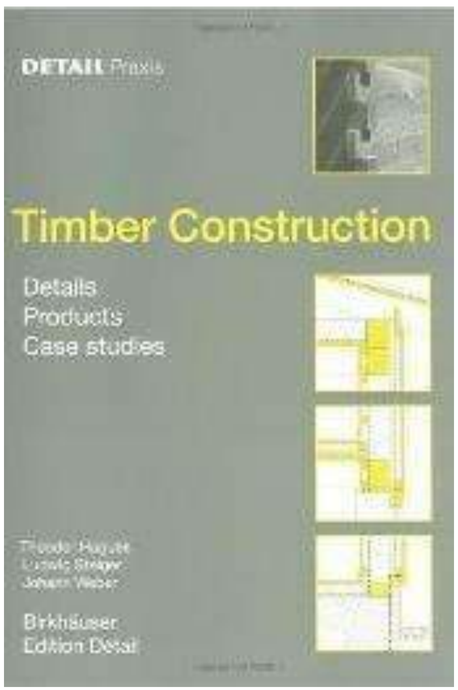
Timber Structures
(material, design & case study)

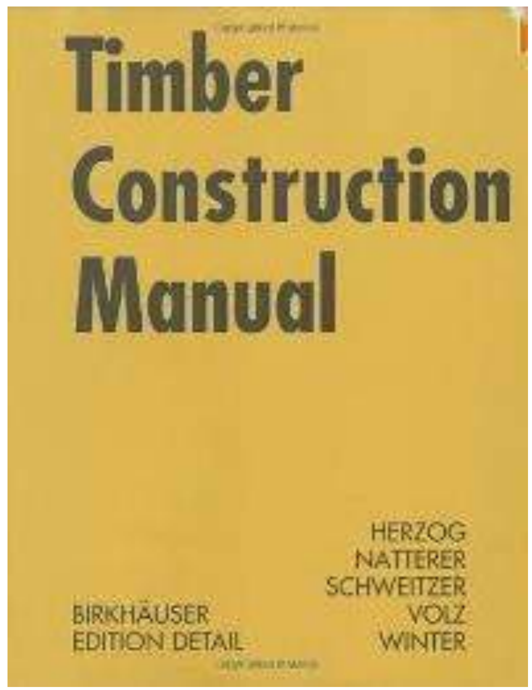
University of Cambridge
Year 2 Architecture
by Simon Smith

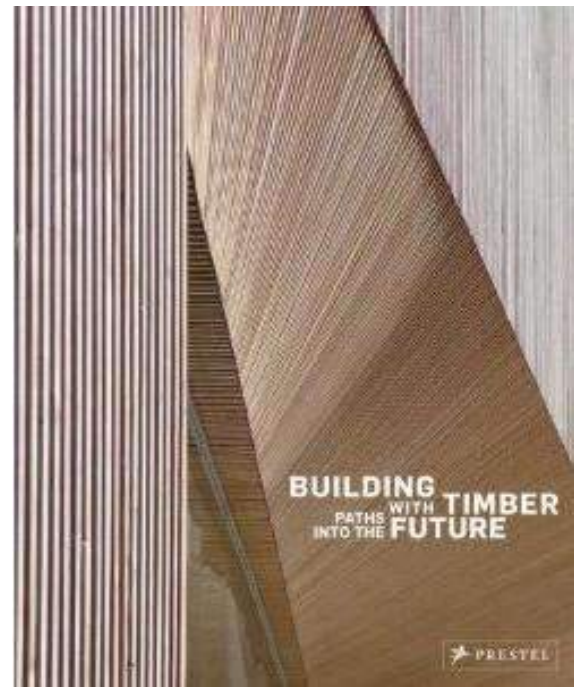
References

www.trada.co.uk – Timber Research and Development Association

Specific student resource area







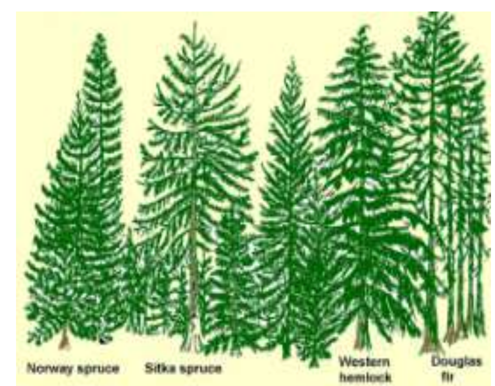
Contents

Trees and wood

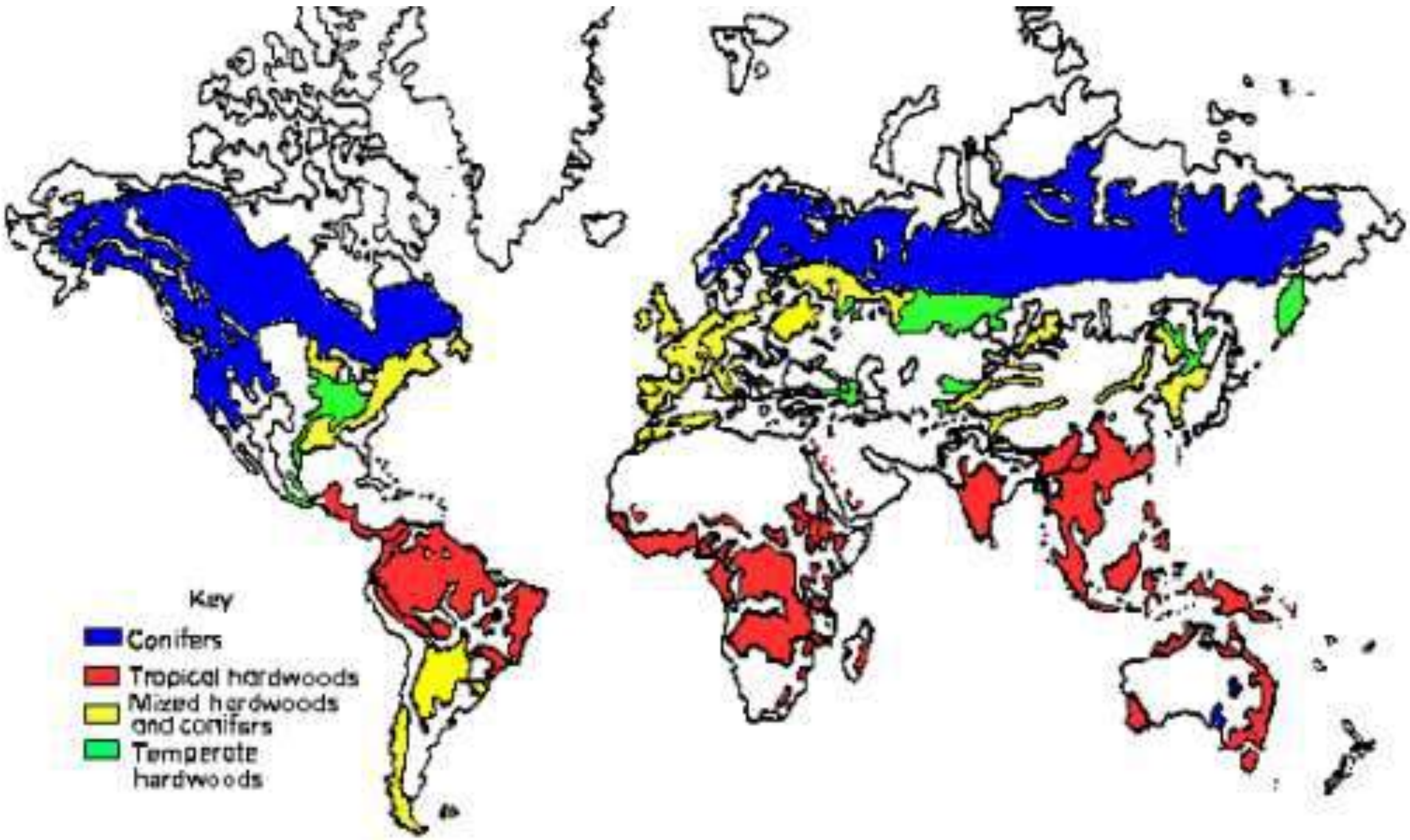
"The best friend of man is the tree. When we use the tree respectfully and economically, we have one of the greatest resources on the earth"

Frank Lloyd Wright

- Approximately 20% of worlds land surface covered by trees
- 97% of all softwood used in Europe comes from European forests
- 30% increase in wooded area in Europe between 1990-2000
- Trees are on average 60-80 years old on harvest
- Primary softwoods used for construction are spruce (whitewood) and pine (redwood)



Forest distribution

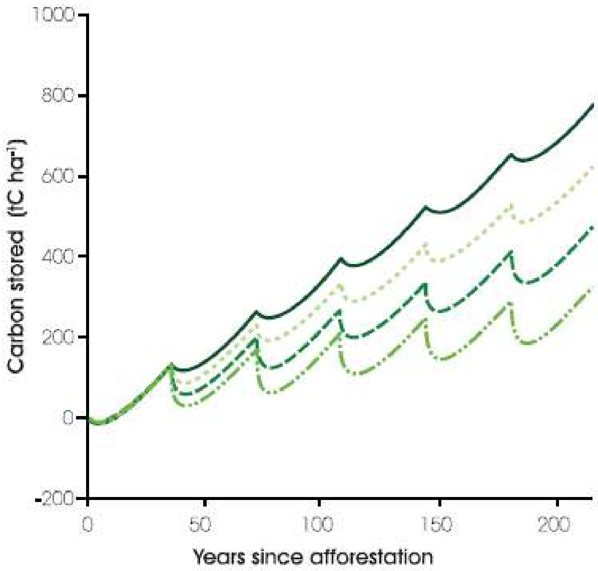


www.earthobservatory.nasa.gov/Features/ForestCarbon/page1.php

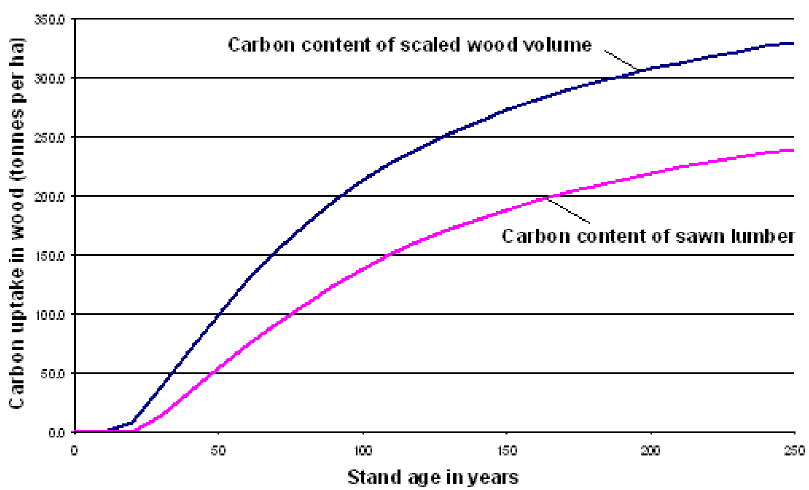
Trees and carbon

- Wood is about 50% carbon (by dry mass)
- x 3.67 to convert C to CO2
- Broadleaf forests 100-250 tC per ha
- Conifer plantations 70-90 tC per ha
- Carbon uptake 4 tC per ha per year in fast growing stands

Figure 3.9
Likely changes in the carbon stored in a Sitka spruce plantations on a peaty gley over six rotations. See the text for explanation. The lines show increasing degrees of disturbance at harvest from the top line down.



Accumulation of carbon in the sample stand



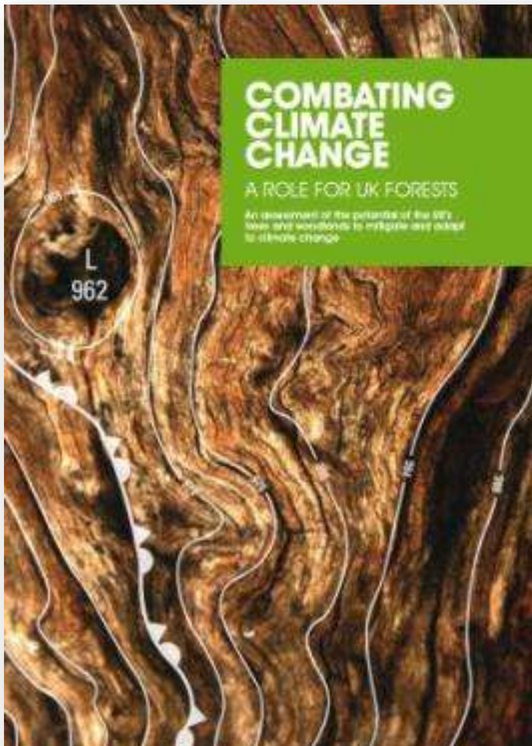
Trees and carbon

Table 6.6

Timber carbon content ($tCO_2e\ m^{-3}$), typical ranges of maximum mean annual volume increment (MMAI: $m^3\ ha^{-1}\ year^{-1}$) and ages of MMAI for a range of conifers and broadleaves grown in Britain or which might be considered for planting under anticipated climate change (after Edwards and Christie, 1981; Lavers, 1983).

Conifers					Broadleaves				
Species	Scientific name	Carbon content	MMAI	Age	Species	Scientific name	Carbon content	MMAI	Age
Sitka spruce	*Picea sitchensis* (Bong.) Carr.	0.62	8–24	64–46	Oak	*Quercus robur* L., *Q. petraea.* (Matt.) Liebl.	1.12	4–8	90–68
Norway spruce	*Picea abies* L. Karst.	0.64	8–20	84–65	Birch	*Betula pendula* (Roth.), *B. pubescens* (Ehrh.)	1.10	4–12	49–40
Scots pine	*Pinus sylvestris* L.	0.84	6–12	82–69	Sweet chestnut	*Castanea sativa* Mill.	0.84	4–10	50–41

Trees and carbon

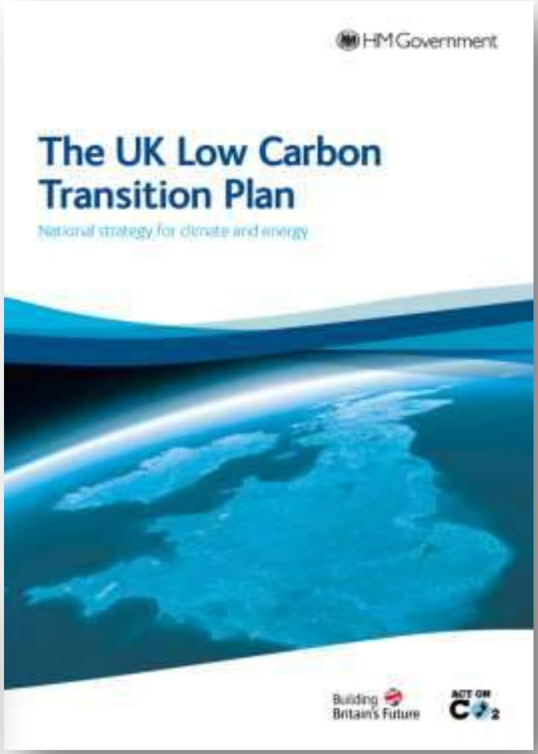


- UK Forestry Commission report
  - UK woodland could provide 10% CHG abatement (Scotland already 12%).
  - UK ‘forest carbon sink’ reducing from 16mt CO2 in 2004 to 5mt CO2 in 2020.
  - Wood fuel potential to save 7mt CO2 in UK.
  - Wood substitution potential to save 4mt CO2 in UK.
  - Estimated 70mt CO2 stored in timber housing in UK.

UK government and trees

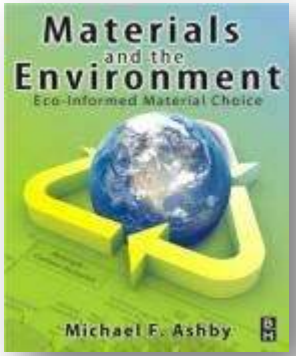
- Recognises that in 2007 forest in England removed 2.9mt CO2, but that this rate is falling.
- Recognises that a major woodland creation scheme is required, target of 10,000 ha per year for 15 years (to remove 50mt CO2 by 2050).
- Woodland creation can also help with employment creation, flood alleviation, water quality improvement and support for wildlife.
- Recognises that woodland resource (timber) needs to be used for fuel and construction.

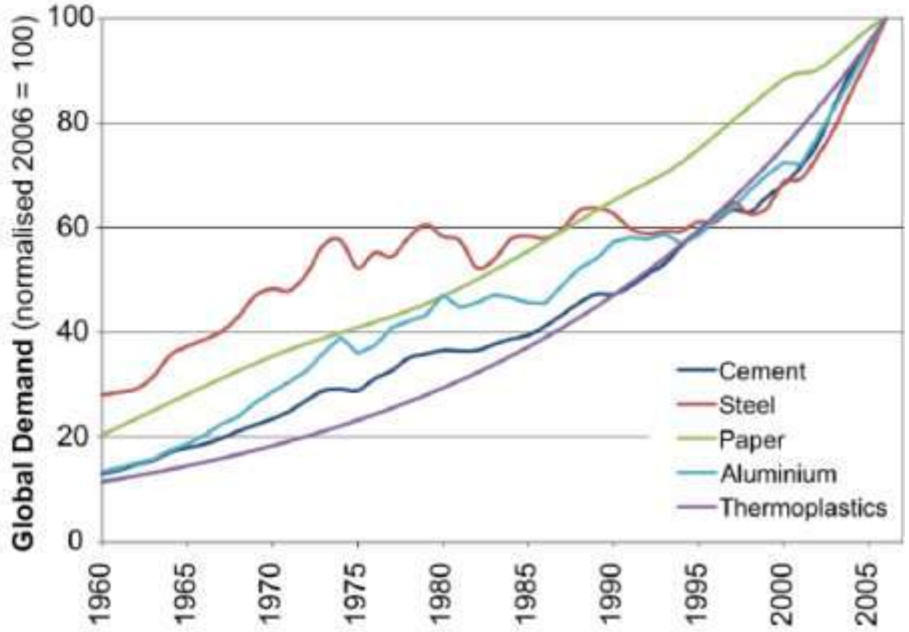
Woodland creation is a very cost-effective way of fighting climate change over the long term, but it requires an upfront investment.

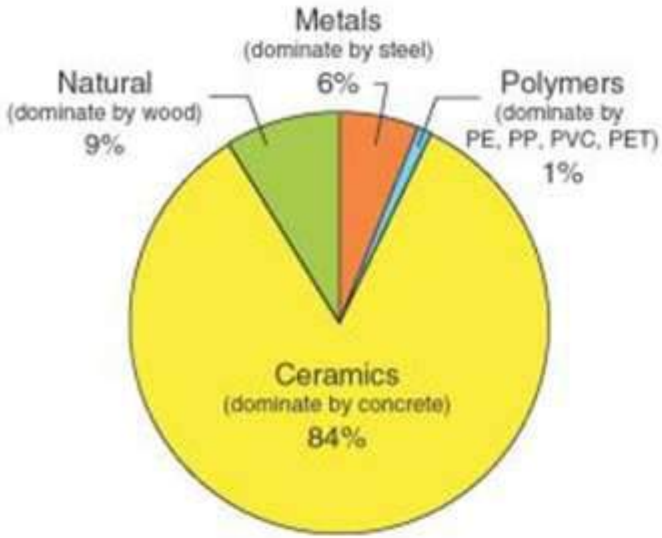


Engineering materials

- 10 billion tonnes pa of engineering materials used globally
- 1.5t person pa, main components are concrete, wood, steel, asphalt, glass, brick
- Concrete is by far the dominant engineering material (factor 10) and responsible for some 5% of global CO_2 emissions
- 10 billion tonnes pa of oil and coal used globally

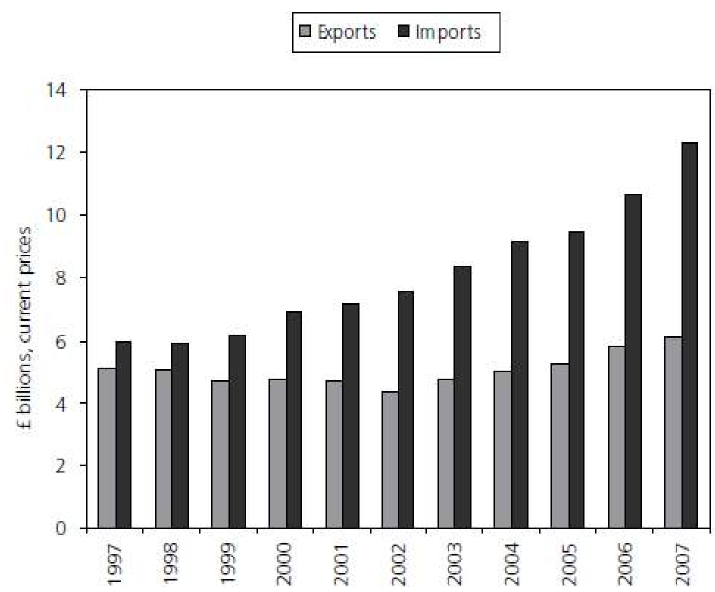






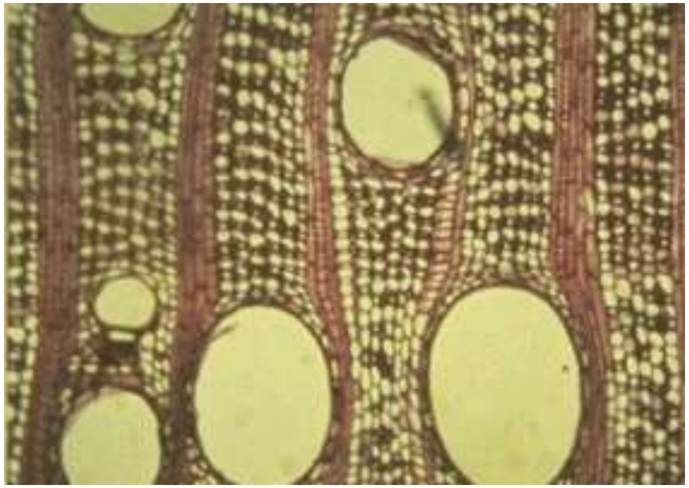
UK construction materials

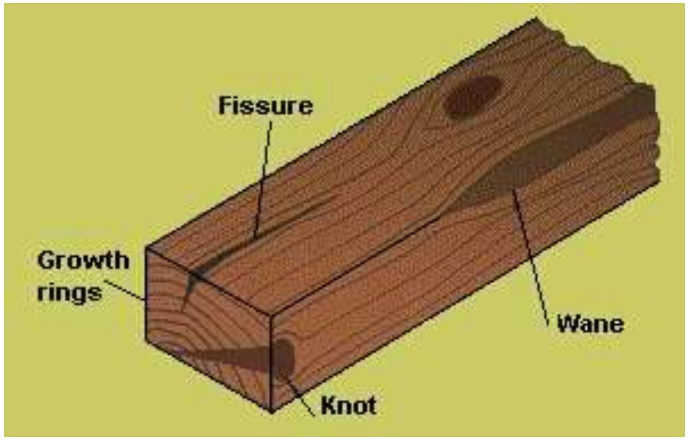
- 400mt construction materials annually
  - 1.4mt steel
  - 100mt concrete
  - 7.5mt timber
- UK is one of world's largest importers of timber



Wood properties

- Timber is anisotropic
  - 5 to 10x weaker across the grain (similar to bundle of straws)
- Affected by moisture
  - 50% moisture content natural state, 12-20% in use (hygroscopic)
  - 20-40% loss in strength in damp conditions
- Strength
  - 100N/mm2 defect free, typical 16-24N/mm2 softwoods used in UK are designed using 6N/mm2
  - Direct correlation strength, stiffness and density
  - Best at resisting short terms loads, creeps under long term load (approx 40% weaker)





Sustainable timber

The Forest Stewardship Council (FSC)

Independent non-governmental organisation supported by WWF

www.fsc-uk.org

Pan European Forest Certification Council (PEFC)

Voluntary private sector initiative

www.pefc.co.uk

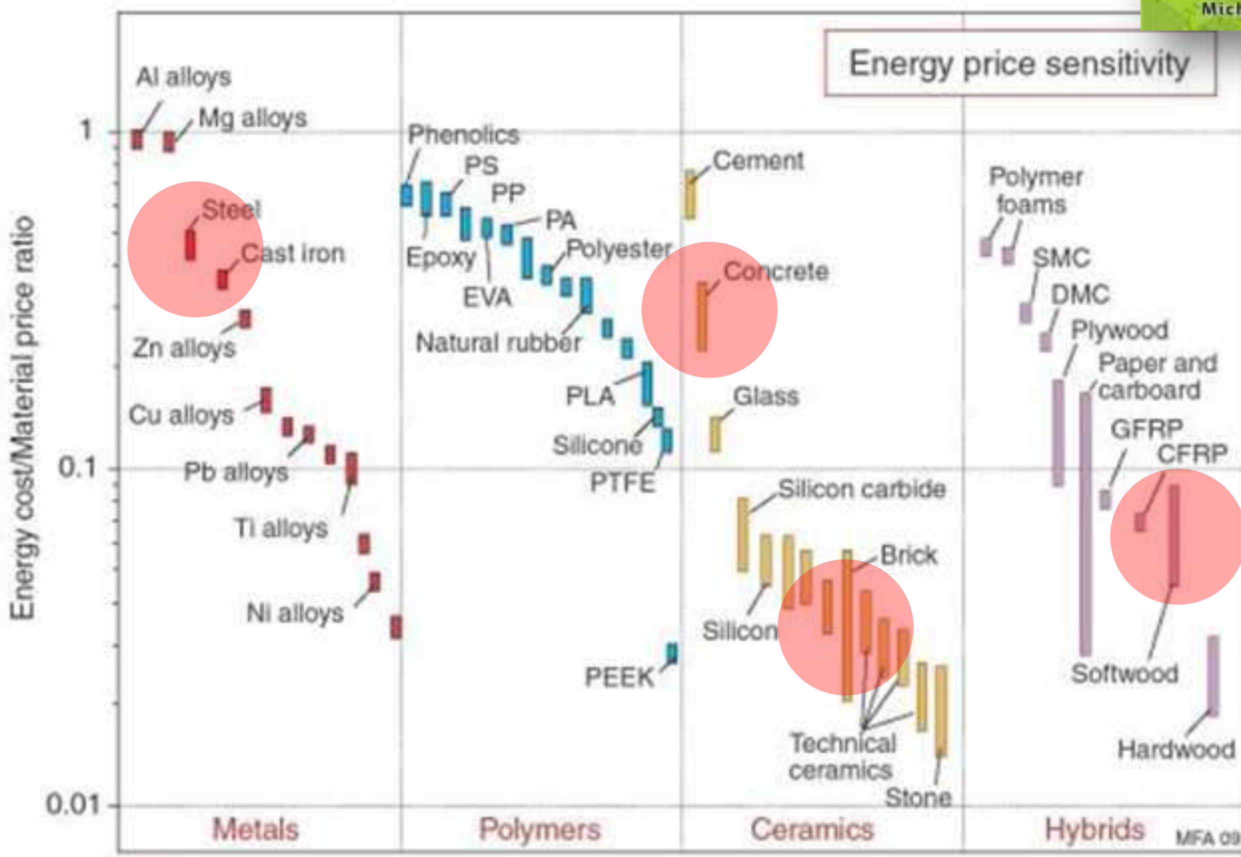
46 million hectares of managed European forest endorsed

Forests Forever Campaign (FFC)

Independent advisory body initiated by the Timber Trade Federation

www.forestsforever/org.uk

Embodied energy

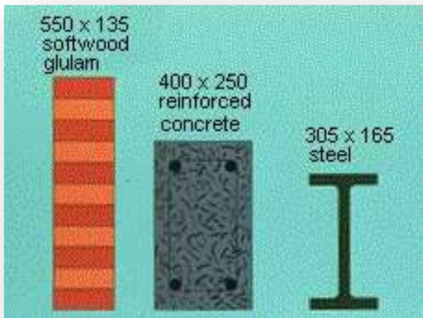


Energy cost represents 100% of material cost

Energy cost represents 10% of material cost

Energy cost represents 1% of material cost

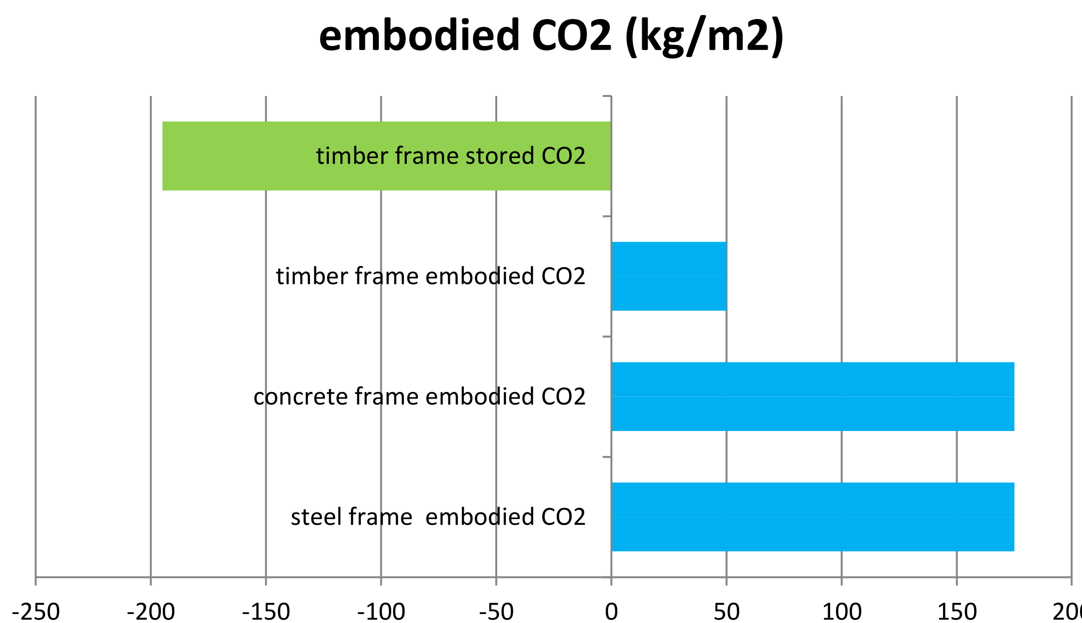
Structural performance and ECO2



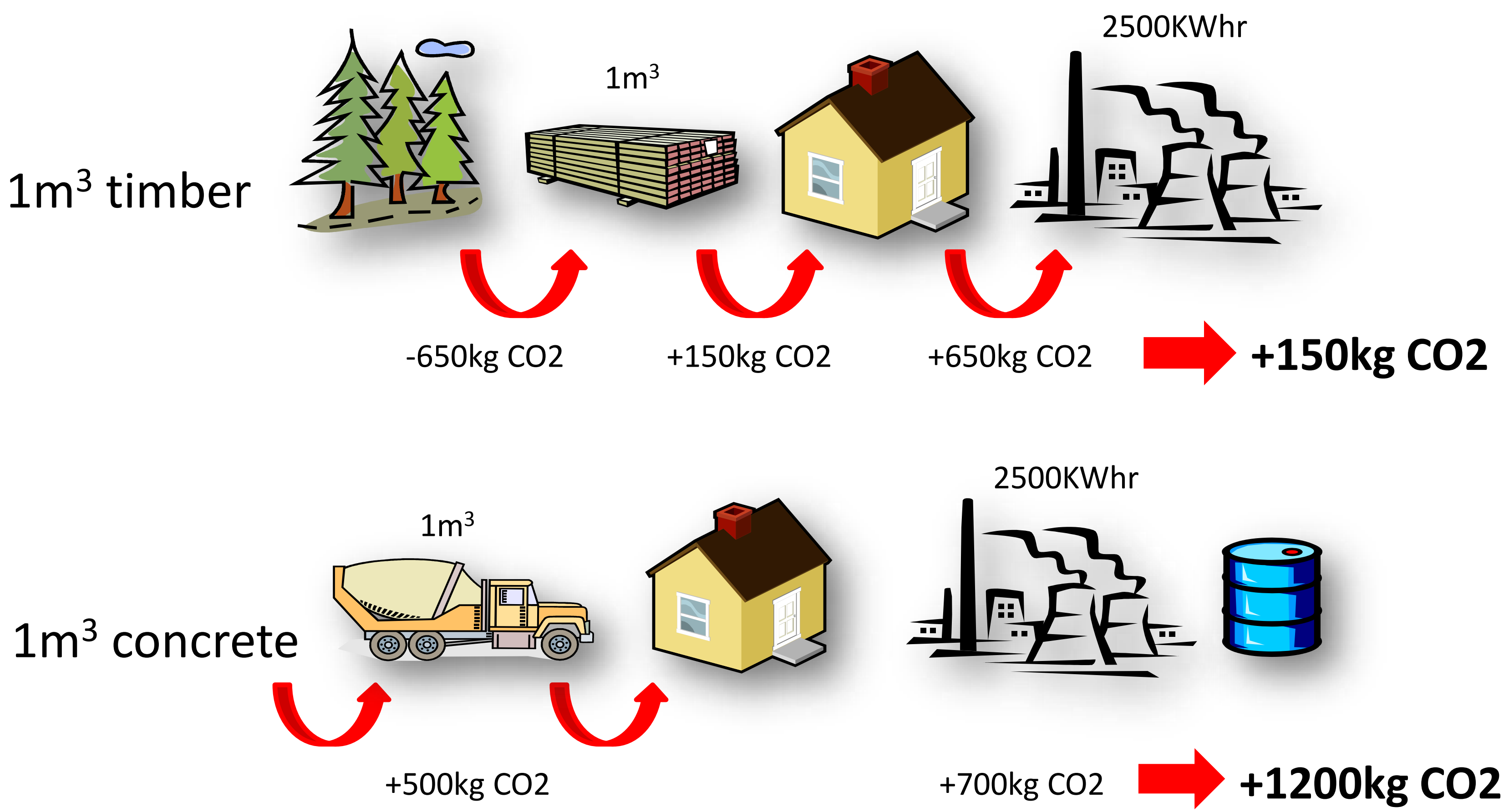
- Timber beam 15kgCO_2
- Concrete beam 50kgCO_2
- Steel beam 60kgCO_2

- But.....60kgCO_2 stored in timber beam

- Timber CLT frame
- Concrete flat slab frame
- Steel frame and holorib concrete floor



CO2 stories for timber and concrete

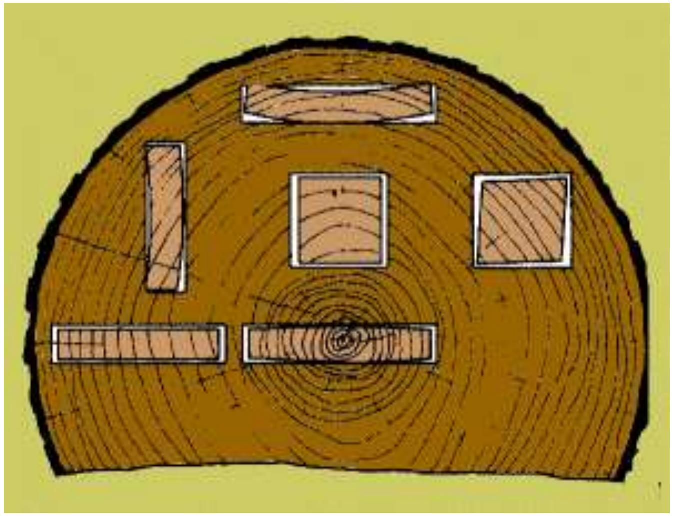


Timber products

- Sawn timber
- Engineered timber
- Manufacture & fabrication
- Structural systems

Sawn timber

- Strength graded
  - C16 and C24 (spruce or pine typically)
  - D30 (oak)
  - Inherent defects in timber mean factor of safety in region of 3 used
- Dimensions limited
  - Typically up to 225mm deep sections
  - Kiln drying limits widths typically to 75mm and lengths to 6m



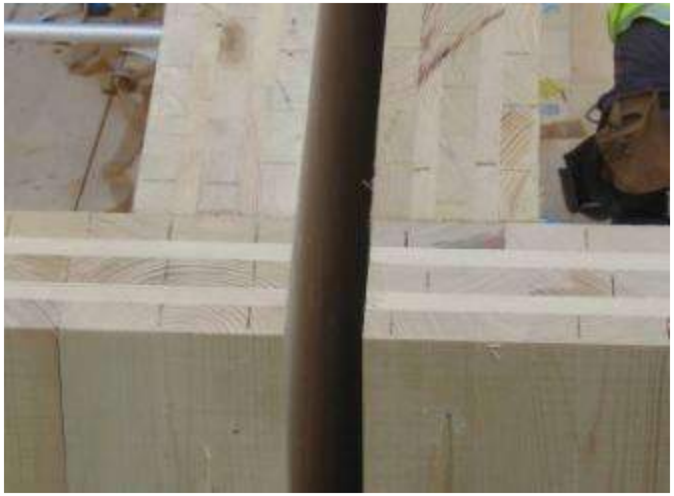
Engineered timber

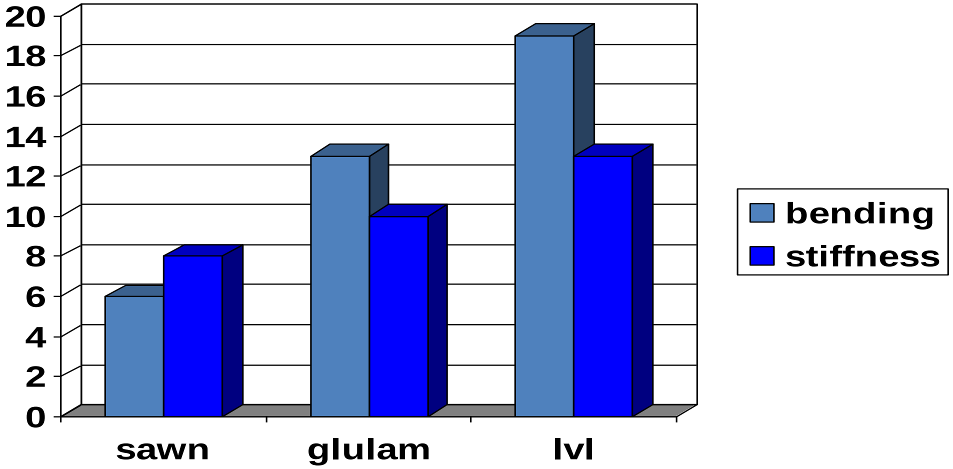
- Reduces effect of defects
- Glues and mechanical fixing have played important role
- Different types:

  Layer – Glulam, Plywood, CLT, LVL

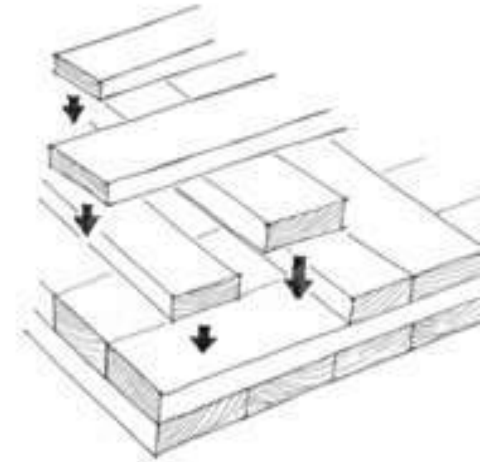
  Particle – Chipboard, PSL, OSB

  Fibre – MDF, Hardboard





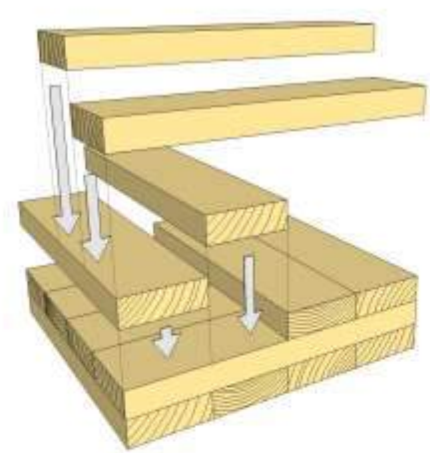
Engineered timber



- Layered/Laminated
  - Glue laminated timber (glulam)
  - Laminated veneer lumber (LVL)
  - Cross laminated timber panels (CLT)
- Particle
  - Orientated strand board (OSB)
  - Particle board (chipboard)

1. Sawing	2. Rotary peeling	3. Clipping
4. Drying	5. Gluing	6. Lay up
7. Hot press	8. Cross-cutting	9. Rip-sawing

CLT product



MMH		Binderholz		KLH		StoraEnso		Leno	
thk	layers	thk	layers	thk	layers	thk	layers	thk	layers
78	3	66	3	57	3	57	3	51	3
94	3	78	3	72	3	83	3	61	3
95	5	90	3	94	3	97	3	71	3
98	3	100	3	95	5	95	5	81	3
106	3	110	3	128	5	138	5	85	5
118	3	130	3	158	5	161	5	85	11
134	5	100	5	60	3	57	3	93	3
140	5	110	5	78	3	74	3	95	5
146	5	130	5	90	3	83	3	99	3
160	5	147	5	95	3	97	3	105	5
173	5	163	5	108	3	103	3	115	5
184	5	181	5	120	3	112	3	125	5
198	5	203	5	117	5	119	3	135	5
214	7	213	5	125	5	126	3	147	5
214	7	233	7	140	5	95	5	153	5
240	7	248	7	146	5	121	5	165	5
240	7	284	7	162	5	138	5	174	6
258	7	299	7	182	5	150	5	186	6
278	7	341	7	200	5	165	5	189	7
				202	7	182	5	201	7
				226	7	196	5	207	7
				208	7	211	5	219	7
				230	7	194	7	231	7
				260	7	216	7	240	8
				280	7	237	7	252	8
				248	8	209	7	264	8
				300	8	223	7	273	9
				320	8	249	7	285	9
						267	7	297	9
						296	7		

- Statistics
  - *2.95m wide (typical 2.4m)*
  - *16.5m long (typical 13.5m)*
  - *Typical 50mm to 300mm thick (500mm thk possible)*
  - *Strength grade C24*
  - *Spruce*

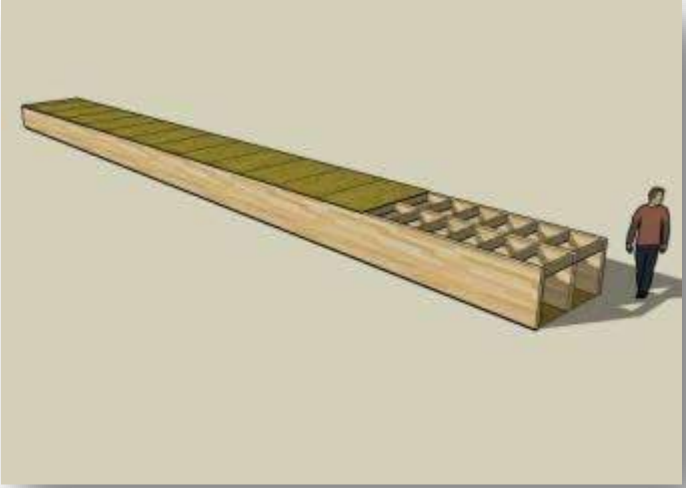
CLT product

- 12 European CLT manufacturers?
  - *KLH* *700,000m^2*
  - *Stora Enso* *500,000m^2*
  - *Mayr-Melnhof Kaufmann* *500,000m2*
  - *Binderholz* *400,000m2*
  - *Merk Finnforest* *200,000m2*
  - *Schilliger* *200,000m2*
- Total combined output say 3,000,000m^2?
  - *Equivalent to over 1,000,000m^2 of new buildings*
  - *Over 300,000tCO2 sequestered*
- Approximately 40,000ha of forest required to support 3million m2 of CLT production


KLH UK
KLH

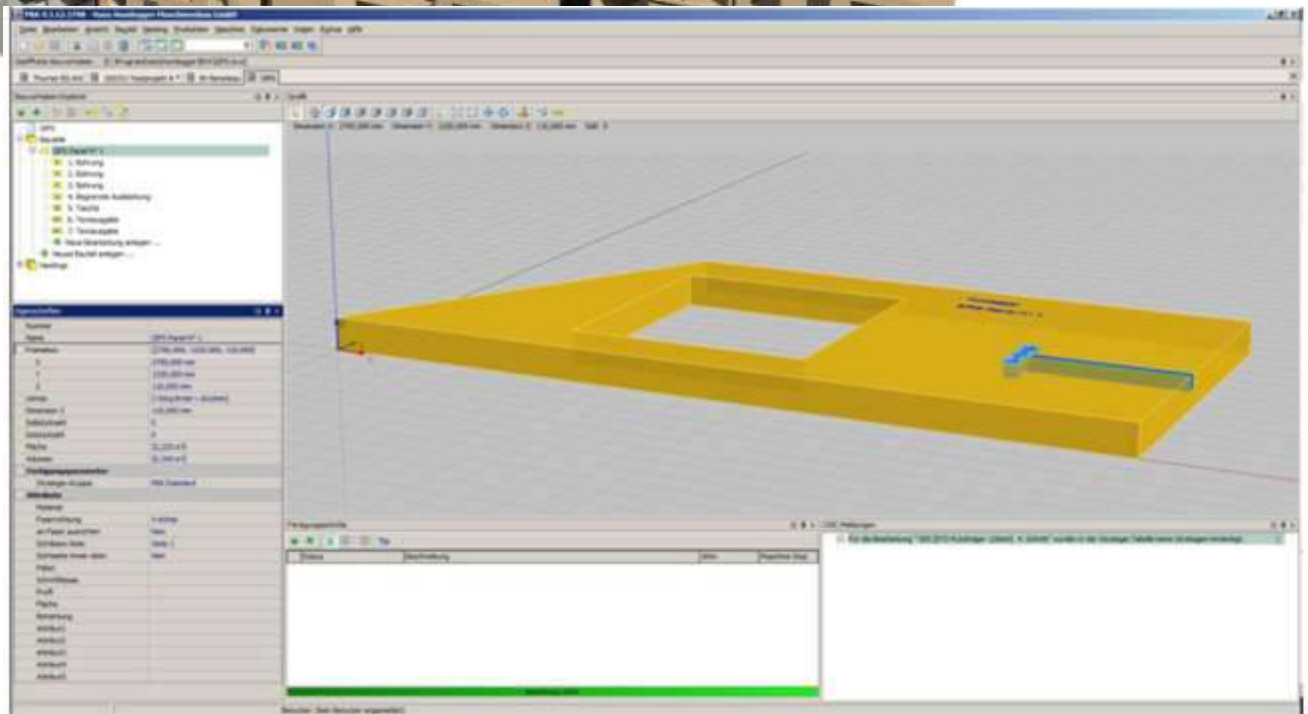
Engineered timber

- Timber cassettes
  - Sometimes referred to as stressed skin
  - Can have insulation integrated (SIPs – structural insulated panels)
  - Beams positively connected (glued, screwed, nailed) to a top and/or bottom sheet material. Together the beams (web) and sheeting (flange) make for a highly efficient spanning element
  - Can be used as roof or floor elements
  - In UK longest recent cassette is 25m roof span over Darlaston Pool in Walsall in 2000.



Fixing technology

Cutting technology

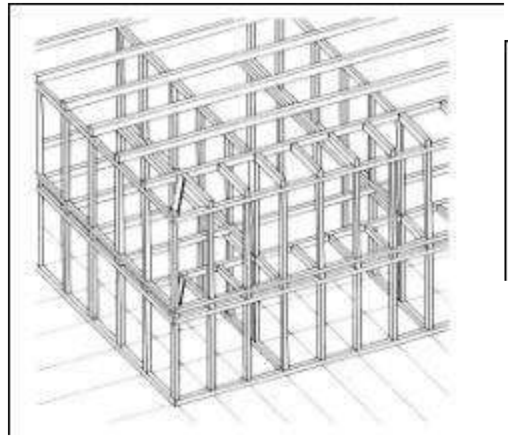


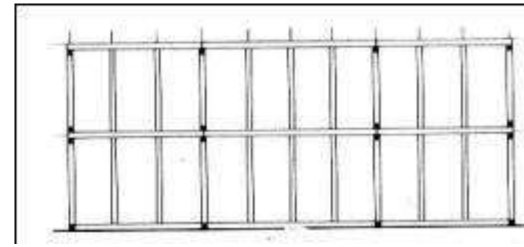
The parts can also be drawn directly with the EKP program.

Structure types

Framed

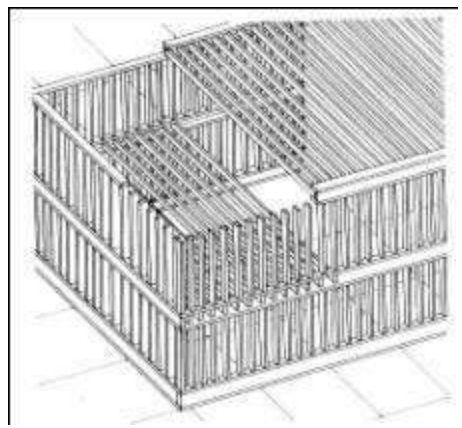
Traditional column and beam frame with primary and secondary beam layouts.

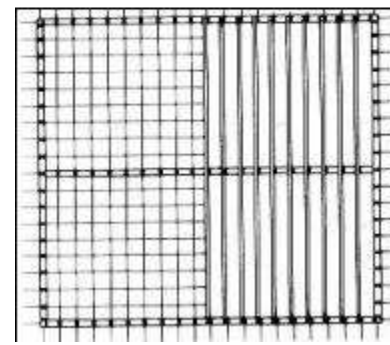




Platform

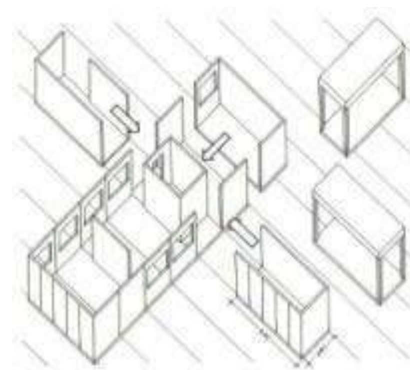
Typically cellular construction built insitu with a series of wall studs supporting floor joist. Built up level by level.

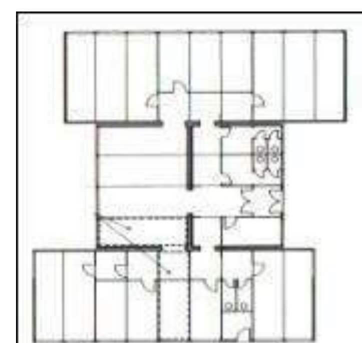




Panelised or Volumetric

Pre-fabricated wall and floor panels fixed on site to give fast track construction.





Design

- Strength
- Stiffness
- Design codes
- Rules of thumb

Design

	Bending parallel to grain N/mm2	Tension parallel to grain N/mm2	Compression parallel to grain N/mm2	Compression perpendicular to grain N/mm2	Shear parallel to grain N/mm2	Modulus of elasticity MEAN N/mm2	Modulus of elasticity MINIMUM N/mm2	Density kg/m3
C16 Spruce	5.3	3.2	6.8	2.2	0.67	8800	5800	370
D40 Oak	12.5	7.5	12.6	3.9	2.00	10800	7500	700

- Strength and stiffness depends on a number of factors:
    - Species of timber
    - Moisture content of timber
    - Duration of load
    - Direction of stress within timber
    - Defects present in timber
    - Slenderness
- Direct correlation between density and strength

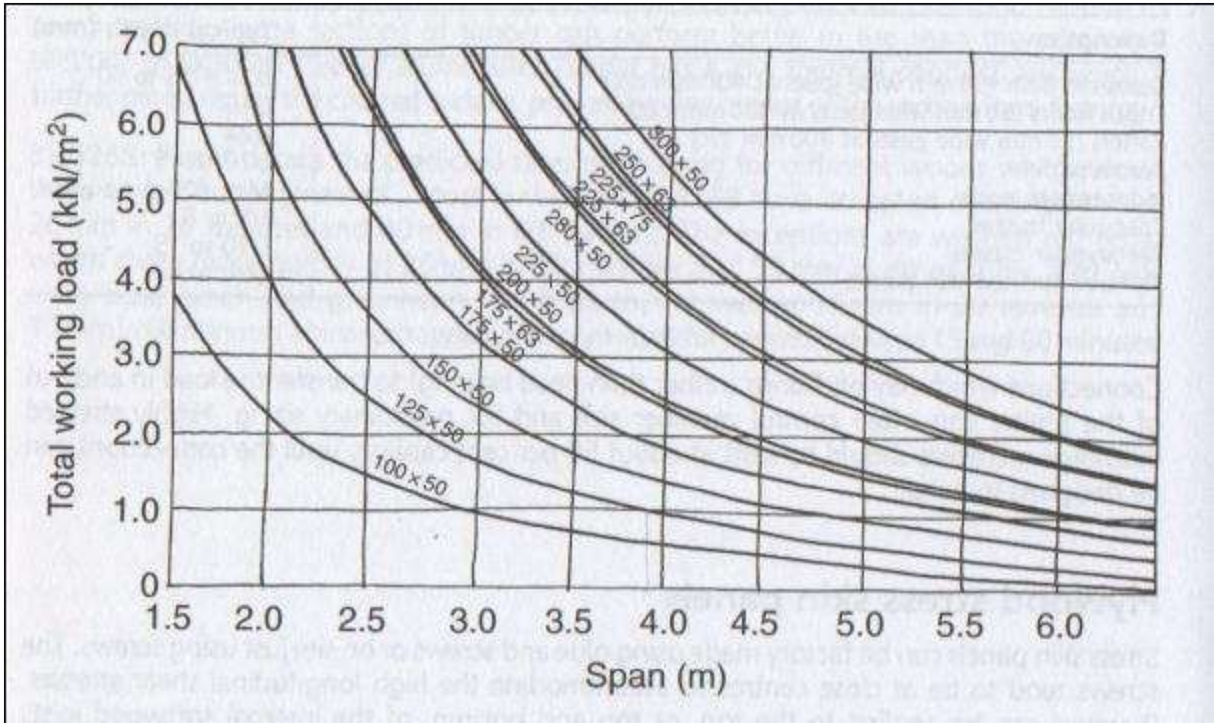
Design

Maximum load-bearing capacity, uniformly distributed loads (tonnes)

Glulam section in mm	Span in metres																
	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
56 x 225	2.37	1.88	1.44	1.04	0.78	0.60	0.48	0.38	0.31	0.26	0.21						
66 x 315	5.53	4.40	3.64	3.10	2.63	2.05	1.64	1.34	1.11	0.93	0.79	0.67	0.58	0.50	0.44	0.38	
90 x 315	7.54	5.99	4.97	4.23	3.58	2.80	2.24	1.83	1.51	1.27	1.07	0.92	0.79	0.68	0.59	0.52	0.45
90 x 360	8.86	7.67	6.36	5.42	4.72	4.17	3.40	2.78	2.31	1.94	1.65	1.42	1.23	1.07	0.94	0.82	0.73
90 x 405	9.95	9.61	7.97	6.80	5.92	5.24	4.69	4.01	3.34	2.82	2.40	2.07	1.80	1.57	1.38	1.22	1.08
115 x 405	12.72	12.27	10.18	8.68	7.56	6.69	5.99	5.12	4.26	3.60	3.07	2.65	2.30	2.01	1.77	1.56	1.39
115 x 495	15.55	15.55	14.95	12.76	11.12	9.85	8.83	7.99	7.30	6.71	5.75	4.97	4.33	3.81	3.36	2.99	2.67
115 x 630	19.80	19.80	19.80	19.80	17.86	15.83	14.20	12.87	11.76	10.82	10.01	9.31	8.70	8.16	7.16	6.39	5.73

- Load duration factors:
  - Long term 1.00 (ie dead + live load)
  - Medium term 1.25 (ie dead + snow load)
  - Short term 1.50 (ie dead + live + snow load)
  - Very short term 1.75 (ie dead + live + snow + wind load)
- Slenderness factors:
  - 1.00 at slenderness ratio 0
  - 0.75 at slenderness ratio 50 (ie 275mm wide column 4m long)
  - 0.40 at slenderness ratio 100 (ie 275mm wide column 8m long)
  - 0.10 at slenderness ratio 200 (ie 275mm wide column 12m long)
- Moisture content:
  - 40% to 20% reduction in strength and stiffness for 20%+ moisture content

Rules of thumb

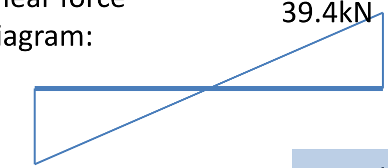


- Typical span/depth ratios
  - Domestic floors — L/20
  - Office floors — L/15
  - Rafters — L/24
  - Beams — L/10 to 15
  - Arch — L/50
- Typical span/depth ratios
  - Triangular trusses — L/5 to 8
  - Rectangular trusses — L/10 to 15
  - Stressed skin panels — L/30 to 40
  - Solid timber panels — L/30

Timber beam design example

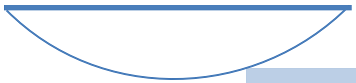
A glulam timber floor beam spanning l = 7.5m
Spacing of beams is 3m
Lightweight floor construction = 1 kN/m2
Office floor loading = 2.5 kN/m2
ie: beam loading w = 3m x (1 + 2.5) = 10.5 kN/m

Shear force diagram:



$SF = \frac{wl}{2}$

Bending moment diagram:



$BM = \frac{wl^2}{8}$

Design:
Choose initial beam size based on span to depth ratios
For timber beams span to depth ratios of 10-15 are recommended, therefore 7.5m / 12.5 = 600mm
From glulam supplier information try a beam 115mm x 630mm & C24 timber grade

Allowable stresses:
As the glulam beam is made from C24 grade timber we use C24 timber allowable stresses:
Allowable bending stress = 7.5N/mm2 x K_7 x K_{15} = 9.6N/mm2*
Modulus of elasticity = 10,800N/mm2 x K_{20} = 11,550N/mm2*
**Allowable stresses in glulam beams are affected by a number of factors (number of laminations, depth of beam etc.)*
Assumed that beam is fully restrained by floor against lateral torsional buckling

Bending check:
Bending stress in beam = $\frac{BM}{z} = \frac{73.8x6}{115x630^2}$ = 9.7N/mm2
Where z = elastic modulus = $\frac{bd^2}{6}$
Applied stress is marginally higher than allowable

Deflection check:
Deflection = $\frac{5wl^4}{384EI} = \frac{5x10.5x7500^4x12}{384x11,550x115x630^3}$ = 15.6mm
Where I = second moment area = $\frac{bd^3}{12}$
Allowable deflection = 0.003 x span = 22.5mm

Embodied CO2:
=0.115x0.63x160
=12kgCO2/m

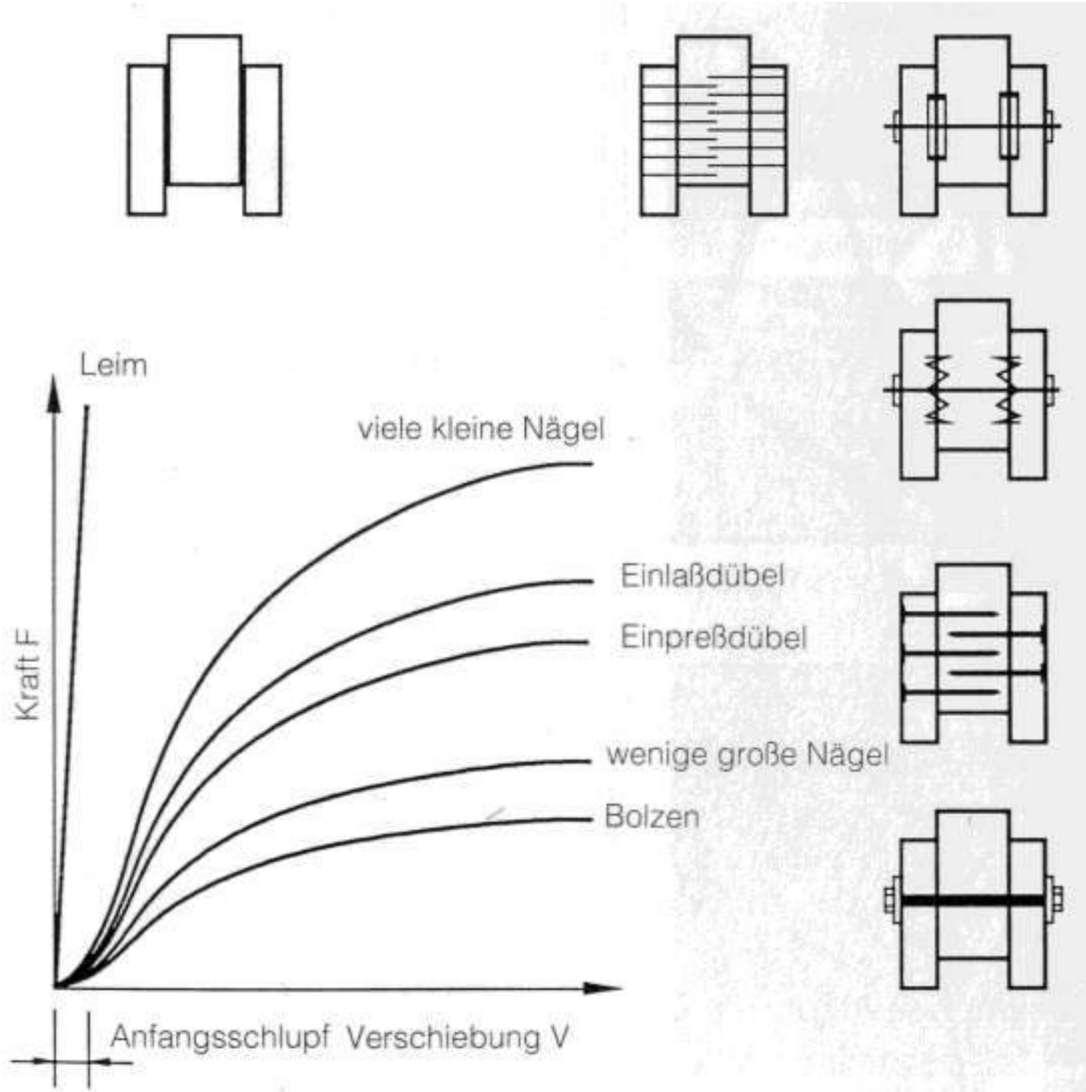
Sequestered CO2:
=0.115x0.63x650
=47kgCO2/m

Connections

- Direct bearing
- Mechanical
- Glued

Connections

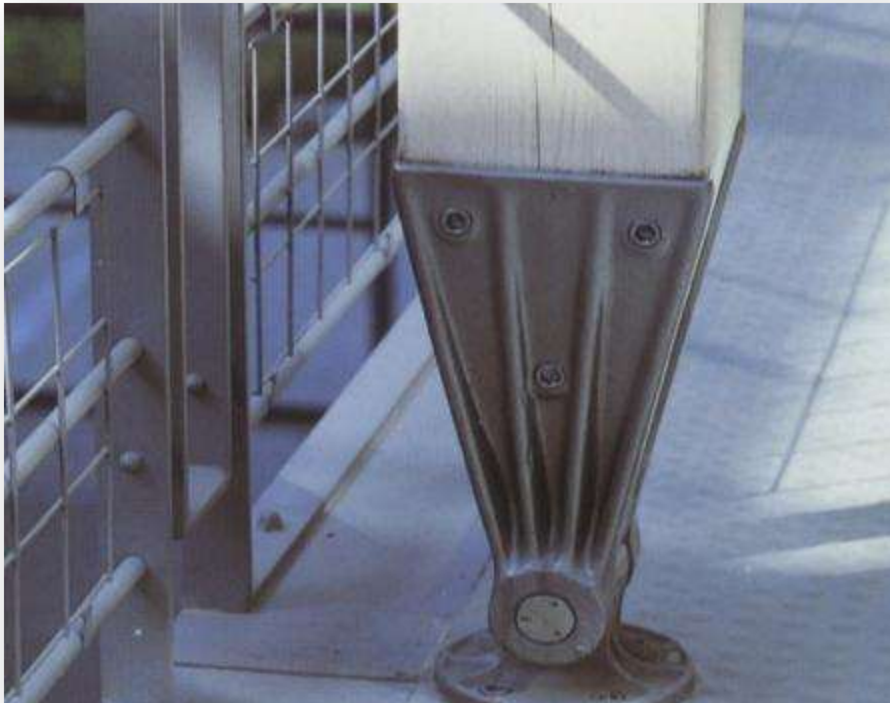
- Glued connections strongest and stiffest
- Connections with multiple small fixings (ie nails or screws) are also efficient



Verformungsverhalten verschiedener Verbindungsmittel


R194
R1107

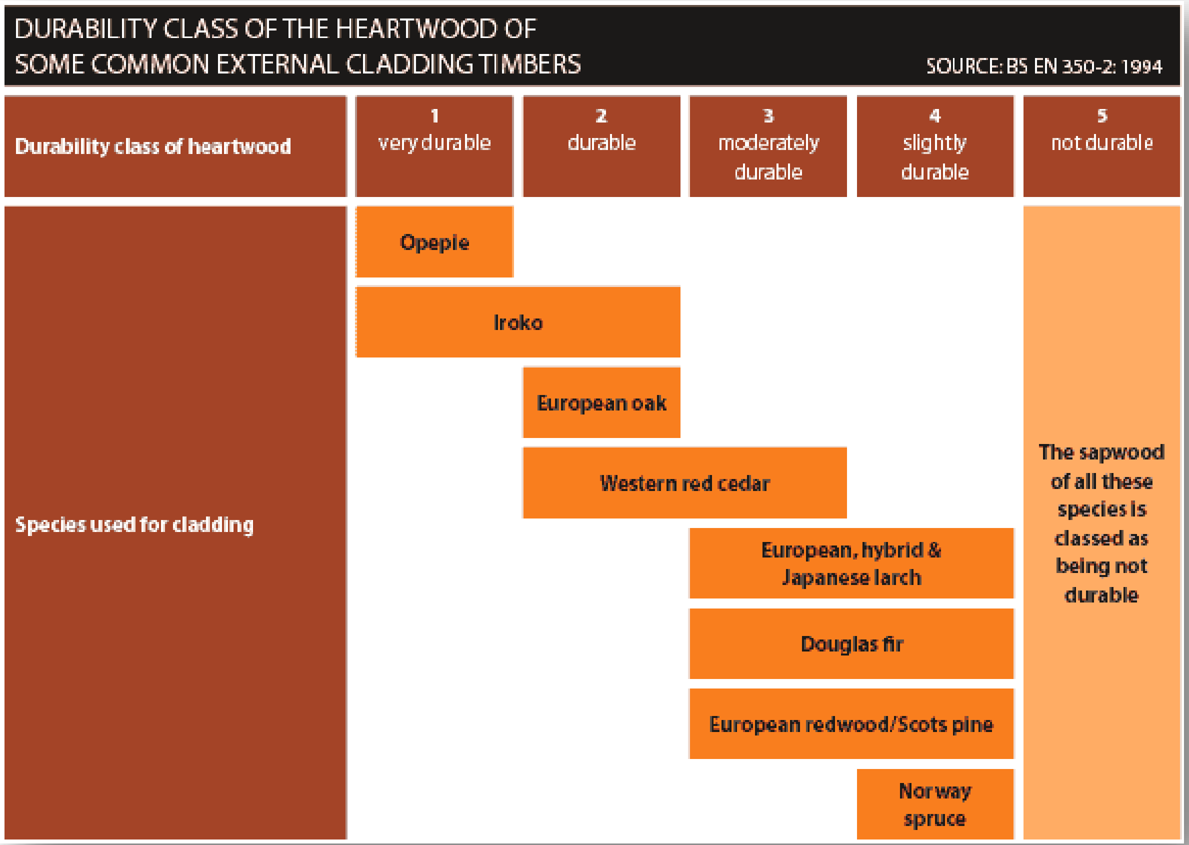

bluest




ATICS

- Preservative treatments
- Fire

Durability



- Timber durability relates to resistance to fungal or insect attack
- Fungal attack can only occur where moisture content of timber is 20%+
- BS 5268 and Eurocode 5 define 3 service classes:
  - *service class 1 internal heated environment (tmc 12%)*
  - *service class 2 covered heated/unheated (tmc 15-18%)*
  - *service class 3 external (tmc 20%+)*
- Service class 1 and 2 timber should be protected from weather on site and not exceed moisture content of 20% and 24% respectively

Durability

Timber Durability

BS EN 350-2 : 1994 lists the natural durability of solid wood to wood-destroying fungi for selected species. A five class system is used to define the resistance of heartwood:

- Very durable
- Durable
- Moderately durable
- Slightly durable
- Not durable (includes all sapwood)

Hazard Class

BS EN 335-2 : 1992 lists the various hazard classes:

- Internal dry, insect risk
- Internal, risk of wetting
- External, above ground, frequent wetting
- Direct soil or fresh water contact
- Marine situations

SELECTING A SPECIFICATION APPROACH ON THE BASIS OF TIMBER PROPERTIES AND PRICE

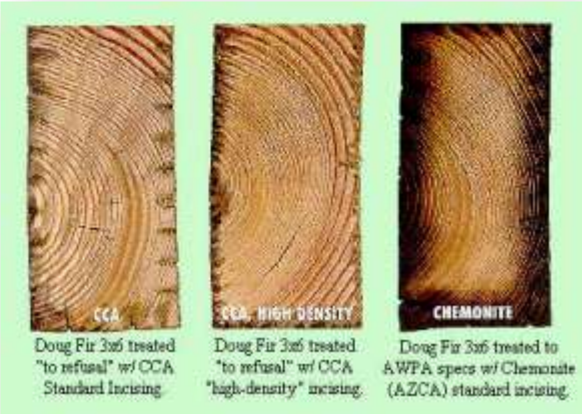
Common name Plus origin where important	Durability class Of heartwood against fungal decay	Movement class	Density range & mean density Kg/m³	Treatibility class[1]		Relative price[2]
				Heartwood	Sapwood	
Opepe[3]	Very durable	Small	740-750-780	Moisture permeability is not generally important when these species are used as cladding		High
Iroko[3,4]	Very durable or durable	Small	630-650-670			
Robinia[4]		Medium	720-740-800			
Sweet chestnut	Durable	Small	540-590-650			
European oak		Medium	670-710-760			
Western red cedar North American		Small	330-370-390			
Douglas fir North American	Moderately durable	Small	510-530-550			Medium
European larch[5]		Small	570-600-650			
Western red cedar Home grown		Small	330-370-390			
Redwood/Scots pine[4]	Moderately durable or slightly durable	Medium	500-520-540	3-4	1	Low
Douglas fir[4] Home grown		Small	470-510-520	4	2-3	Medium
Lodgepole pine[4,7]		Small	430-460-470	3-4	1	Low
Norway spruce	Slightly durable	Medium	440-460-470	3-4	3[9]	
European elm[8]		Medium	630-650-680	2-3	1	High
Japanese or hybrid larch[5,7]		Small	470-600-650	4	2[9]	Low
Western hemlock[7] Home grown		Small	470-490-510	2-3	1	
Sitka spruce[4,7]	Slightly durable or not durable	Small	400-440-450	3	2-3	

KEY

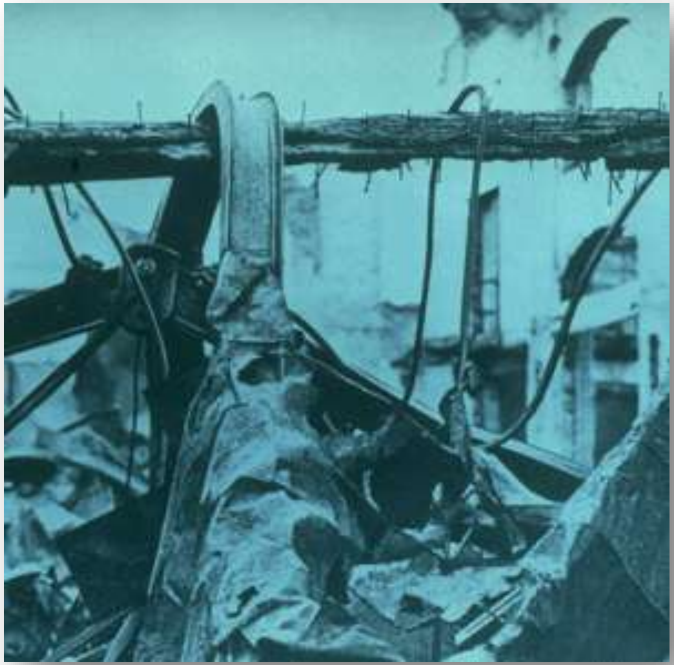
Using natural durability	**Approach 1** The heartwood of these species is generally suitable for use as external cladding without preservative treatment or a water repellent coating. Sapwood should always be removed.
Using timber preservation	**Approach 2** The standard approach to using these species for external cladding is to pressure treat the timber with a suitable preservative. Sapwood is not removed. Species that can be easily treated with preservatives are preferred.
Using careful detailing combined with measures that reduce water uptake.	**Approach 3** An alternative, but more uncertain, approach is to use careful detailing to promote drainage and ventilation, combined with a water repellent, but moisture vapour permeable, coating. The sapwood is not removed and so the use of a species with relatively impermeable sapwood may also reduce moisture uptake. Regular maintenance is essential with this approach.

Durability

- Treatments
  - New regulation has mean the introduction of new products.
  - Chemical treatment (pressure impregnation or surface applied)
  - Thermowood (heat treated, no chemical treatment)
  - Accoya (modified wood)



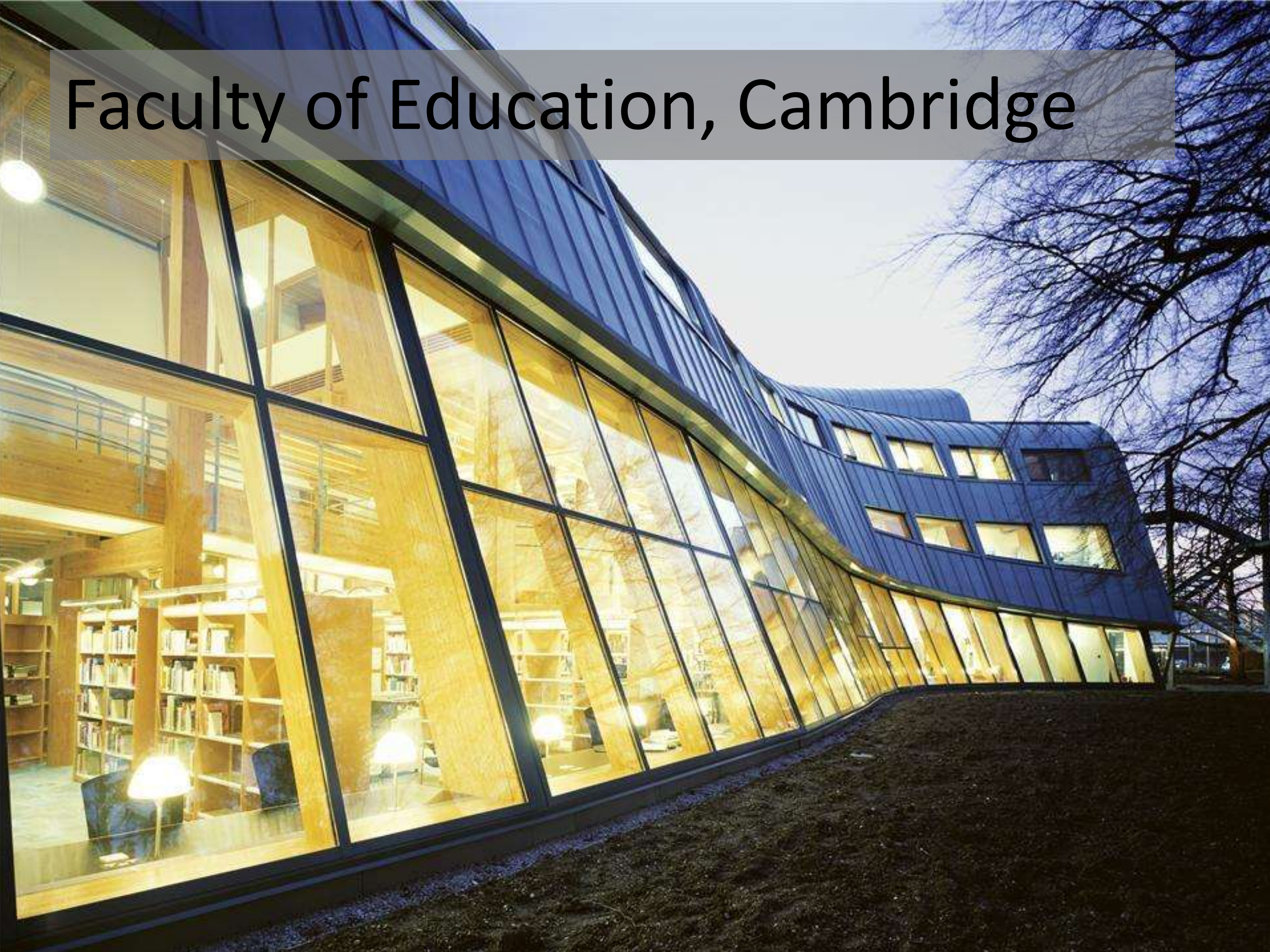
Fire

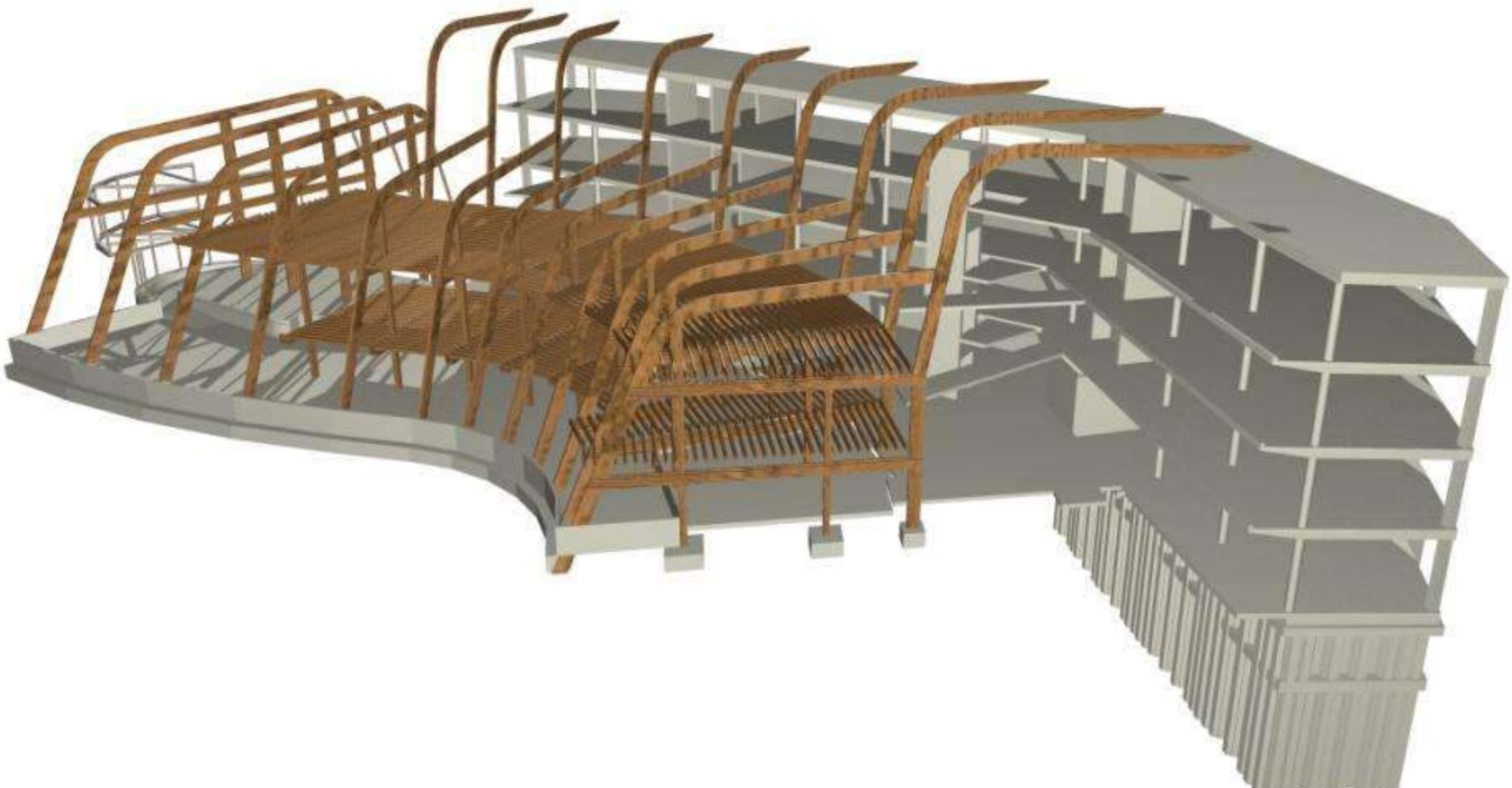


- Recent high profile cases
  - Colindale – during construction
- Fire resistance
  - Large sections char at rate of 0.6-0.7mm/min
  - Oversize timber sections to provide structural integrity during fire (ie timber can be unprotected)
- Spread of flame
  - For large sections treatment is still required by building regulations

Case studies

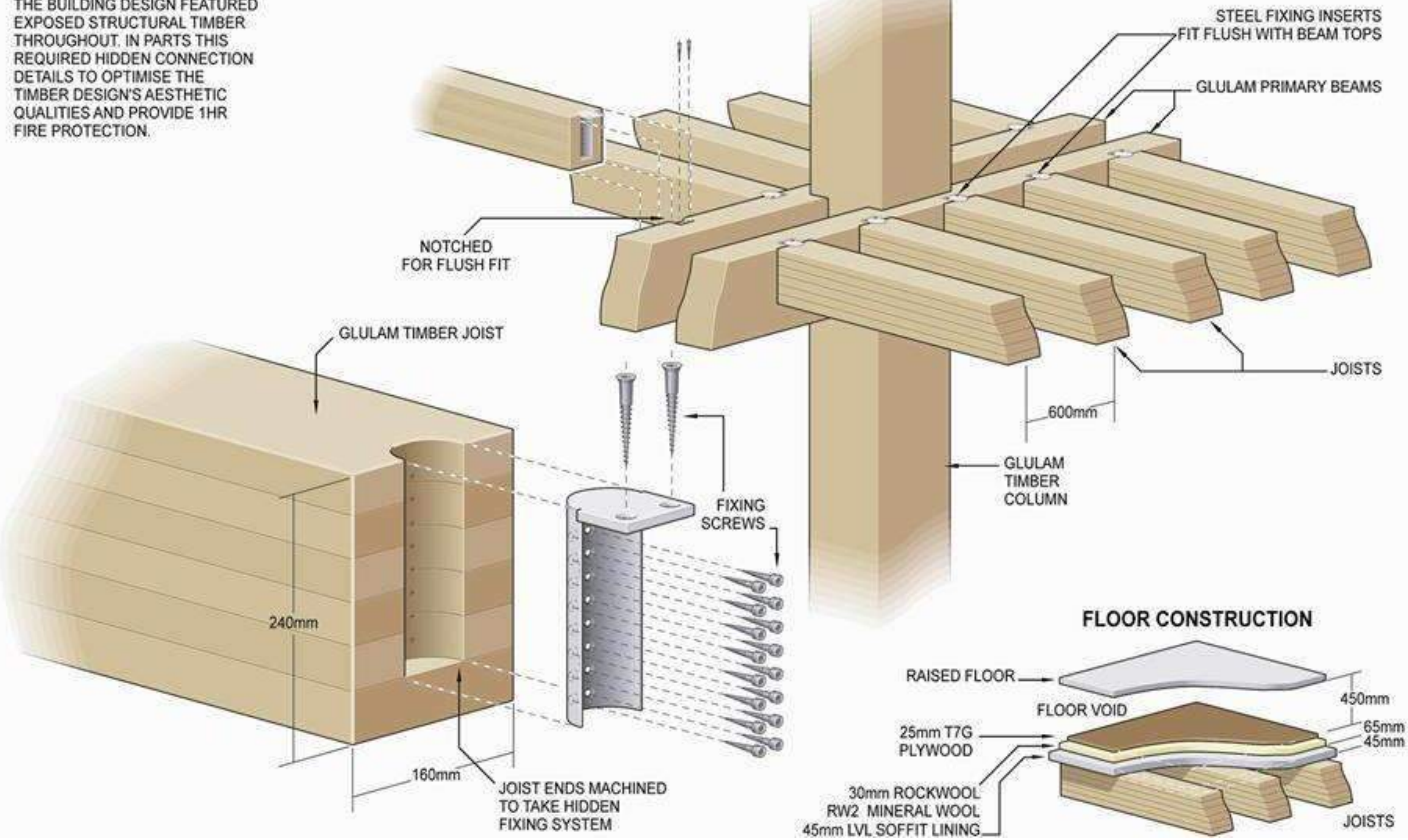
- UK projects
  - Faculty of Education, Cambridge
  - SmartLife Building Academy, Cambridge
  - Mossbourne Academy, London
  - British Geological Survey, Nottingham
  - St John Fisher School, Peterborough
  - Open Academy
  - City Academy


Faculty of Education, Cambridge



HOMERTON COLLEGE – HIDDEN JOIST CONNECTION

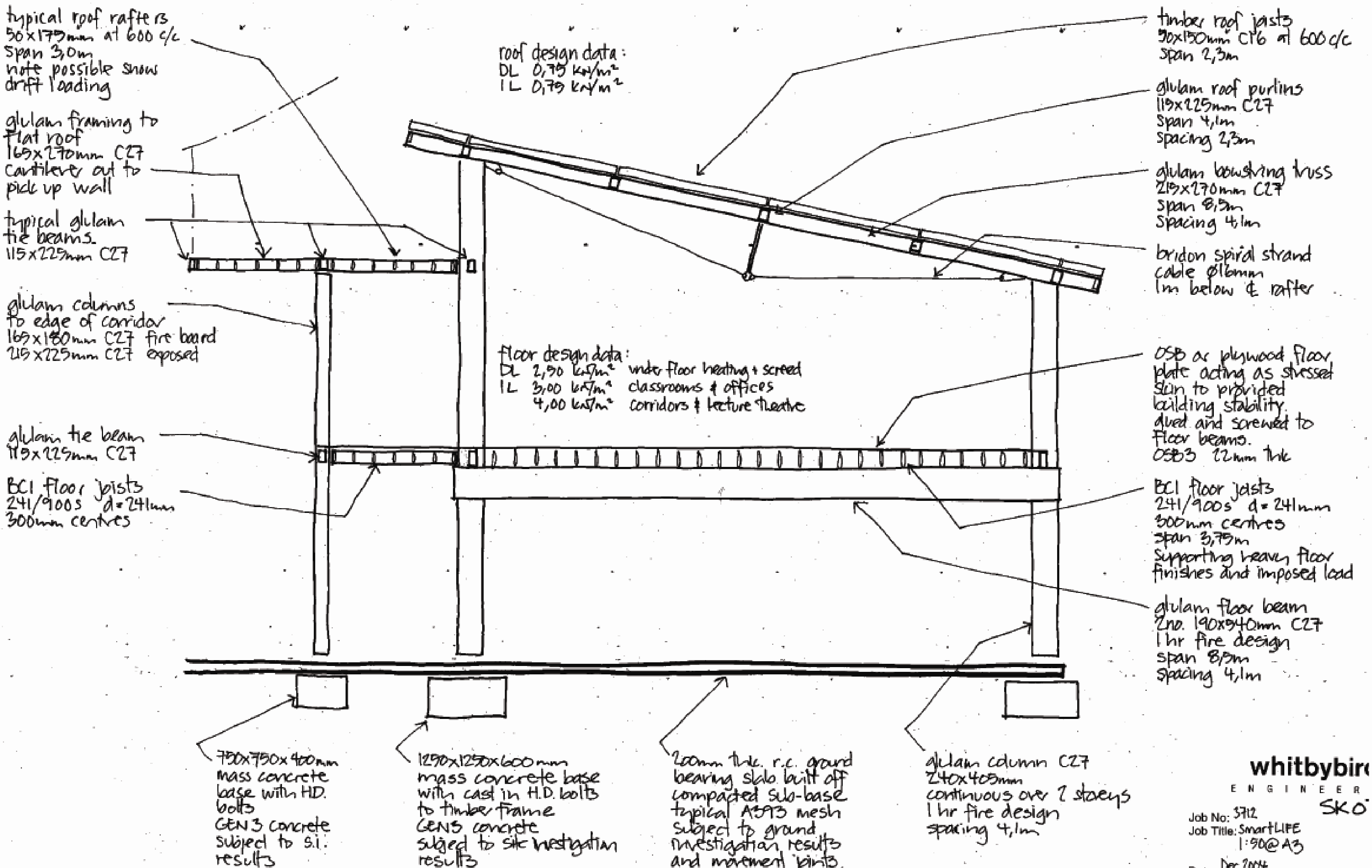
THE BUILDING DESIGN FEATURED EXPOSED STRUCTURAL TIMBER THROUGHOUT. IN PARTS THIS REQUIRED HIDDEN CONNECTION DETAILS TO OPTIMISE THE TIMBER DESIGN'S AESTHETIC QUALITIES AND PROVIDE 1HR FIRE PROTECTION.



SmartLife, Cambridge


mart

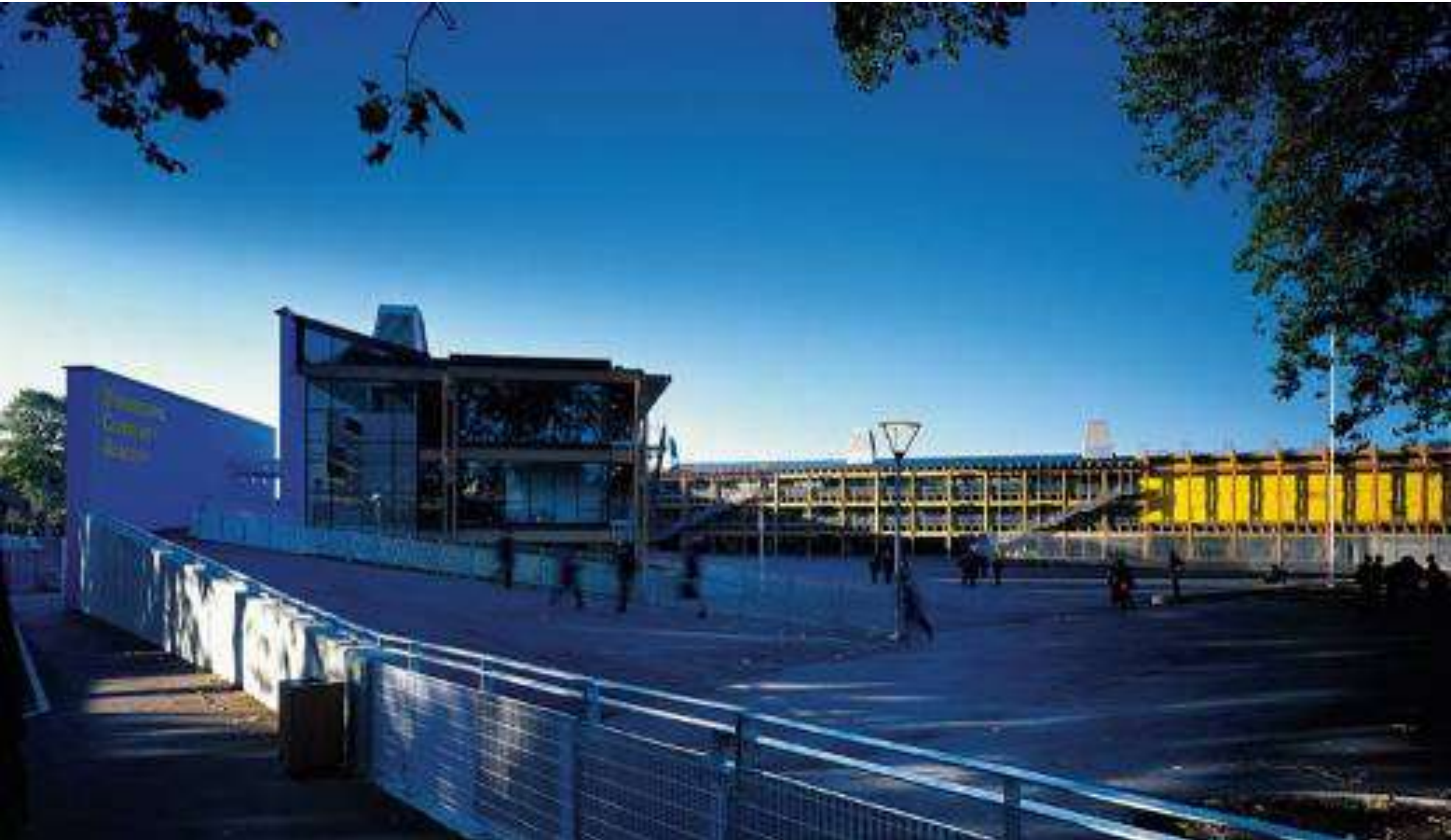
Section: 1:50 @ A3

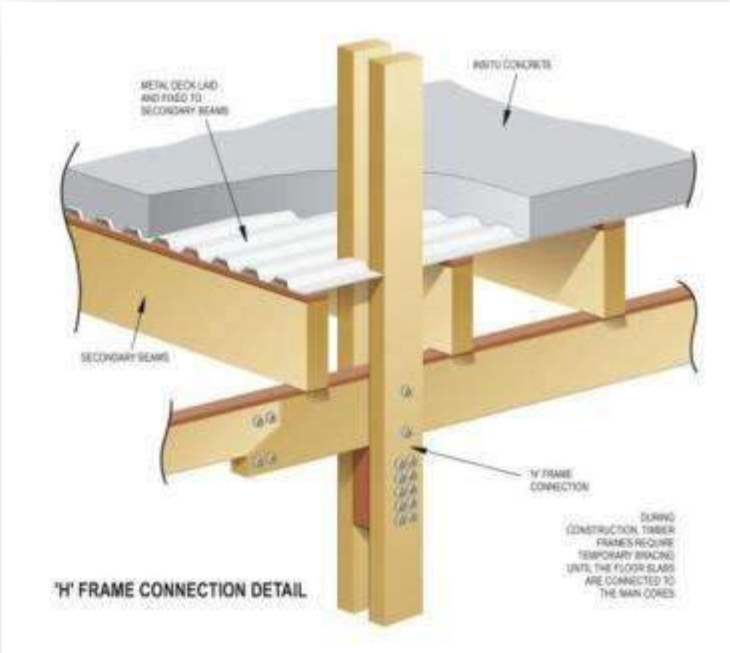


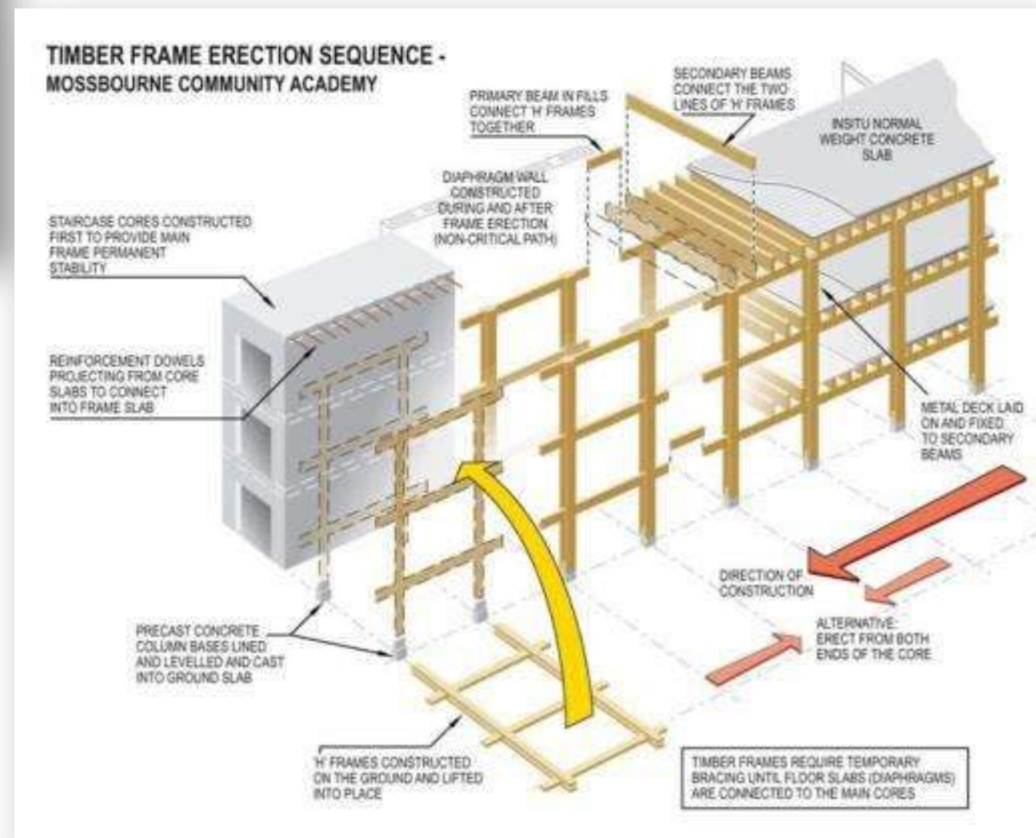
whitbybird
ENGINEERS
SKO

Job No: 3712
Job Title: SmartLIFE 1:50 @ A3
Date: Dec 2004
Ref: SECTION

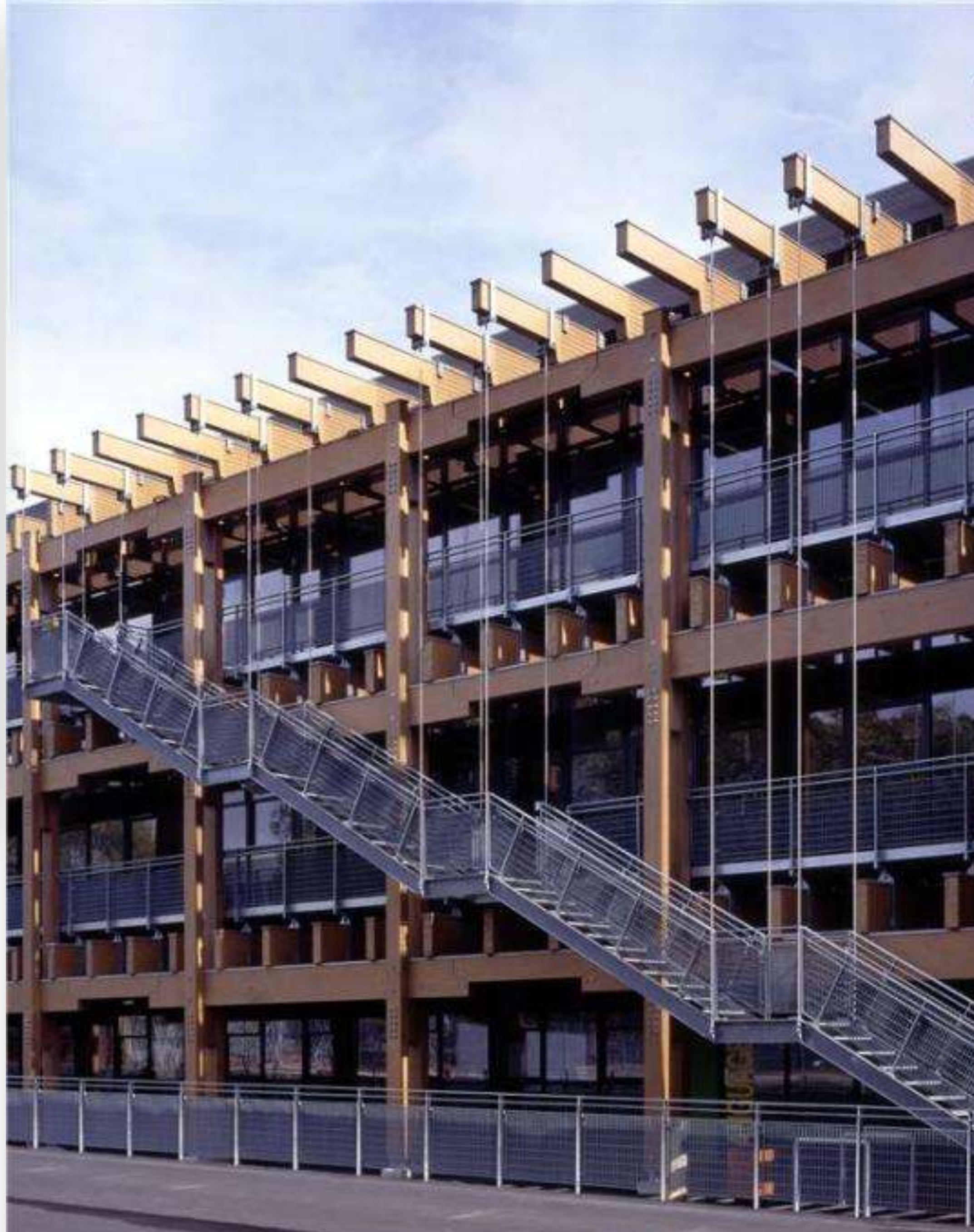
Mossbourne Academy, London



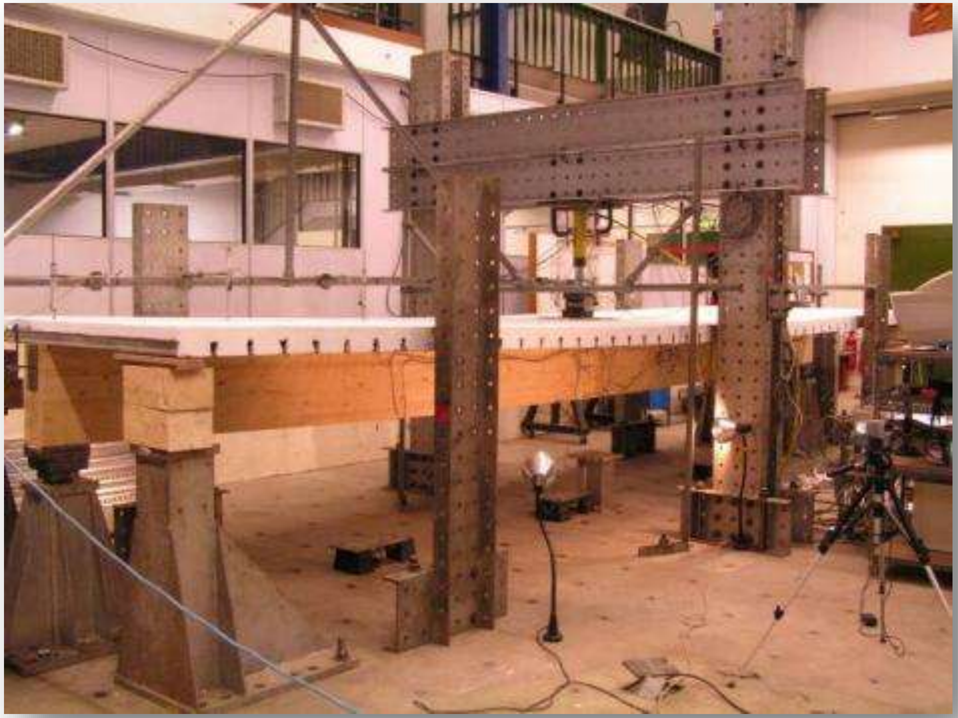

INSITU CONCRETE
METAL DECK LAID AND FIXED TO SECONDARY BEAMS
SECONDARY BEAMS
'H' FRAME CONNECTION
DURING CONSTRUCTION, TIMBER FRAMES REQUIRE TEMPORARY BRACING UNTIL THE FLOOR SLABS ARE CONNECTED TO THE MAIN CORES
'H' FRAME CONNECTION DETAIL

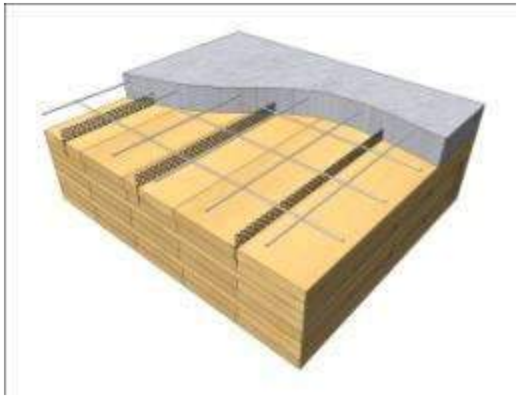

TIMBER FRAME ERECTION SEQUENCE -
MOSSBOURNE COMMUNITY ACADEMY
PRIMARY BEAM IN FILLS CONNECT 'H' FRAMES TOGETHER
SECONDARY BEAMS CONNECT THE TWO LINES OF 'H' FRAMES
INSITU NORMAL WEIGHT CONCRETE SLAB
DIAPHRAGM WALL CONSTRUCTED DURING AND AFTER FRAME ERECTION (NON-CRITICAL PATH)
STAIRCASE CORES CONSTRUCTED FIRST TO PROVIDE MAIN FRAME PERMANENT STABILITY
REINFORCEMENT DOWELS PROJECTING FROM CORE SLABS TO CONNECT INTO FRAME SLAB
METAL DECK LAID ON AND FIXED TO SECONDARY BEAMS
DIRECTION OF CONSTRUCTION
ALTERNATIVE: ERECT FROM BOTH ENDS OF THE CORE
PRECAST CONCRETE COLUMN BASES LINED AND LEVELLED AND CAST INTO GROUND SLAB
'H' FRAMES CONSTRUCTED ON THE GROUND AND LIFTED INTO PLACE
TIMBER FRAMES REQUIRE TEMPORARY BRACING UNTIL FLOOR SLABS (DIAPHRAGMS) ARE CONNECTED TO THE MAIN CORES


MATHEMATICS



Timber concrete composite floor





BGS, Nottingham


Pos 103/8

St John Fisher School, Peterborough

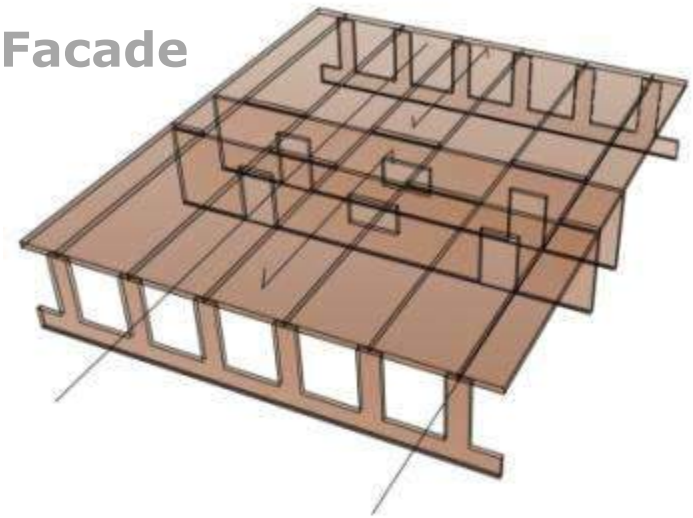

AINSCOUGH
Fisher School
WIEHAG

Open Academy, Norwich

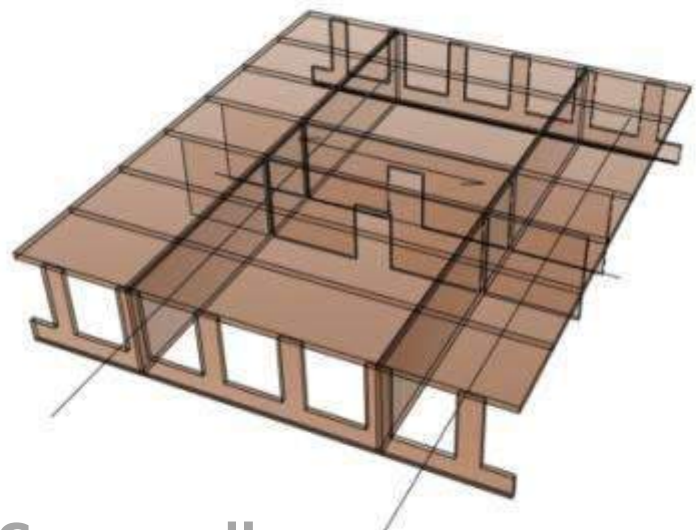
City Academy, Norwich


AINSCOUGH
ACCESS RENTALS

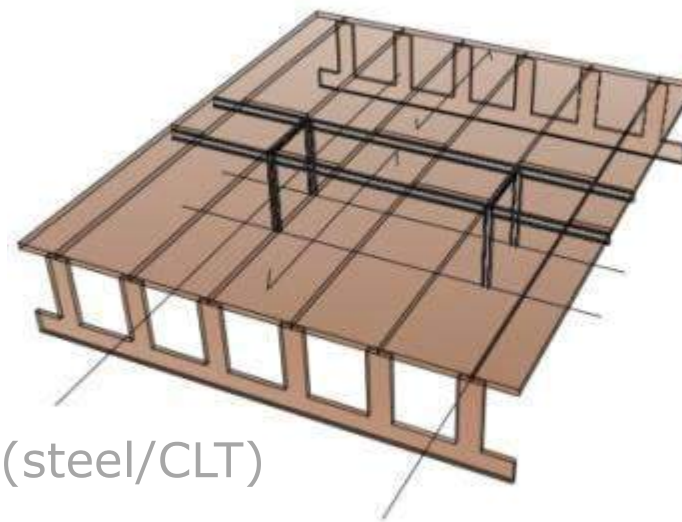
Structural frame options



Loadbearing Facade



Crosswall



‘Hybrid’ (steel/CLT)

Other timber structures

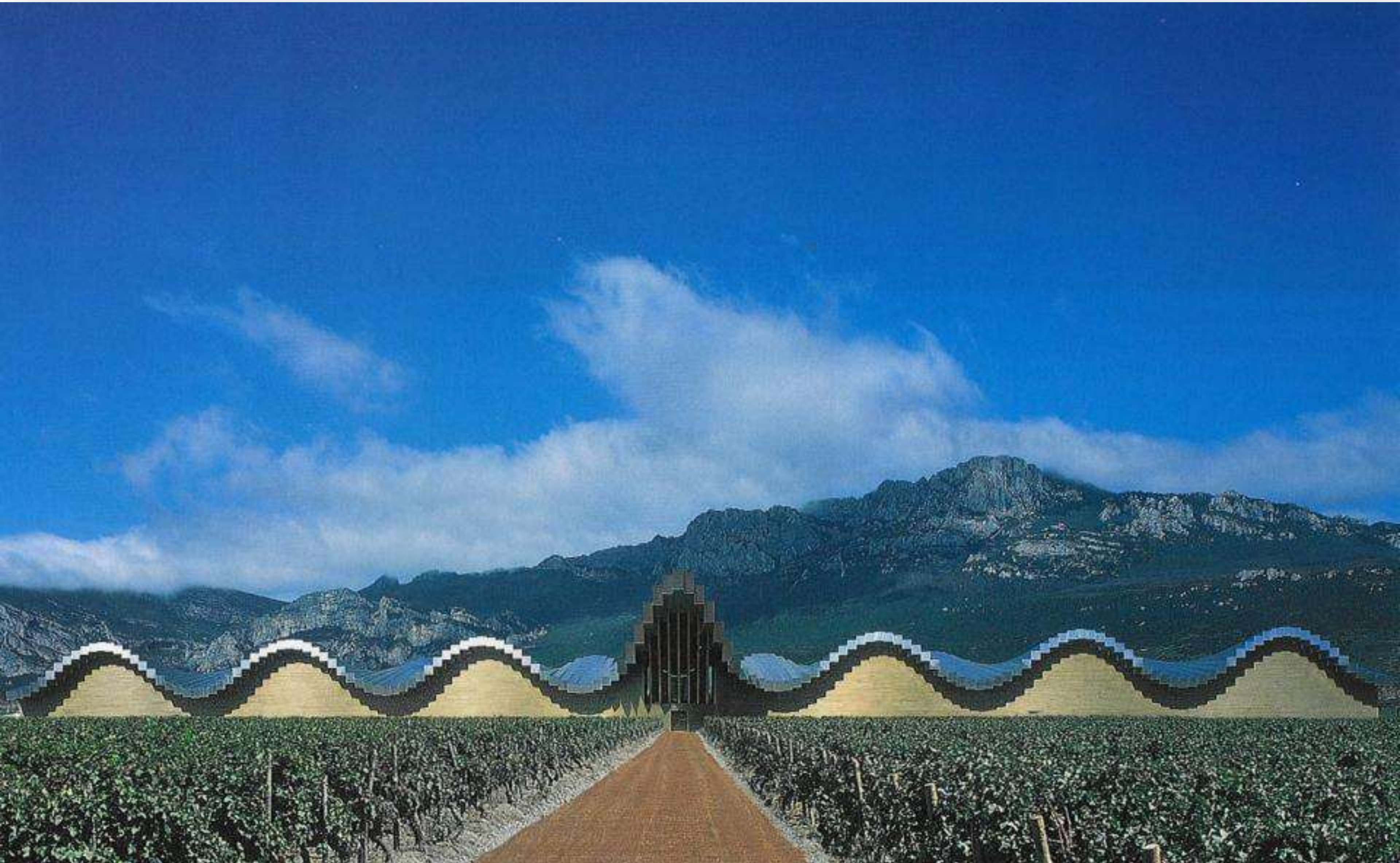
- Buildings
- Bridges
- Etc.

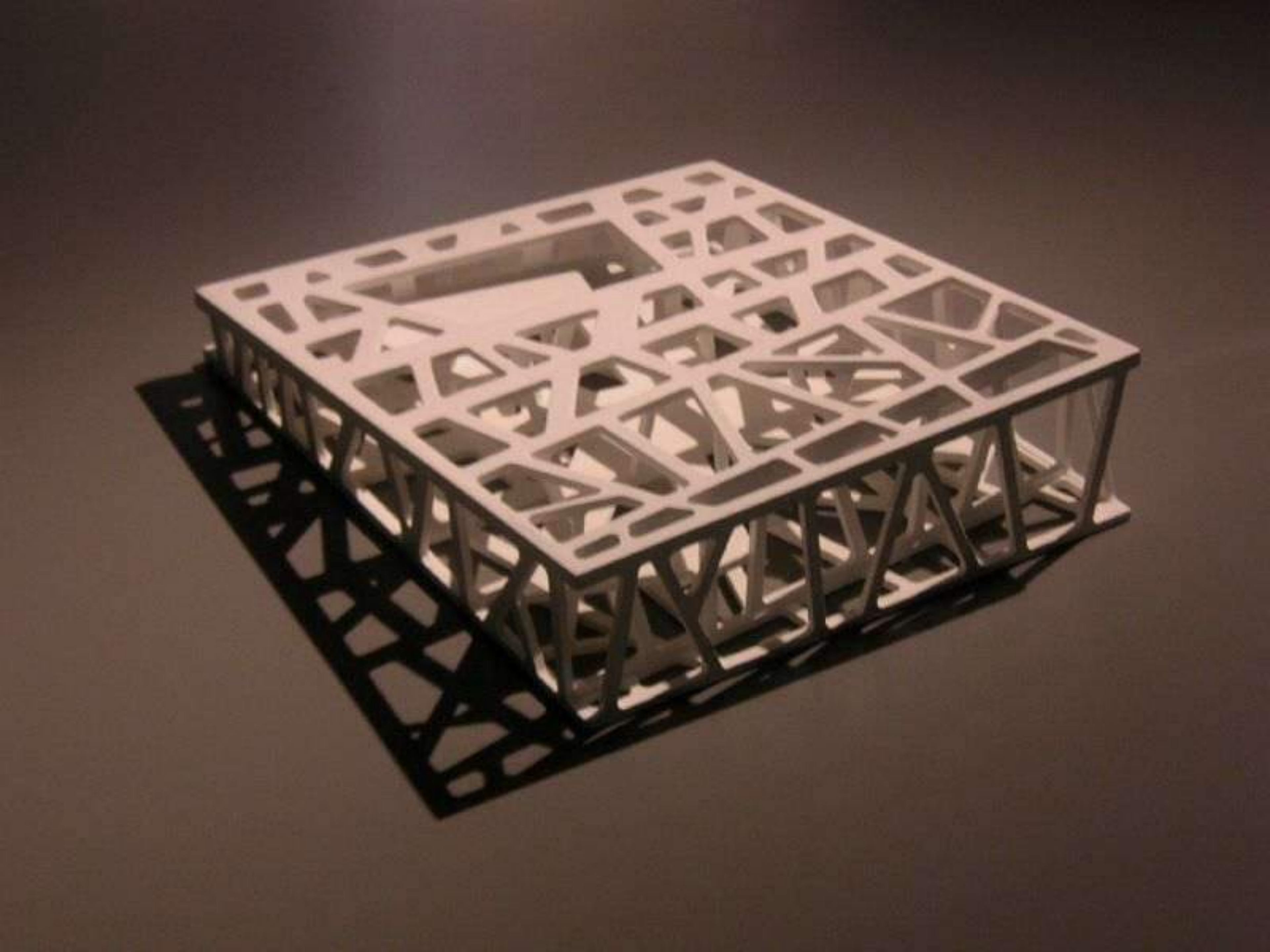
Buildings

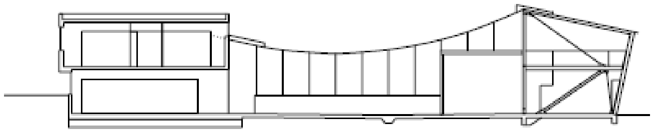
Tamedia office building - Zurich

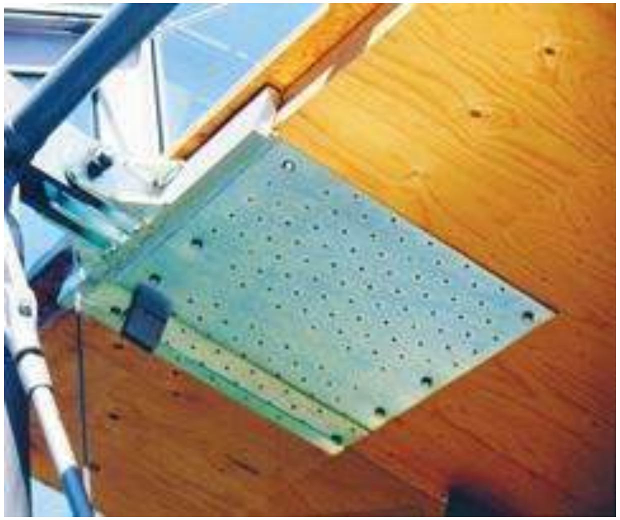
by Shigeru Ban Architects



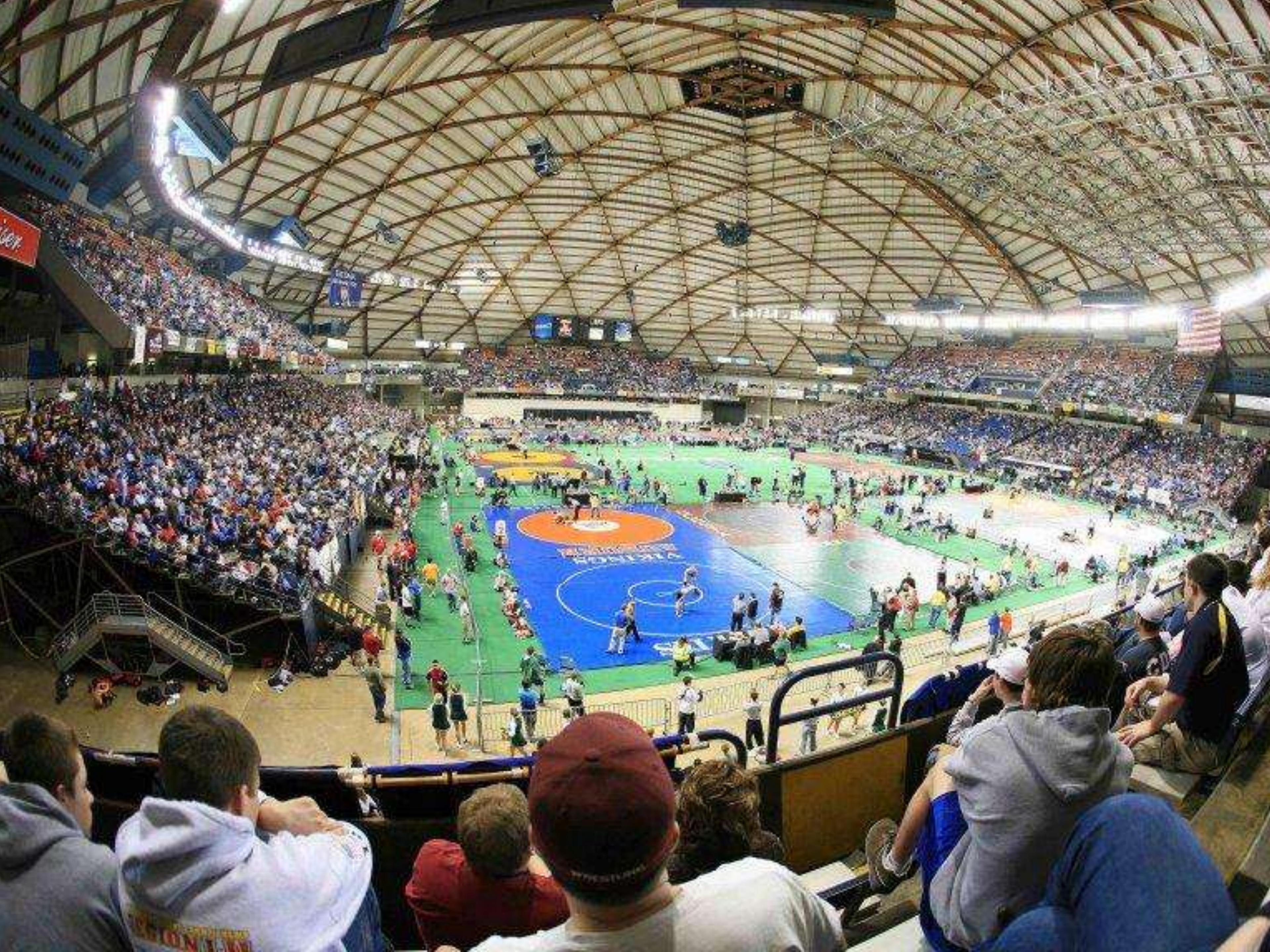

PERI

L'Aquila, Italy

- Earthquake rebuilding
  - 381 apartments in 2 phases
  - 11,000m3 of cross laminated timber
  - Fast track construction

Skelleftea, Sweden

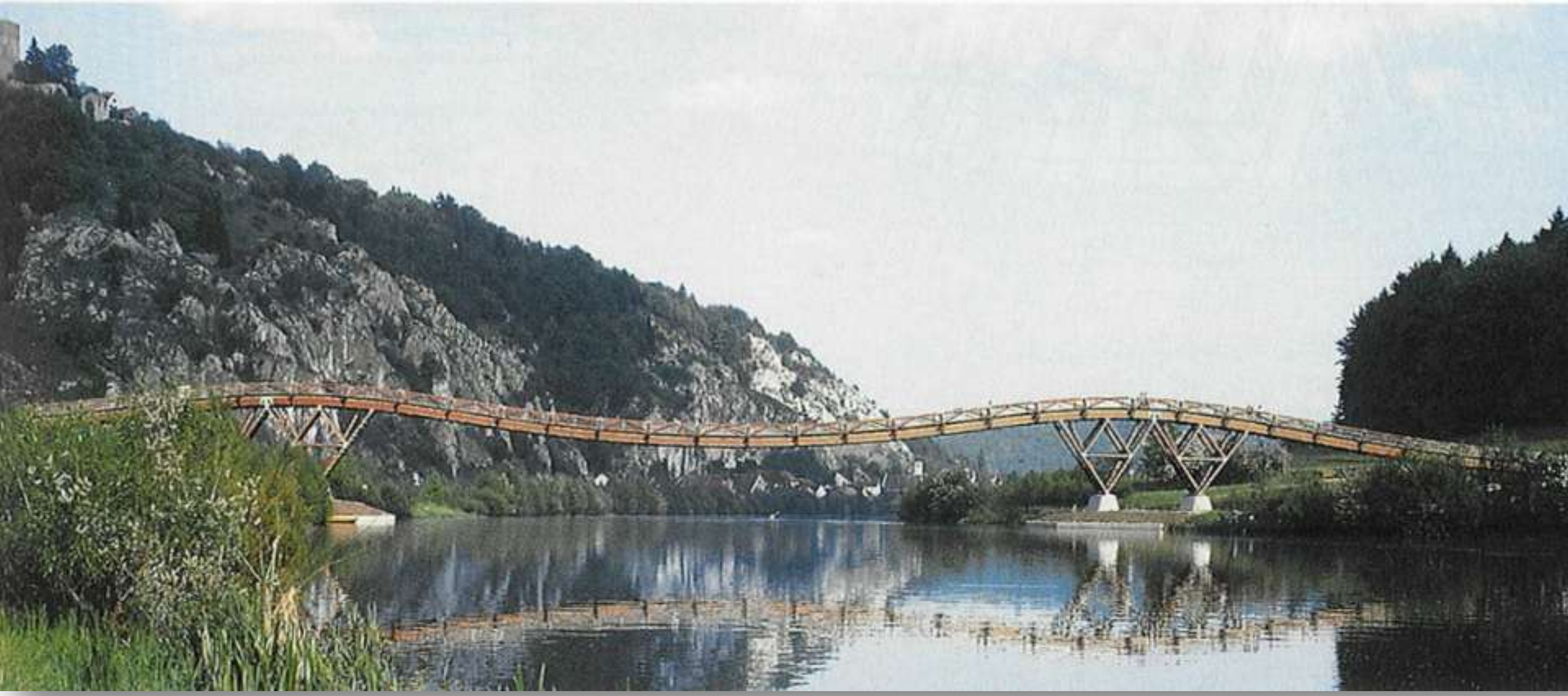
- Mixed use timber building
  - 141 space multi-storey car park
  - Cross laminated timber
  - Fire engineered



Bridges



5 8 2004



Other….