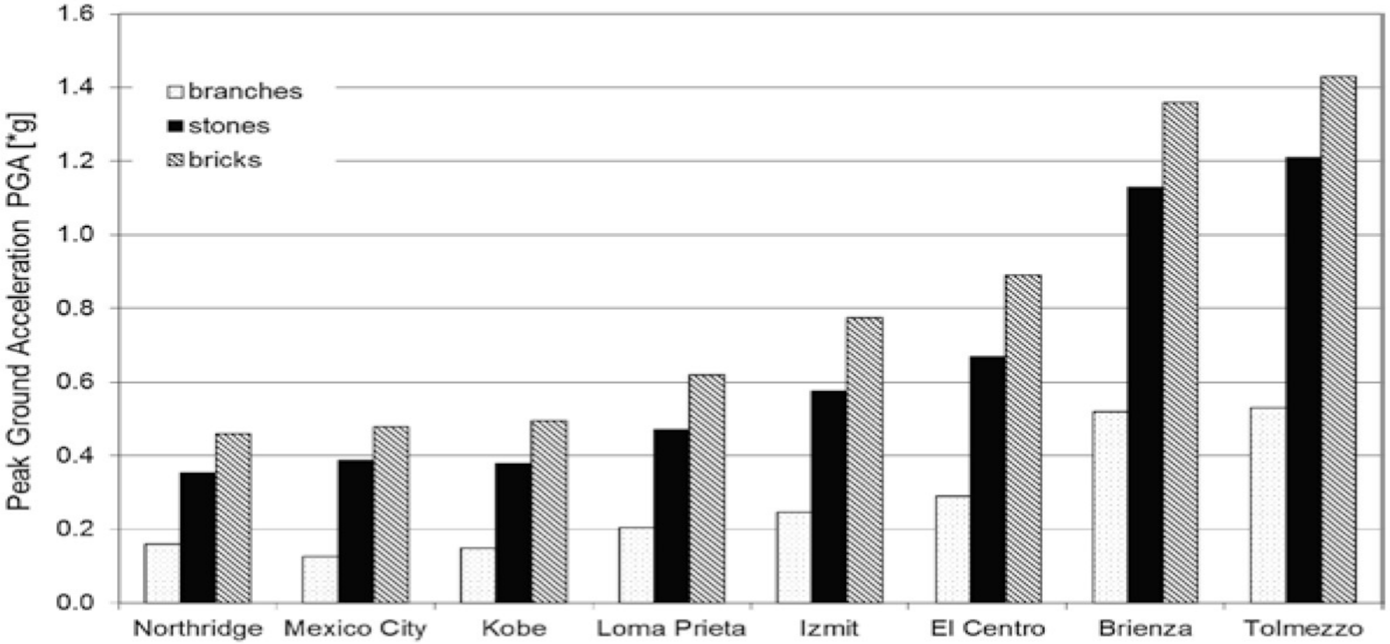


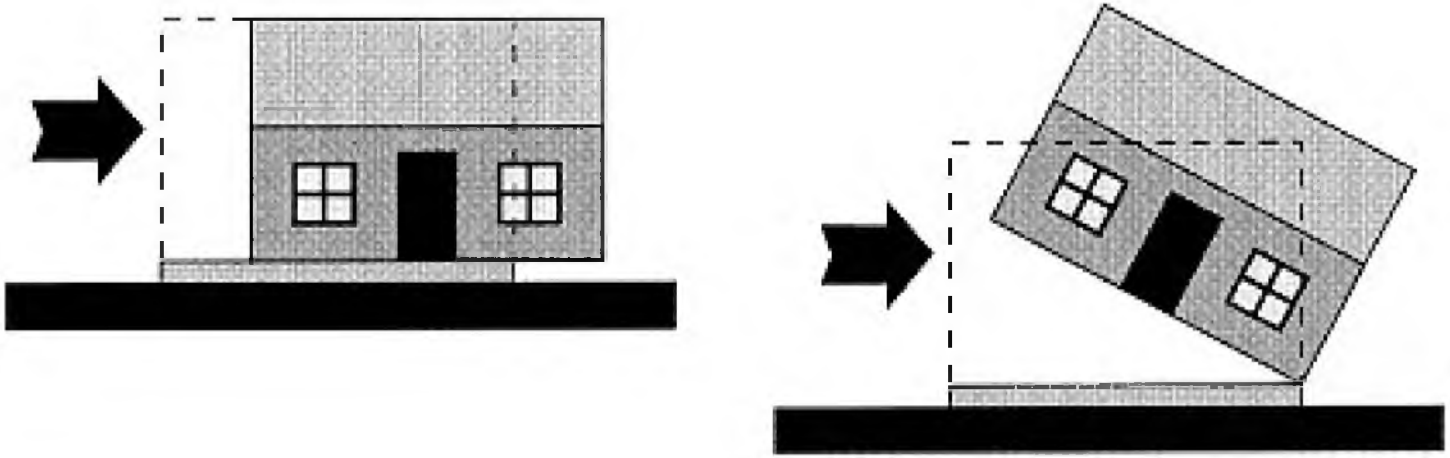
Fig. 9.7 Peak ground acceleration at near-collapse state of a two-storey traditional timber frame house

to facilitate the preservation of the Building Heritage

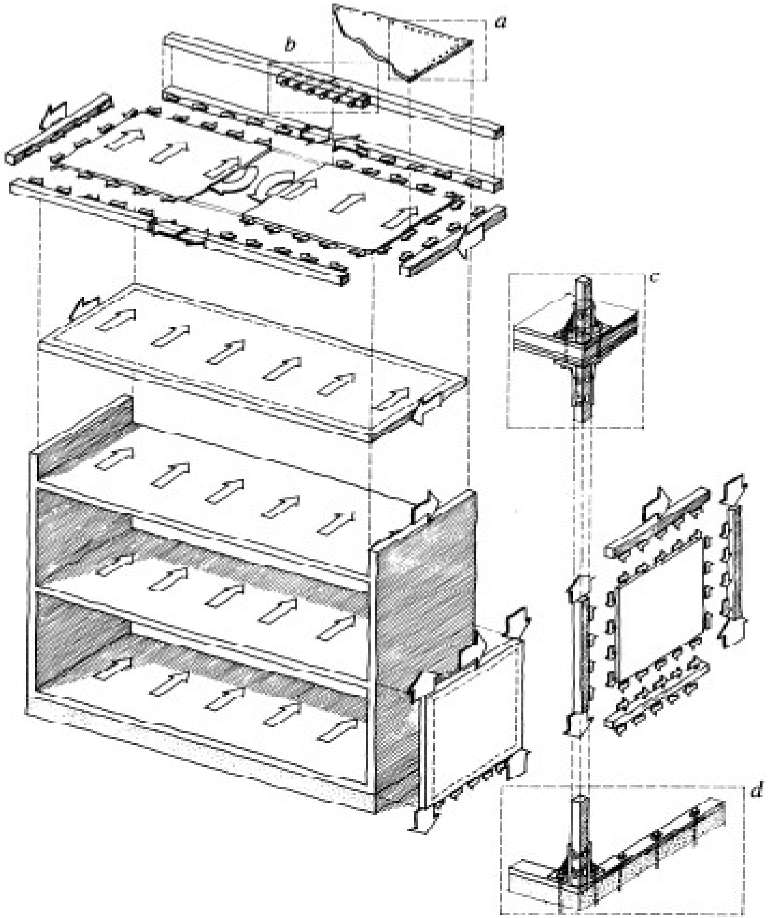
recent experience…

by M.Yasumura

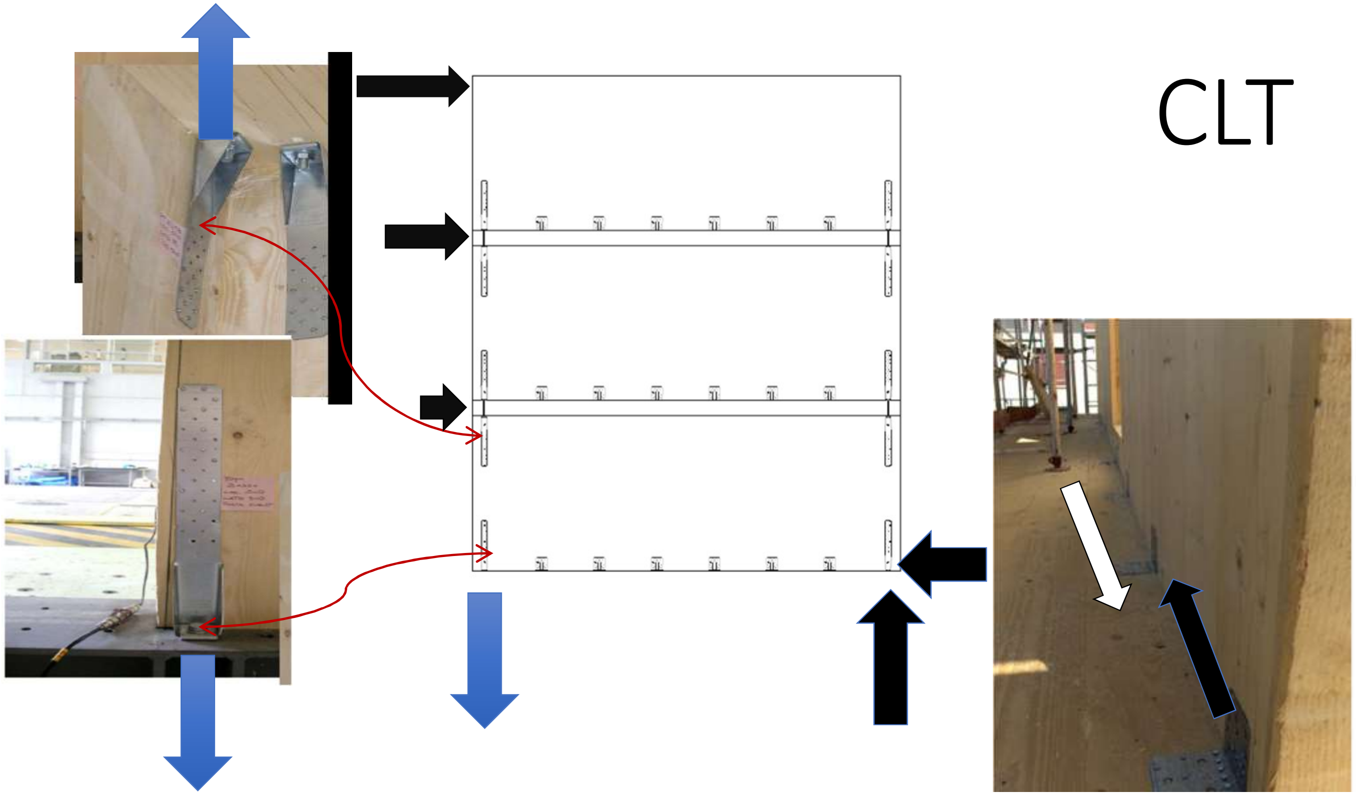

by M.Yasumura



TF



CLT



E-Defense Miki testing laboratories, October 2005

FOWL - Forest and Other Wooded Land

Trentino land 0.62 M ha

Trentino FOWL 0.34 M ha

Share of FOWL 55 %

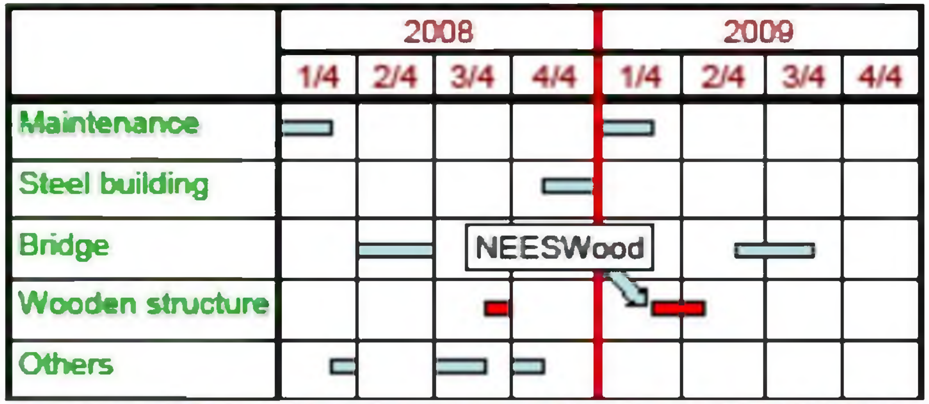
Trentino

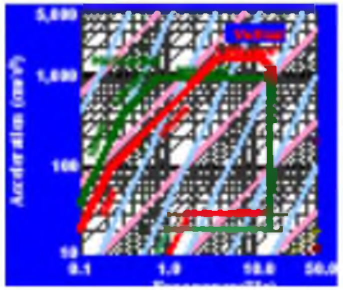
Amount of timber felled annually 100 000 m^3
Capacity of sustainable exploitation 500 000 m^3

The Largest Shake Table in the World "E-Defense"

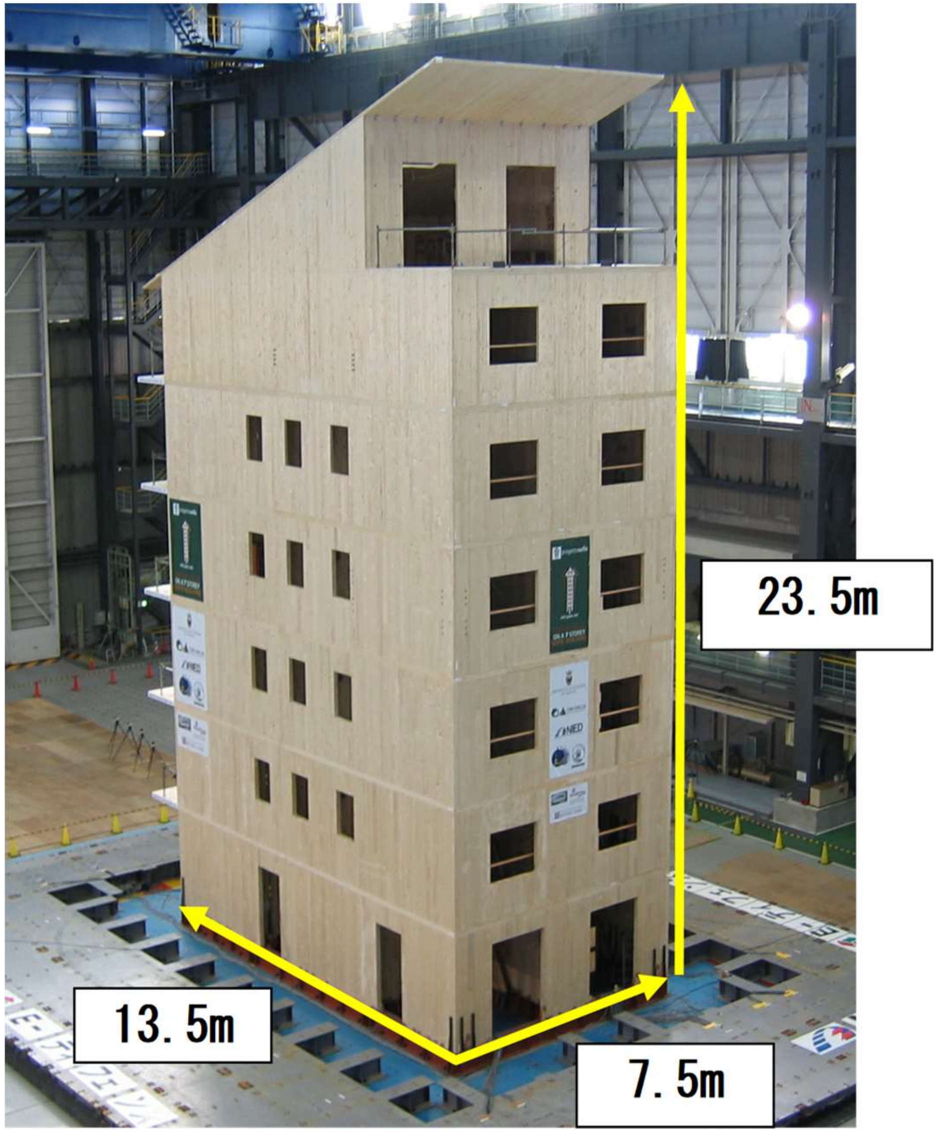
Table Size	*20m x 15m*	
Payload	*12MN(1200ton)*	
Shaking Direction	*X, Y - Horizontal*	*Z - Vertical*
Max. Acceleration (at Max. Loading)	*900cm/s²*	*1500cm/s²*
Max. Velocity	*200cm/s*	*70cm/s*
Max. Displacement	*±100cm*	*±70cm*

2008-2009 Schedule of E-Defense

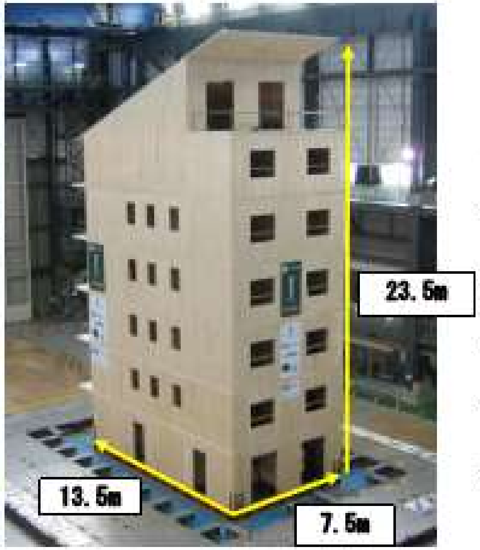


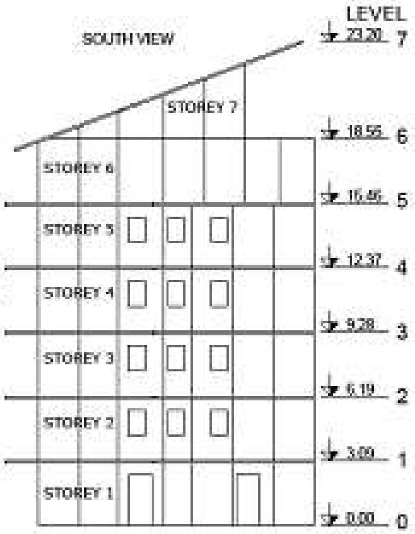


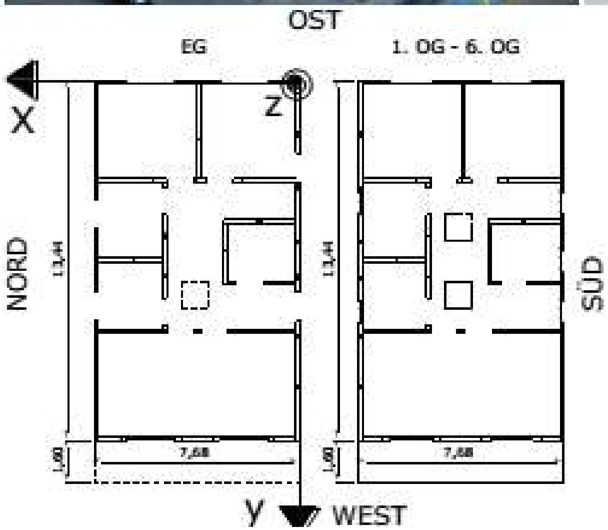
SEISMIC TESTS IN MIKI (JP) 2007, OCT 23

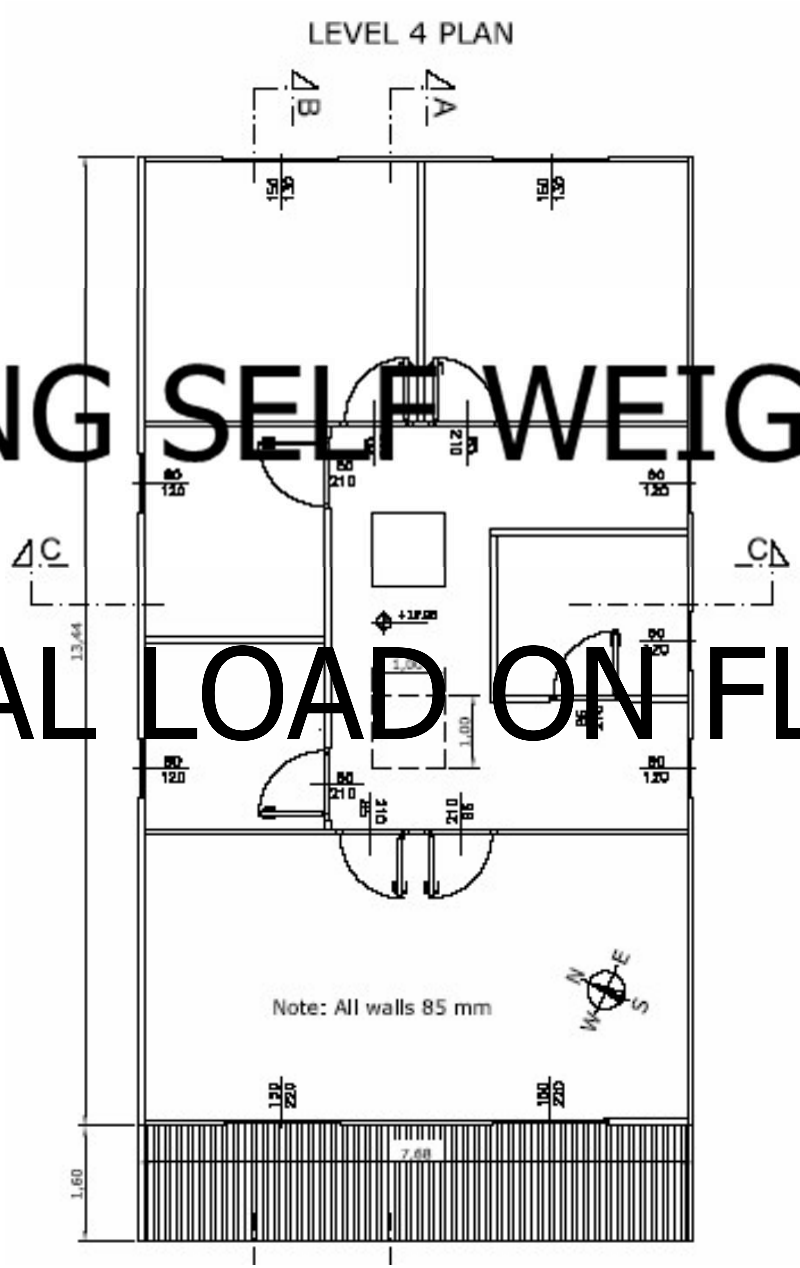


CLT seven storey building design









BUILDING SELF WEIGHT 120 t

ADDITIONAL LOAD ON FLOORS 150 t

Level	z_i (m)	m_i (tonne)	F_i (kN)	$\sum F_i$ (kN)
6	18.55	20.1	488	488
5	15.46	48.1	974	1462
4	12.37	51.3	831	2293
3	9.28	53.5	650	2943
2	6.19	55.4	449	3392
1	3.01	61.2	247	3639

(a) X-z plane

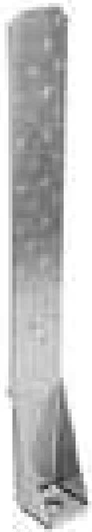
Level	z_i (m)	m_i (tonne)	F_i (kN)	$\sum F_i$ (kN)
6	18.55	20.1	357	357
5	15.46	48.1	713	1070
4	12.37	51.3	608	1678
3	9.28	53.5	476	2154
2	6.19	55.4	328	2482
1	3.01	61.2	181	2663

(b) Y-z plane

Fig. 7.16 – Lumped m_i and associated z_i values, and calculate F_i and $\sum F_i$ values

connections

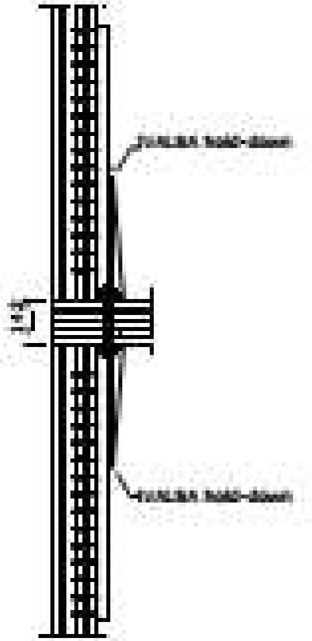
(a)



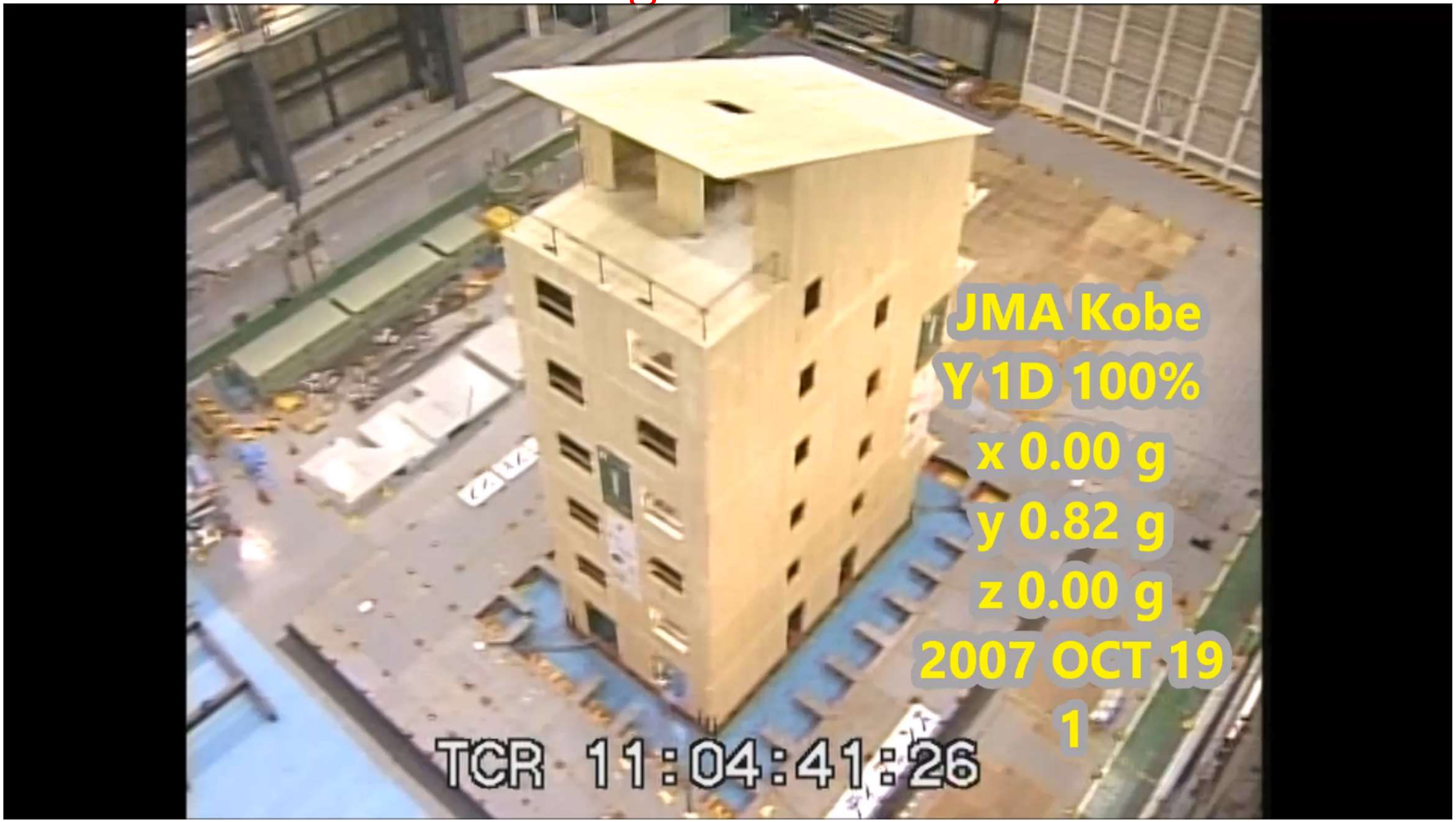
(b)

(c)

(d)



E-Defense Miki testing laboratories, October 2007



Low Residual Deformations:

re-thinking seismic design…

"safety of life"

F1
Grand prix de Belgique 2012

Resilience, the new challenge in earthquake engineering

16th. World Conference on Earthquake Engineering

Santiago Chile , 2017

The motto of the Conference was:

Resilience → i.e.: **"immediate occupancy"**

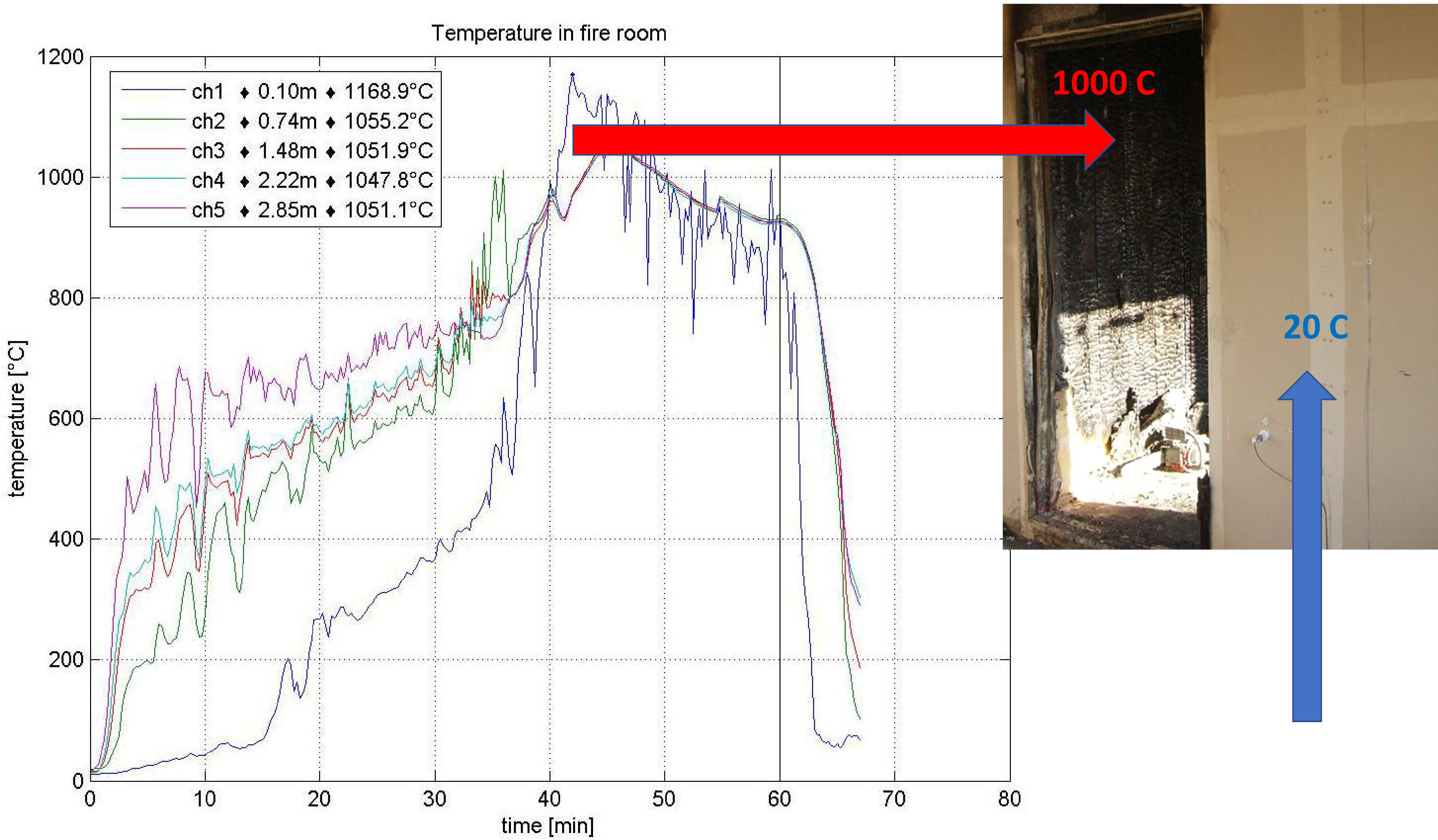
This motto means that the actual seismic design criteria of "**safety of life**" requesting that buildings do not collapse must be replaced by codes that allow cities to continue operating in few days avoiding to evacuate millions of people of a mega-city.

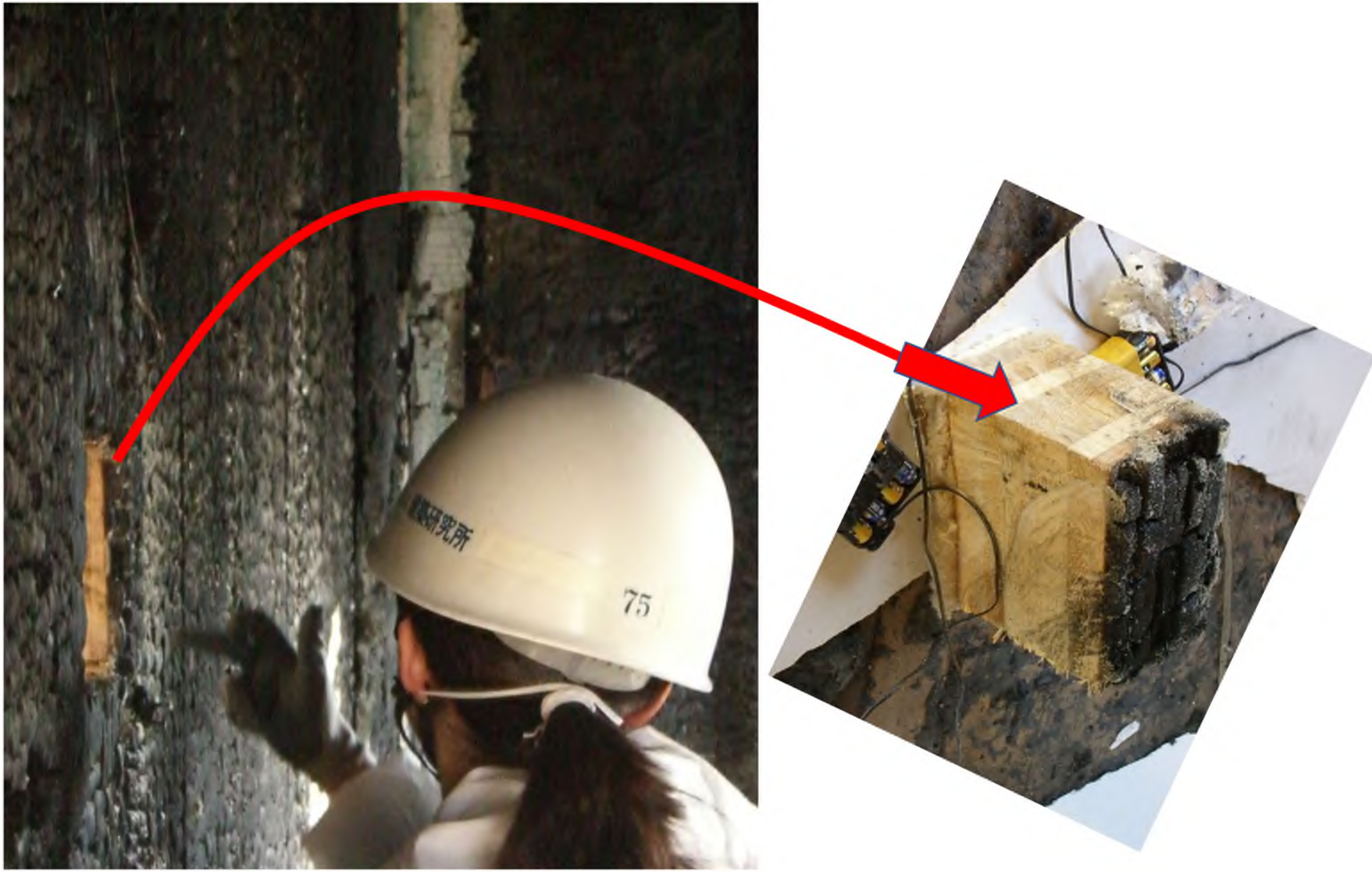
As a civil engineer
I would never say that a construction material is better than an other material, but I can for sure say that:

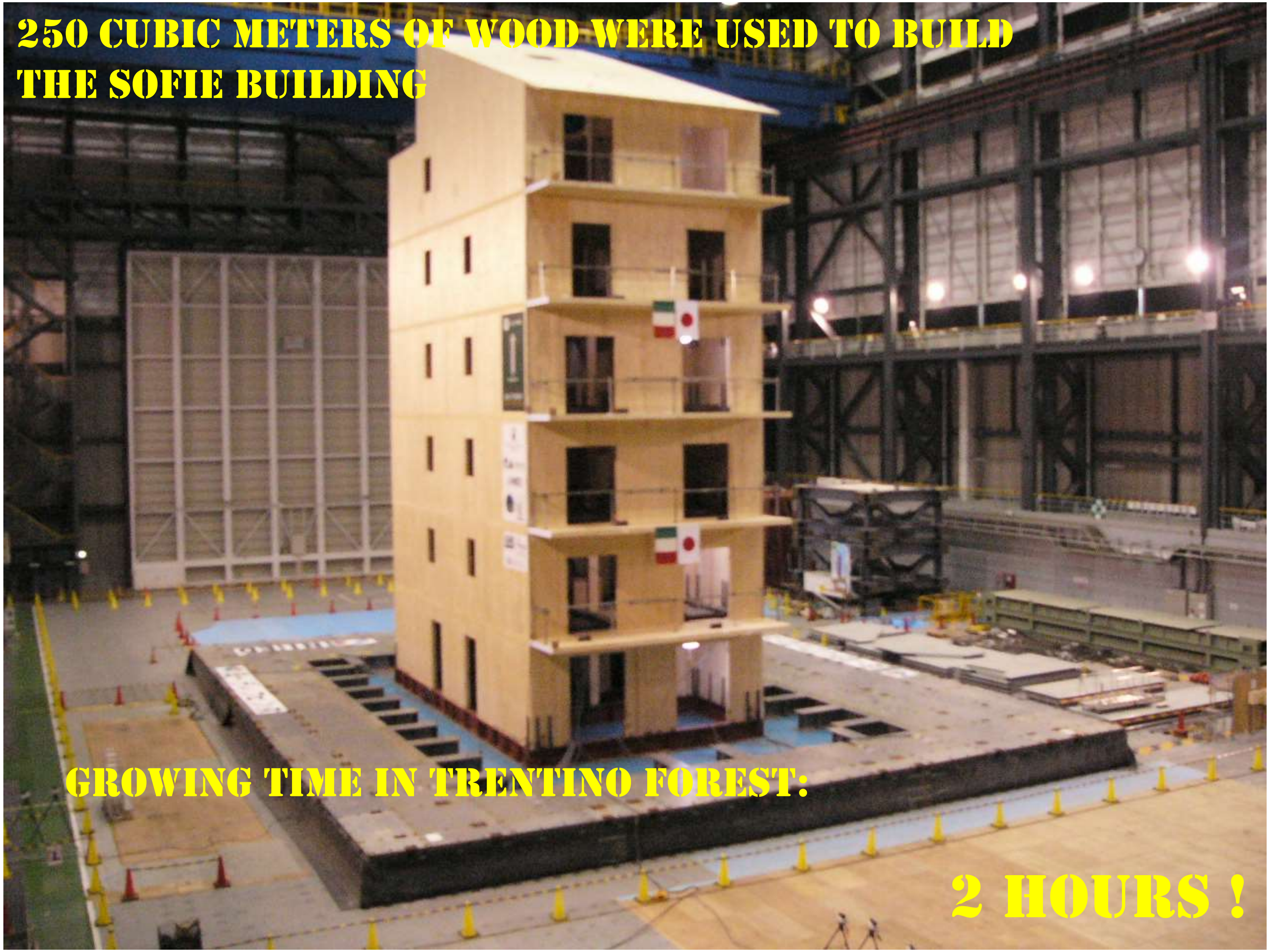
with wood this target - resilience - is reachable at very competitive costs in comparison to traditional materials!

FIRE TEST IN TSUKUBA (JP) MARCH 2007


IVALSA


Temperature in fire room
ch1 ♦ 0.10m ♦ 1168.9°C
ch2 ♦ 0.74m ♦ 1055.2°C
ch3 ♦ 1.48m ♦ 1051.9°C
ch4 ♦ 2.22m ♦ 1047.8°C
ch5 ♦ 2.85m ♦ 1051.1°C
temperature [°C]
time [min]
0
200
400
600
800
1000
1200
0
10
20
30
40
50
60
70
80
1000 C
20 C


75


250 CUBIC METERS OF WOOD WERE USED TO BUILD
THE SOFIE BUILDING
GROWING TIME IN TRENTINO FOREST:
2 HOURS !


250 *PICEA ABIES* SEEDS...

oops... this is the END!

Thank you!