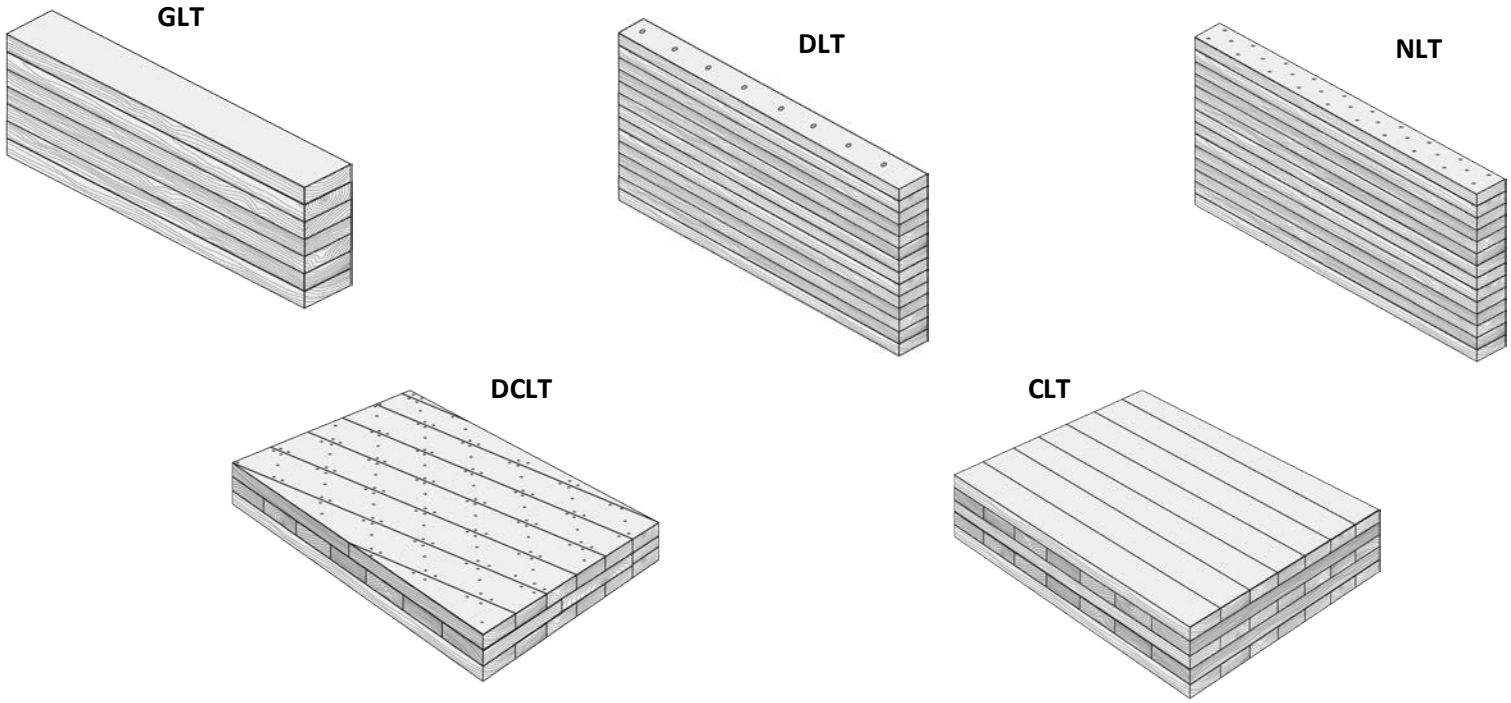
Edinburgh Napier UNIVERSITY

Centre for Offsite Construction + Innovative Structures

Research Methodology Into Mass Timber Systems:

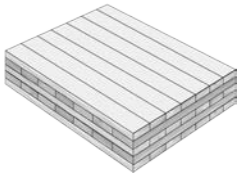
- *Cross laminated timber*
- *Glue laminated timber*
- *Nail laminated timber*
- *Dowel laminated timber*

Wojciech Plowas



COCIS Research Into Mass Timber Systems – UK Cross laminated timber

Outputs:



- ❑ The mechanical properties are comparable to the commercially made product
- ❑ UK Sitka spruce can be processed to the requirements necessary for CLT
- ❑ UK CLT from spruce have been manufactured at commercial CLT facility in Germany (W.u.J Derix GmbH)
- ❑ Small scale demonstration of UK CLT

Fig 1: UK CLT – Pilot manufacture

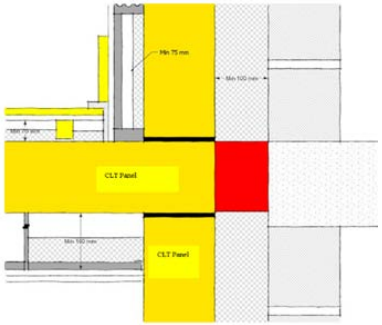


Fig 2: UK CLT – Design and analysis

Fig 3: UK CLT – Pilot project

UK species investigated: *Sitka Spruce, Scots Pine, Douglas Fir, Western Hemlock, Lawson Cypress, Larch*

COCIS Research Into Mass Timber Systems – UK Glue laminated timber

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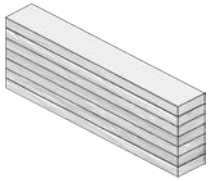


- Approx. 90% of GLT in the UK is imported from Scandinavia, Austria or Germany
- UK GLT is a viable alternative to commercial products in terms of structural performance
- With appropriate optimisation, UK GLT could be utilised for domestic construction
- Its possible to fabricate GL20c-GL24c using a home-grown resource

Fig 4: UK GLT – Pilot manufacture

Fig 5: UK GLT – Bending tests

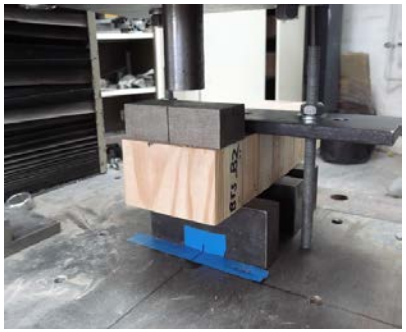
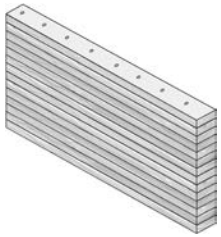


Fig 6: UK GLT – Shear tests

UK species investigated: *Sitka Spruce, Scots Pine, Douglas Fir and Larch*

COCIS Research Into Mass Timber Systems – UK Dowel laminated timber

Outputs:



- ❑ DLT is a product that can be developed within the UK using the local resource
- ❑ UK grown timber could be used to manufacture DLT for floors and walls
- ❑ Focus of the DLT application should be within the domestic housing market
- ❑ Optimum DLT specification: 30mm thick laminations (Larch) + 20mm beech dowels

Fig 7: DLT – Pilot manufacture

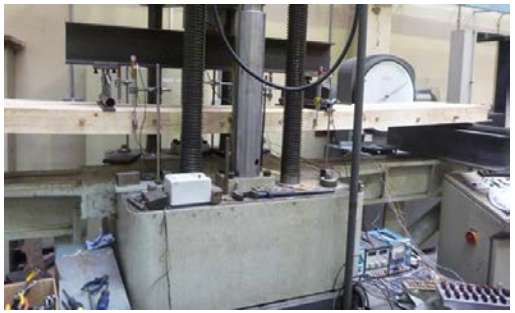


Fig 8: DLT – Bending tests

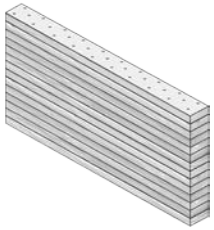
Fig 9: DLT – Pilot project

UK species investigated (lamellae): *Sitka Spruce, Scots Pine and Larch*

UK species investigated (dowels): *Birch, Scots Pine, Beech, Ash, Sycamore and Oak*

COCIS Research Into Mass Timber Systems – UK Nail laminated timber

Outputs:



- ❑ UK NLT exhibit higher racking strength and a similar stiffness to timber frame panels.
- ❑ Tests showed that the addition of 9mm OSB leads to lower overall deflections
- ❑ Aluminium nailing, would lead to greater costs due to about 10% wastage on the nails
- ❑ Tests showed that aluminium nails lead to greater deflections at serviceability limits

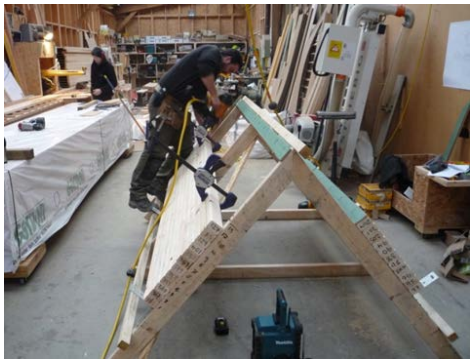


Fig 10: NLT – Pilot manufacture

Fig 11: NLT – Point load tests

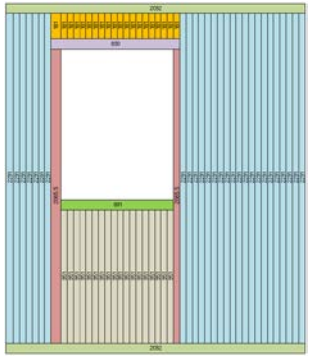


Fig 12: NLT – Fabrication drawing

UK species investigated (lamellae): *Sitka Spruce*

Research Methodology Into Mass Timber Systems

Objectives:

- ❑ To compile existing information and demonstrate the uses of Mass Timber in the UK
- ❑ To develop consistent research methodology into Mass Timber systems
- ❑ To identify gaps in knowledge and propose future work needed for commercialisation

Research Methodology into Mass Timber Systems:

Step 1 – Mass Timber Product
- Description
- Applications
- Manufacturing process

Step 2 - Preliminary investigation
- Market review
- Potential manufacturers
- Resource availability
- Lamella characterisation
- Lamella lay-up and geometry
- Adhesive, nails or dowels

Step 3 - Compliance criteria
- Mechanical resistance
- Bond strength
- Durability
- Resistance and reaction to fire
- Release of dangerous substances

Step 4 – Pilot Manufacture
- Panels manufactured
- Production environment
- Manufacture appraisal

Step 5 - Primary investigation
- Properties derived from calculations
- Tests on full scale panels
- Verification of the results

Step 6 - Design and Analysis
- Applying test results to building scenarios
- Detailing to BS
- Performance modelling
- Identifying best end use

Step 7 - Pilot Project
- Trial product on a pilot project
- Full process appraisal

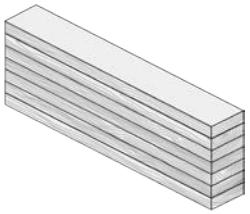
Step 8: Future work
- Further development
- Identifying barriers
- Product certification
- Promotion

Step 1 – Mass Timber Product

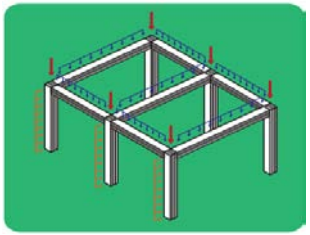
- Description
- Applications
- Manufacturing process

Step 1 - Product review & applications

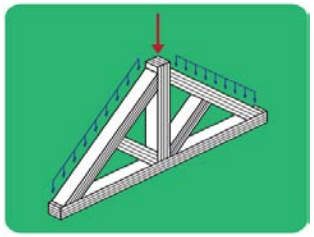
Glue laminated timber:



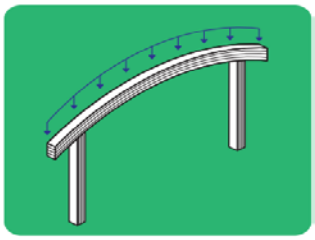
Post and Beam



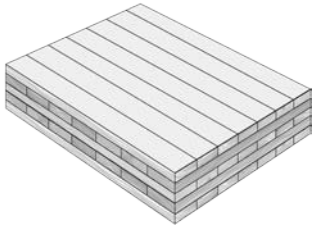
Featured trusses



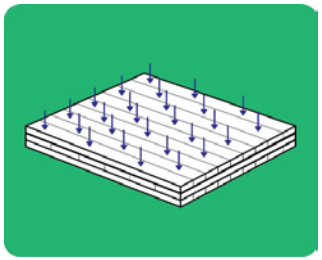
Curved structural shape



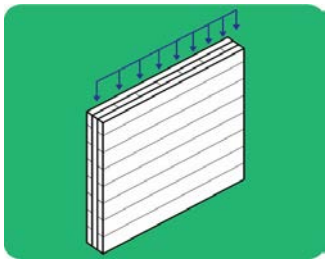
Cross laminated timber:



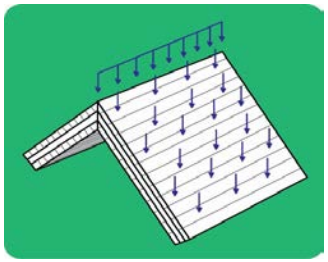
Floor:



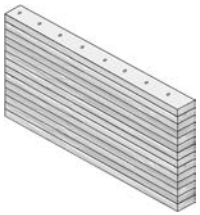
Wall:

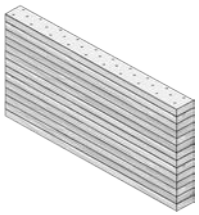


Roof:

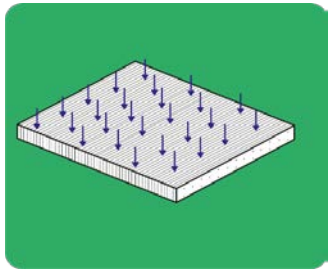


Nail laminated timber & Dowel laminated timber:

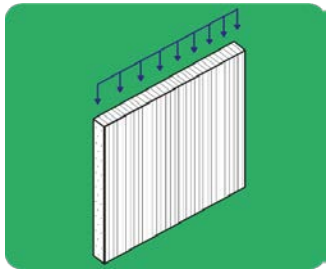




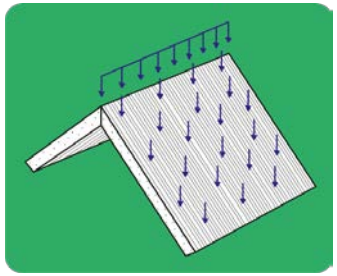
Floor:



Wall:



Roof:



Step 1 - Product review & applications (cont.)

Structural applicability of Mass Timber Systems:

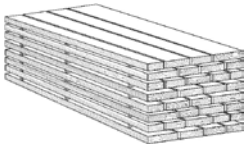
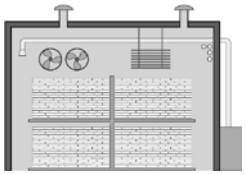
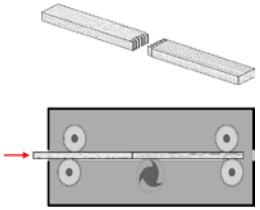
OFTEN USED	SOMETIMES USED	NOT USED BUT POSSIBLE	NOT APPLICABLE
•••	••	•	

		LOW RISE 1-4 storeys						MID RISE 5-10 storeys					
		frame	wall	roof	floor	core	partition	frame	wall	roof	floor	core	partition
GLUED SOLID TIMBER	CLT	•	•••	•••	•••	•••	•••		•••	•••	•••	••	••
	GLT	•••		••	••						••		
NON-GLUED SOLID TIMBER	DLT		•••	••	••	•••	•		•	•	••	•	
	NLT		•••	••	••	•••	•		•	•	••	•	

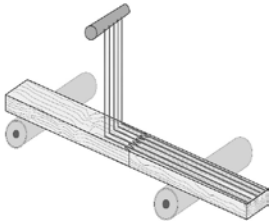
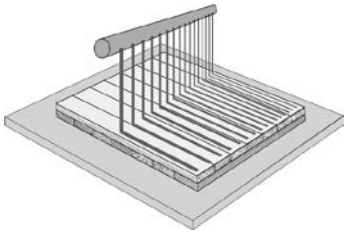
Step 1 - Manufacturing process

- ❑ Processes involved
- ❑ Equipment needed
- ❑ Standard requirements
- ❑ Skills required

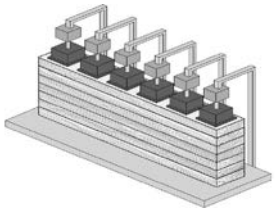
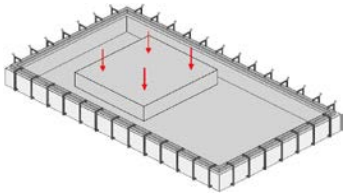
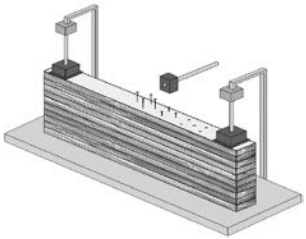
Board preparation:

Adhesive application:

Pressing/Nailing:

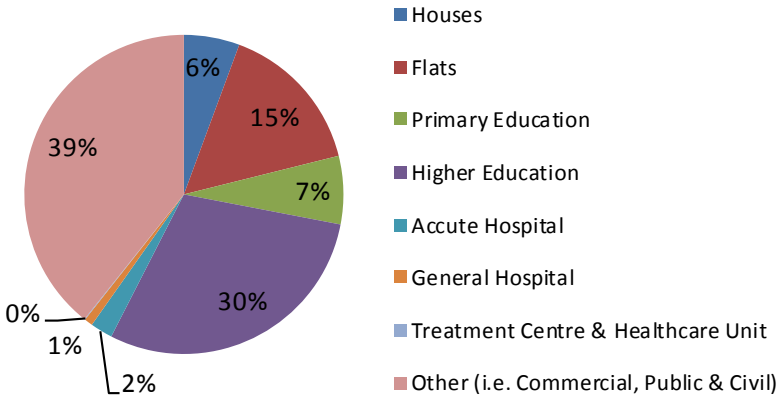
Step 2 - Preliminary investigation

- Market review
- Potential manufacturers
- Resource availability
- Lamella characterisation
- Lamella lay-up and geometry
- Adhesive, nails or dowels

Step 2 - Preliminary investigation

- ❑ Market review
- ❑ Resource availability
- ❑ Lamella characterisation
- ❑ Lamella layup and geometry
- ❑ Adhesive characteristics
- ❑ Nail/dowel characteristics

Potential mass timber volume share by sector:



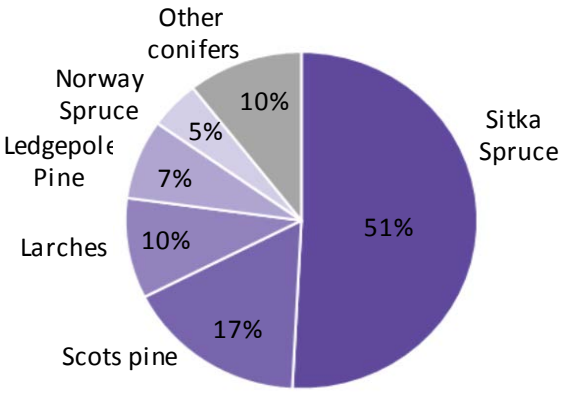
Mass Timber Systems - approximate minimum start-up capital investment requirements:

CapEx (Approx.)	Mass Timber System	Rational
High > €5M	Cross laminated timber (CLT)	• Stringent product approval and quality assurance requirements • Production line requires high level of quality control • Normally integrated with pre-lamination process of grading and finger-jointing • Normally integrated with post-lamination process of CNC machining.
Med > €2M	Nail laminated timber (NLT) & Dowel laminated timber (DLT)	• Facilities are generally low to medium capacity, given that the product application is restricted to 'niche' low rise, one-off housing or low-rise commercial and public sector building. • Normally integrated with post-lamination process of CNC machining.
Low < €2M	Glue laminated timber(GLT)	• Facility can be set up for low volume application with graded timber supplied as required

Step 2 - Preliminary investigation (cont.)

- ❑ Market review
- ❑ Resource availability
- ❑ Lamella characterisation
- ❑ Lamella layup and geometry
- ❑ Adhesive characteristics
- ❑ Nail/dowel characteristics

50-year forecast of softwood availability (FC, 2014):



Grading trades yield for strength class (single grade/reject):

Species	Grading trades yield for class (single grade/reject)						
	C14	C16	C18	C20	C22	C24	C27
British spruce [1]	100%	100%	90%	73%	55%	26%	9%
			Remaining timber grade to C16				
UK-grown larch [2]	100%	100%	100%	100%	90%	65%	≈35%
					Remaining timber grade to C14 or C16		

[1] Sitka spruce and Norway spruce combined from UK and Ireland

[2] Hybrid, Japanese and European larch

Step 3 - Compliance criteria

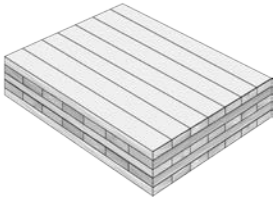
- Mechanical resistance
- Bond strength
- Durability
- Resistance and reaction to fire
- Release of dangerous substances

Step 3 - Compliance Criteria & assessment methods

- ❑ Mechanical resistance
- ❑ Durability
- ❑ Resistance to fire
- ❑ Bonding strength
- ❑ Dimensional stability
- ❑ Reaction to fire

Compliance criteria & assessment methods for CLT:

Based on: BS EN 16351:2015 *'Timber structures — Cross laminated timber — Requirements*



CLT

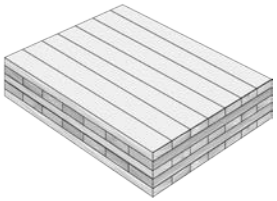
Characteristic	Symbol	Assessment method	Test Standard	No. of tests	Notes/Compliance Criteria
1. Mechanical properties perpendicular to the plane of cross laminated timber					
1.1 Modulus of Elasticity	$E_{0,mean}$	Bending test	BS EN 16351:2015 & BS EN 408:2010	7-15	No. of test depend on the width of specimens. Test setup as per BS EN 16351:2015 cl. F3.1
1.2 Bending Strength	$f_{m,k}$				
1.3 (Rolling) Shear stiffness	$G_{9090,mean}$	Shear test	BS EN 16351:2015 &/or EN 789:2004	7-15	Number of test depend on the width of specimens possible test set ups
1.4 (Rolling) Shear strength	f				
1.5 Compressi					-
1.6 Tensile Stre					-
2.1 Modulus of					setup as per BS EN 6351:2015 cl. F4.1
2.2 Bending Str					
2.3 Shear stiffness	$G_{090,mean}$	Bending test	BS EN 16351:2015 & BS EN 408:2010	20	Test setup as per BS EN 16351:2015 cl. F4.4
2.4 Shear strength	$F_{v,090,k}$	Shear test	BS EN 16351:2015 & BS EN 408:2010	20	Test setup as per BS EN 16351:2015 cl. F4.2
2.5 Compressive Strength	$f_{c,0,k}$	Compression test	BS EN 408:2010	30	-
2.6 Tensile Strength	$f_{t,0,k}$	Tension test	BS EN 408:2010	30	-
3. Bonding strength of cross laminated timber					
3.1 Bonding Strength of glue lines between layers	*Delam* (%)	Delamination test	BS EN 16351:2015	10	Declared as Pass Delam or Pass Shear
	f_v	or Shear test	BS EN 16351:2015	10	
4. Resistance to fire of cross laminated timber					
4.1 Geometrical data	L, t, w	Measurement	BS EN 16351:2015 & EN 14081–1	3	Charring rate (of layers), declared based on species used and strength class
4.2 Density of timber	ρ	Assess, check or test	BS EN 16351:2015 & EN 14081–1	3	
4.3 Species	-	Check	BS EN 16351:2015	-	
5. Reaction to fire of cross laminated timber					
5.1 Reaction to Fire	-	Check	EN 14081–1	-	Declared based on fire class of layers or tests
	-	or Fire test	EN 13501-1	-	
6. Dimensional stability of cross laminated timber					
6.1 Moisture deformation factor or species	k_{cor}	Check	BS EN 16351:2015	-	Check that species listed in BS EN 16351 are used
7. Release / content of dangerous substances					
7.1 Formaldehyde emission	E1, E2	Check or test	BS EN 16351:2015	-	Declared as formaldehyde release class (E1 or E2)
8. Durability of bonding strength & against biological attack					
8.1 Species	-	Check	BS EN 16351:2015	-	-
8.2 Adhesive characteristic	-	Check or test	BS EN 16351:2015		Usually provided by adhesive/preservative manufacturer
8.4 Preservative treatment	-	Check or test	BS EN 16351:2015		

(NOTE: all mechanical properties of CLT can also be derived from calculations)

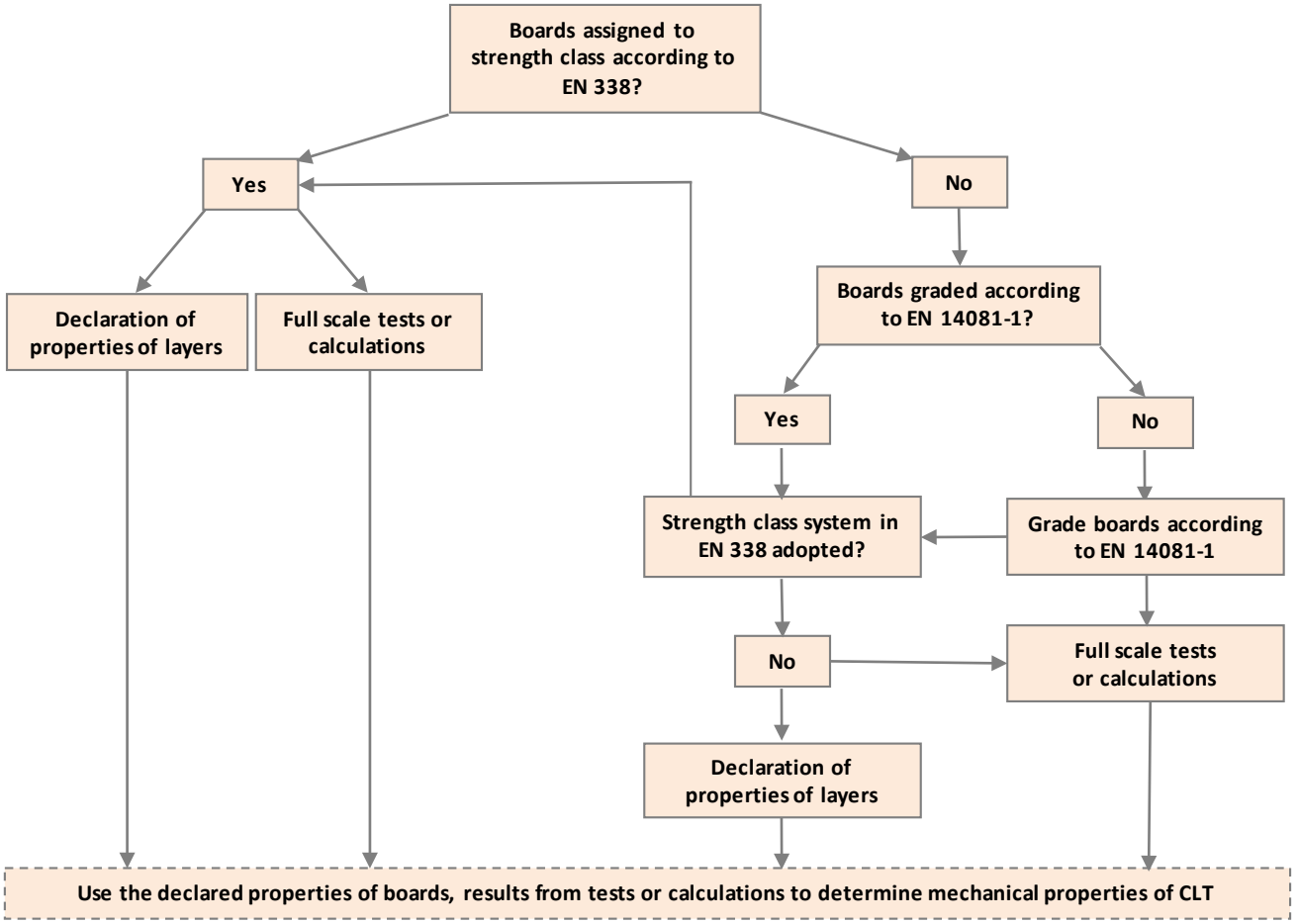
Step 3 - Compliance Criteria & assessment methods

- ❑ Mechanical resistance
- ❑ Durability
- ❑ Resistance to fire
- ❑ Bonding strength
- ❑ Dimensional stability
- ❑ Reaction to fire

Verification of Mechanical Resistance of CLT:



CLT

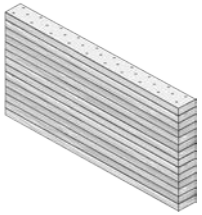


Step 3 - Compliance Criteria & assessment methods

- ❑ Mechanical resistance
- ❑ Durability
- ❑ Resistance to fire
- ❑ Bonding strength
- ❑ Dimensional stability
- ❑ Reaction to fire

Compliance criteria & assessment methods for NLT:

Based on: EAD 130011-00-0304 *'Prefabricated wood slab element made out of mechanically jointed square-sawn timber members to be used as a structural elements in buildings'*



NLT/DLT

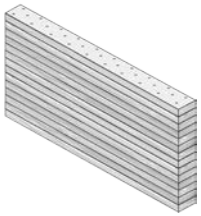
(NOTE: all mechanical properties of NLT can also be derived from calculations)

Characteristic	Symbol	Assessment method	Test Standard	No. of tests	Notes/Compliance Criteria
1. Mechanical properties perpendicular to the plane of nail laminated timber					
1.1 Modulus of Elasticity	$E_{0,mean}$	Bending test	BS EN 408:2010	30	Bending tests in accordance with EN 408 cl. 9, 10 and 19
1.2 Bending Strength	$f_{m,k}$				
1.3 Compressiv					EN 408 cl. 15,16
1.4 Tensile Stren					EN 408 cl. 13
2.1 Modulus of E					cordance with 10 and 19
2.2 Bending Stre					
2.3 Shear stiffne					EN 408 cl. 19
2.4 Shear strength	$F_{v,090,k}$				
2.5 Compressive Strength	$f_{c,0,k}$	Compression test		30	Testing according to EN 408 cl. 15,16
2.6 Tensile Strength	$f_{t,0,k}$	Tension test		30	Testing according to EN 408 cl. 13
1.3 (Racking) Shear stiffness	R	Racking test	BS EN 594:2011	30	Shear tests may be performed following the principles of EN 594
1.4 (Racking) Shear strength	F_{max}				
3. Dimensional stability of nail laminated timber					
3.1 Tolerances of dimensions	L, w, d	Check/Measurement	EN 1309-1	-	Dimensional changes due to varying MC shall not have inadmissible effects on performance and stability of NLT
3.2 Stability of dimensions	MC (%)	Check/Measurement		-	
4. Durability / In-service environment					
4.1 Species	-	Check	EN 350-2	-	Service class to EC5 shall be given
5. Reaction to fire of nail laminated timber					
5.1 Reaction to Fire	-	Check	EN 14081–1	-	Declared based on fire class of layers or tests
	-	or Fire test	EN 13501-1	-	
6. Resistance to fire of nail laminated timber					
4.1 Geometrical data	L, w, d	Measurement	EN 14081–1 and/or EN 13501-2	-	Charring rate (of layers), declared based on species used and strength class
4.2 Density of timber	ρ	Assess, check or test		-	
4.3 Species	-	Check		-	
7. Other requirements					
7.1 Water vapour permeability	μ	Test	EN ISO 10456	-	-
7.2 Airborne sound insulation	R	Test	EN ISO 10140-2	-	-
7.3 Impact sound insulation	$L_{n,w}$ (C_I)	Test	EN ISO 10140-3	-	-
7.4 Thermal conductivity	λ	Check	EN ISO 10456	-	-
7.5 Air permeability	Class A-C	Test	EN 12114	-	-
7.6 Thermal inertia	c_p	Check	EN ISO 10456	-	-
7.3 Impact sound insulation	$L_{n,w}$ (C_I)	Test	EN ISO 10140-3	-	-
7.4 Thermal conductivity	λ	Check	EN ISO 10456	-	-
7.5 Air permeability	Class A-C	Test	EN 12114	-	-
7.6 Thermal inertia	c_p	Check	EN ISO 10456	-	-

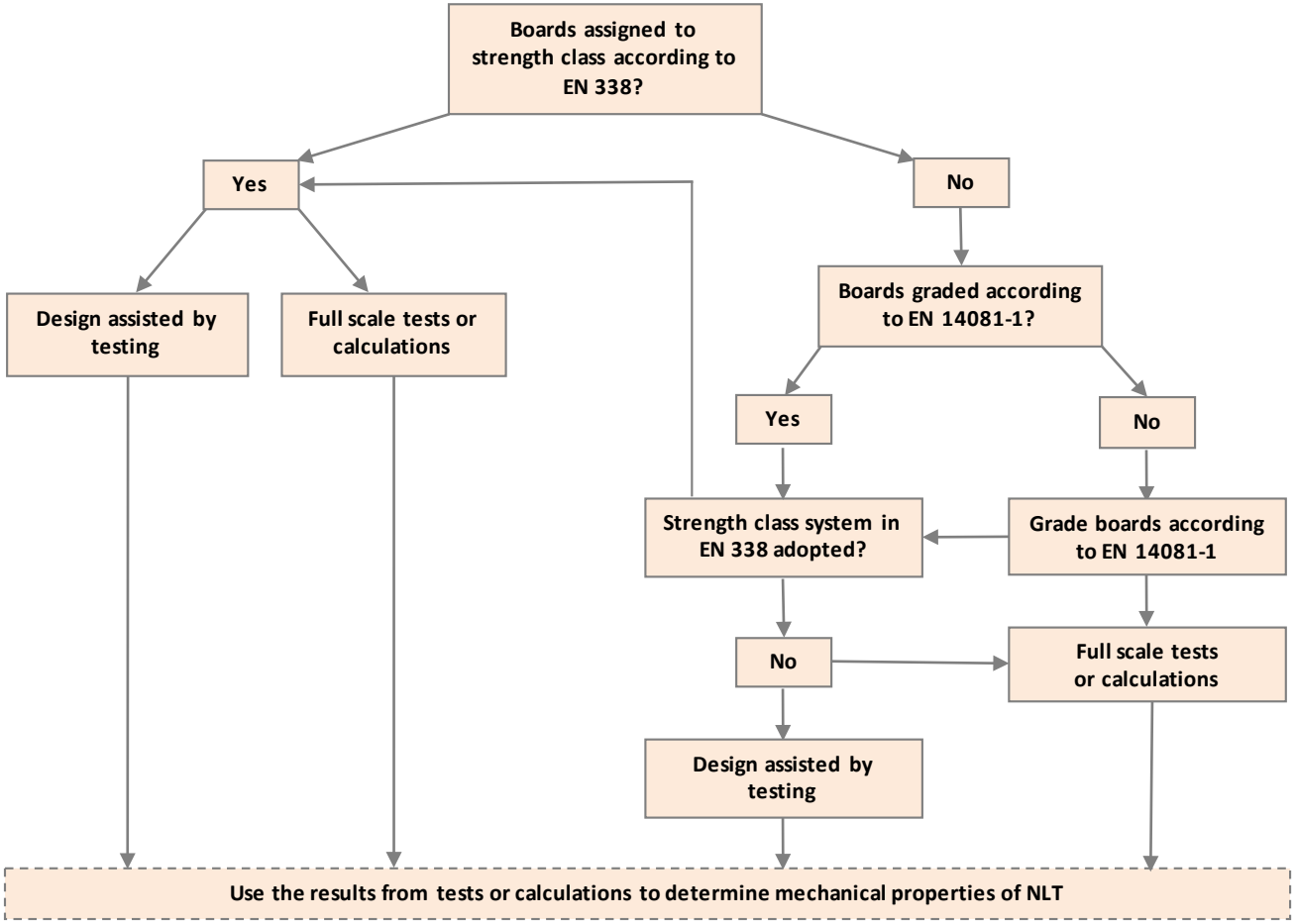
Step 3 - Compliance Criteria & assessment methods

- ❑ Mechanical resistance
- ❑ Durability
- ❑ Resistance to fire
- ❑ Bonding strength
- ❑ Dimensional stability
- ❑ Reaction to fire

Verification of Mechanical Resistance of NLT & DLT:



NLT/DLT



Step 4 – Pilot Manufacture

- Panels manufactured
- Production environment
- Manufacture appraisal

4. Pilot Manufacture – UK CLT

- ❑ Specification of manufactured panels
- ❑ Production environment assessment
- ❑ Manufacture appraisal

Pilot manufacture of UK CLT:

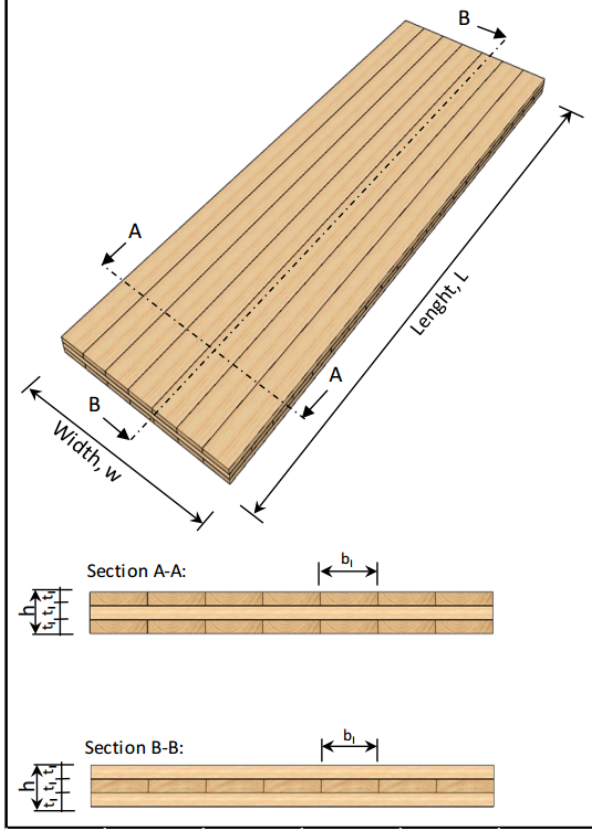
UK Timber species:
Sitka Spruce, Scots pine, Douglas fir, Western Hemlock, Lawson Cypress

Manufactured by:
W.u.J. Derix GmbH (Germany), Norbuild

Press types:
Hydraulic and Vacuum

Adhesives used:
Purbond HB S709, Melanine Urea Formaldehyde (MUF) 1255/7555

CLT - UK Sitka Spruce (Derix)



Cross laminated timber element	
Wood species:	UK Sitka Spruce
Number of layers:	3 ≤ n ≤ 5
Layer thickness and orientation (3ply):	30l-40c-30l
Layer thickness and orientation (5ply):	40l-30c-30l-30c-40l
Strength class of layers:	100% C16
Panel width, w:	2.9 to 3.0 m
Panel length, L:	10.5 to 13.5 m
Panel depth, h:	100 to 170 mm
Type of adhesive:	(MUF) 1255/7555
Bonded surface:	Face
Large finger joints:	No
Manufactured by:	W.u.J. Derix GmbH
Controlled environment:	Yes
Year of manufacture:	2014
Press type:	Hydraulic press
Number of panels manufactured:	2
Boards	
Strength graded to EN 14081:	Yes
Strength class:	C16
Surface:	Planed
Thickness, t_l	30 to 40 mm
Width, b_l	100 to 170 mm
Ratio width to thickness	≥ 4:1
Finger joints	Yes
Moisture content to EN 13183-2:	11 - 15%
Mean Densiy	415 kg/m^3

4. Pilot Manufacture – UK GLT

- ❑ Specification of manufactured panels
- ❑ Production environment assessment
- ❑ Manufacture appraisal

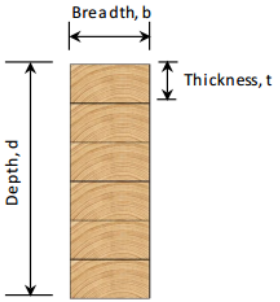
Pilot manufacture of UK GLT:

UK Timber species:
Sitka Spruce, Scots pine, Douglas fir, Larch

Manufactured by:
Norbuild, Buckland Timber, Wood Knowledge Wales

Press types:
Hydraulic/mechanical

Adhesives used:
Purbond HB S309, Melanine Urea Formaldehyde (MUF) BASF Kauramin

Sitka Spruce Pilot manufacture of GLT	
	
Glue Laminated Timber element	
Breadth, b	86 mm
Depth, d	252 mm
Length	4800 mm
Number of layers	6
GLT type	Combined
GLT strength class	N/A
Large finger joints	N/A
Adhesive	Purbond HB S309
Manufactured by	Norbuild
Manufactured to EN 14080	Yes
Boards	
Material	Sitka Spruce
Strength graded to EN 14081-2	No
Strength class	N/A
Thickness, t	42 mm
Finger joints	N/A
Moisture content to EN 13183-2	≈15% (avg.)
Mean Density to EN 384	397 kg/m^3

4. Pilot Manufacture

- ❑ Specification of manufactured panels
- ❑ Production environment assessment
- ❑ Manufacture appraisal

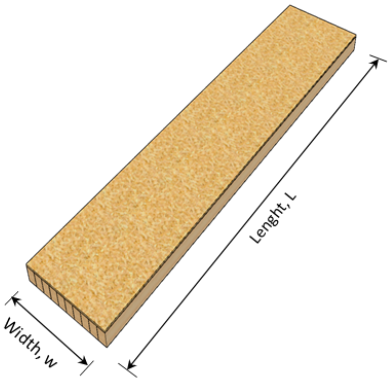
Pilot manufacture of UK NLT:

UK Timber species:
Sitka Spruce

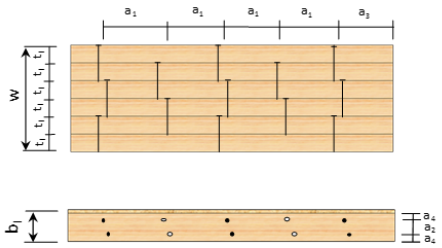
Manufactured by:
MAKAR

Fixings used:
3.1 mm Ring shank nails (ITW)

NLT - UK Sitka Spruce



Nail spacing and plank lay-up:

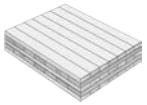


Nail laminated timber element	
Wood species:	UK Sitka Spruce
Width, w	0.45 to 2.34 m
Length, L	2.40 m
No. of planks:	10 to 52
Manufactured by:	MAKAR
Year of manufacture:	2012
Number of panels manufactured:	38
Boards	
Strength class	C16
Thickness, t_l	45 mm
Width, b_l	70 mm
Moisture content to EN 13183-2:	16%
Fixings	
Fastener type:	Ring shank nail
Diameter:	3.1 mm and 32.7 mm
Length:	90 mm and 89 mm
Material	Steel and Aluminium
Supplier:	ITW
Spacing parallel to the grain, a1	200 mm
Spacing perpendicular to the grain, a2	28 mm
End distance, a3	200 mm
Edge distance, a4	22 mm
Sheating	
Sheathing type:	OSB3
Sheathing thickness:	9 and 11 mm
Fastener type:	Ring shank nail
Diameter:	2.8 mm
Length:	50 mm
Material	Steel
Intermediate spacing:	300 mm
Perimeter spacing:	150 mm

Step 5 - Primary investigation

- Properties derived from calculations
- Tests on full scale panels
- Verification of the results

5. Primary investigation



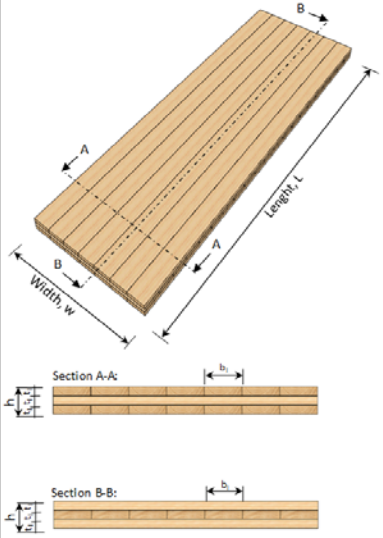
CLT

- ❑ Properties derived from calculations
- ❑ Tests on full scale panels/beams
- ❑ Analysis and verification of the results

- Test programmes of home-grown CLT carried out by Edinburgh Napier University and Graz University (bottom)
- Example of home grown CLT panel - mechanical properties and other specifications derived tests and calculations presented in ETA format (right)

Test type	Test standard	Property assessed		No. of samples tested	Tested by
Sitka Spruce CLT (Derix)					
Bending perpendicular to CLT	BS EN 16351:2015 BS EN 408:2010	Bending strength	$f_{m,k}$	10	Graz University of Technology, Institute of Timber Engineering and Wood Technology, Lignum Test Centre
		Bending stiffness	$E_{0,mean}$		
Bending in plane of CLT	BS EN 16351:2015 BS EN 408:2010	Bending strength	$f_{m,k}$	10	
		Bending stiffness	$E_{0,mean}$		
Rolling hear	BS EN 16351:2015	Rolling shear strength	$f_{R,k}$	24	
Shear	BS EN 14080:2013	Shear strength	$f_{v,k}$	10	
Delamination	BS EN 16351:2015	Delamination	$Delam_{tot}$	20	
Varying species CLT (Sitka Spruce, Scots Pine, Douglas Fir, Western Hemlock, Lawson Cypress, Larch)					
Bending perpendicular to CLT	BS EN 16351:2015 BS EN 408:2010	Bending strength	$f_{m,k}$	4	Edinburgh Napier University, Institute for Sustainable Construction
		Bending stiffness	$E_{0,mean}$		
Bending in plane of CLT	BS EN 16351:2015 BS EN 408:2010	Bending strength	$f_{m,k}$	4	
		Bending stiffness	$E_{0,mean}$		
Glue line shear	BS EN 16351:2015	Shear strength	f_v	5	

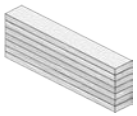
CLT - UK Sitka Spruce (Derix)



Cross laminated timber element		
Wood species:		UK Sitka Spruce
Number of layers:		3 ≤ n ≤ 5
Layer thickness and orientation (3ply):		30l-40c-30l
Layer thickness and orientation (5ply):		40l-30c-30l-30c-40l
Panel width, w:		2.9 to 3.0 m
Panel length, L:		10.5 to 13.5 m
Panel depth, h:		100 to 170 mm
Type of adhesive:		(MUF) 1255/7555
Bonded surface:		Face
Large finger joints:		No
Manufactured by:		W.u.J. Derix GmbH
Reaction to fire:		D-s2, d0
Durability against biological attack:		2
Service classes:		1 and 2
Boards		
Strength graded to EN 14081:		Yes
Strength class:		C16
Surface:		Planed
Thickness, t_l		30 to 40 mm
Width, b_l		100 to 170 mm
Ratio width to thickness		≥ 4:1
Finger joints		Yes
Moisture content to EN 13183-2:		11 - 15%
Mean Density		415 kg/m³
Mechanical resistance		
1. Perpendicular to cross laminated timber		
Modulus of elasticity	$E_{0,mean}$	8332 N/mm²
Shear modulus	G_{mean}	532 N/mm²
Rolling shear modulus	$G_{R,mean}$	84.4 N/mm²
Bending strength	$f_{m,mean}$	25.8 N/mm²
Tensile strength	$f_{t,90,k}$	0.4 N/mm²
Compression strength	$f_{c,90,k}$	2.2 N/mm²
Shear strength	$f_{v,k}$	1.94 N/mm²
Rolling shear strength	$f_{R,k}$	2.09 N/mm²
2. In-plane of cross laminated timber		
Modulus of elasticity	$E_{0,mean}$	9495 N/mm²
Shear modulus	G_{mean}	500 N/mm²
Bending strength	$f_{m,k}$	21.75 N/mm²
Tensile strength	$f_{t,0,k}$	13.35 N/mm²
Compression strength	$f_{c,0,k}$	19 N/mm²
Shear strength	$f_{v,k}$	5 N/mm²
Other mechanical actions		
Creep and duration of load		to EN 1995-1-1
Bond integrity		Passed

Values obtained from tests
Values based on BS EN 338

5. Primary investigation



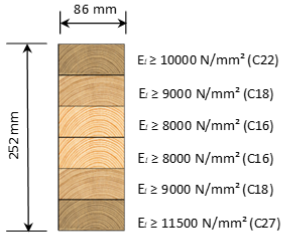
GLT

- ❑ Properties derived from calculations
- ❑ Tests on full scale panels/beams
- ❑ Analysis and verification of the results

- Test programmes of home-grown GLT carried out by Edinburgh Napier University (bottom)
- Example of home grown GLT - mechanical properties and other specifications derived tests and calculations presented in ETA format (right)

Test type	Test standard	No. of samples tested
Larch GLT (homogenous)		
Glue line bond test	BS EN 14080:2013	61
Bending test of finger joints	BS EN 14080:2013 & BS EN 408:2010	21
GLT Bending test	BS EN 14080:2013 & BS EN 408:2010	8
GLT Tension test (perpendicular to grain)	BS EN 408:2010	9
GLT Compression test (perpendicular to the grain)	BS EN 408:2010	16
Sitka Spruce GLT (combined)		
Glue line bond test	Bespoke	6
GLT Bending test	BS EN 14080:2013 & BS EN 408:2010	4
Douglas Fir GLT (combined)		
Glue line bond test	Bespoke	5
GLT Bending test	BS EN 14080:2013 & BS EN 408:2010	4
Scots Pine GLT (combined)		
Glue line bond test	Bespoke	5
GLT Bending test	BS EN 14080:2013 & BS EN 408:2010	4

GLT - UK Sitka spruce



Estimated Glulam strength class - GL24c

Wood species:		Sitka spruce
Type of adhesive		Type 1
Formaldyde emission		E1
Reaction to fire:		D-s2, d0
Durability against biological attack:		2
Service classes:		1 and 2
Coss-section:		86x252 mm
Length:		4800 mm
Bending strength	$f_{m,g,k}$	33 N/mm²
Tensile strength	$f_{t,0,g,k}$	17 N/mm²
	$f_{t,90,g,k}$	0.5 N/mm²
Compression strength	$f_{c,0,g,k}$	21.5 N/mm²
	$f_{c,90,g,k}$	2.5 N/mm²
Shear strength	$f_{v,g,k}$	3.5 N/mm²
Rolling shear strength	$f_{r,g,k}$	1.2 N/mm²
Modulus of elasticity	$E_{0,g,mean}$	11050 N/mm²
	$E_{0,g,05}$	9770 N/mm²
	$E_{90,g,mean}$	300 N/mm²
	$E_{90,g,05}$	250 N/mm²
Shear -modulus	$G_{g,mean}$	650 N/mm²
	$G_{g,05}$	540 N/mm²
Rolling shear modulus	$G_{r,g,mean}$	65 N/mm²
	$G_{r,g,05}$	54 N/mm²
Density	$\rho_{g,k}$	405 kg/m³
Mean density	$\rho_{g,mean}$	475 kg/m³

Values obtained from tests

Values based on estimated GLT strength class

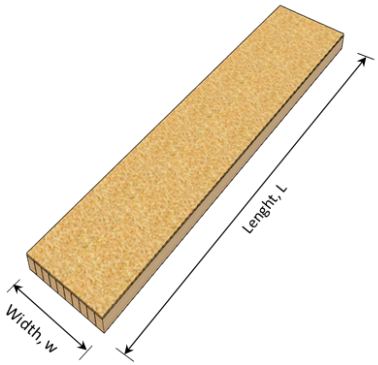
5. Primary investigation

- ❑ Properties derived from calculations
- ❑ Tests on full scale panels/beams
- ❑ Analysis and verification of the results

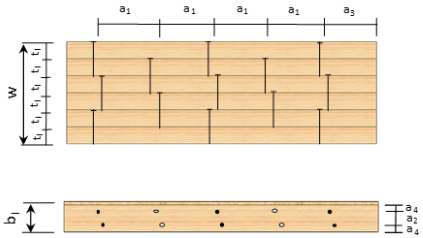
- Test programmes of home-grown NLT carried out by Edinburgh Napier University (bottom)
- Example of home grown NLT - mechanical properties and other specifications derived tests and calculations presented in ETA format (right)

Test type	Test standard	Property assessed		No. of samples tested	Tested by
Bending perpendicular to NLT	BS EN 408:2010	Bending strength	$f_{m,k}$	30	Edinburgh Napier University, Institute for Sustainable Construction
		Bending stiffness	$E_{0,mean}$		
Racking tests	BS EN 594:2011	Racking strength	F_{max}	8	
		Racking stiffness	R		

NLT - UK Sitka Spruce



Nail spacing and plank lay-up:



Nail laminated timber element		
Wood species:		UK Sitka Spruce
Max width, w		≤ 3.45 m
Max length, L		≤ 20 m
Reaction to fire:		D-s2, d0
Service classes:		1 and 2
Boards		
Strength class		C16
Thickness, t_l		≥ 21 mm
Width, b_l		60 to 300 mm
Moisture content to EN 13183-2:		15% ± 3%
Fixings		
Fastener type:		3.1x90mm ring shanks
Spacing parallel to the grain, a1		200 mm
Spacing perpendicular to the grain, a2		28 mm
End distance, a3		200 mm
Edge distance, a4		22 mm
Mechanical resistance		
1. Perpendicular to nail laminated timber		
Modulus of elasticity	$E_{0,mean}$	6064 N/mm²
Shear modulus	G_{mean}	500 N/mm²
Bending strength	$f_{m,k}$	16 N/mm²
Tensile strength	$f_{t,90,k}$	0.4 N/mm²
Compression strength	$f_{c,90,k}$	2.2 N/mm²
Shear strength	$f_{v,k}$	2.2 N/mm²
2. In-plane of nail laminated timber		
Modulus of elasticity	$E_{0,mean}$	8000 N/mm²
Shear modulus	G_{mean}	500 N/mm²
Bending strength	$f_{m,k}$	16 N/mm²
Tensile strength	$f_{t,0,k}$	8.5 N/mm²
Compression strength	$f_{c,0,k}$	17 N/mm²
Shear strength	$f_{v,k}$	3.2 N/mm²
Other mechanical actions		
Racking strength	F_{max}	14.7 kN
Racking stiffness	R	877.4 N/mm

Values obtained from tests
Values based on BS EN 338

Step 6 - Design and Analysis

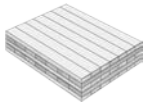
- Applying test results to building scenarios
- Detailing to BS
- Performance modelling
- Identifying best end use

&

Step 7 - Pilot Project

- Trial product on a pilot project
- Full process appraisal

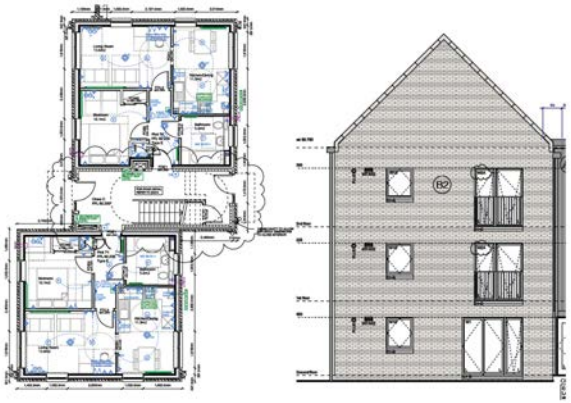
6. Design and Analysis / Pilot Project



CLT

- ❑ Applying test results to building scenarios
- ❑ Detailing in accordance with BS
- ❑ Structural performance modelling
- ❑ Identifying best end use
- ❑ Trial Mass Timber product on a pilot project
- ❑ Full process appraisal

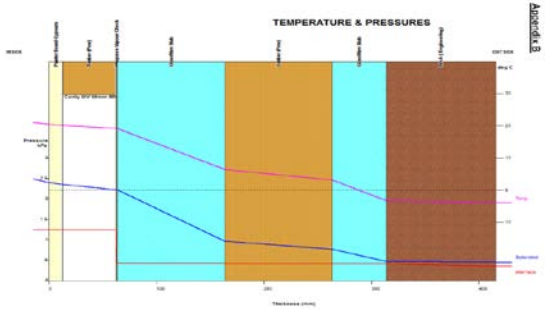
Demonstration Project: Hypothetical construction using CLT from home grown Sitka Spruce - Glasgow Housing Association



CLT structural design

- CLT panels formed walls and floor structure
- Fully compliant with The Building Regulations

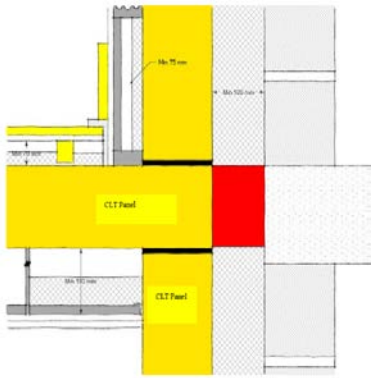
(Design by: Smith and Wallwork engineers)



CLT thermal modelling

Make-up of the components with the UK CLT complies with current thermal requirements as stated in standard 6.1 "Domestic Energy" of the Scottish Building Regulations

(Analysis by: Scottish Energy Centre)



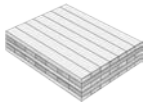
CLT acoustic detailing

Assessment of performance specifications for separating floors, separating walls, internal walls and general detailing issues associated with these partitions.

(Analysis by: Building Performance Centre)

Edinburgh Napier UNIVERSITY

6. Design and Analysis / Pilot Project



CLT

- ❑ Applying test results to building scenarios
- ❑ Identifying best end use
- ❑ Detailing in accordance with BS
- ❑ Trial Mass Timber product on a pilot project
- ❑ Structural performance modelling
- ❑ Full process appraisal

UK CLT vs European CLT:
(design criteria: strength, shear, deflection, vibration)

Educational Building - Long span

Design Example 1 - Summary															
Span	7.5	m		European CLT - 300 L8s - 2				UK CLT - 300 L8s - 2				UK CLT - 320 L8s - 2			
Dead Load	1	kN/m²		Normal Conditions		Fire Conditions		Normal Conditions		Fire Conditions		Normal Conditions		Fire Conditions	
Live Load	3	kN/m²	Strength	26.1%	PASS	14.6	PASS	23.1%	PASS	12.8	PASS	21.2%	PASS	12	PASS
Service class	1		Shear	15.8%	PASS	7.1	PASS	10.6%	PASS	4.3	PASS	9.9%	PASS	4.1	PASS
Shortest term action duration	Medium		Deflections	64.3%	PASS			75.6%	PASS			66.2%	PASS		
			Vibrations (Min 8 Hz)	7.89	CHECK			7.44	FAIL			7.87	CHECK		

Educational Building - Short span

Design Example 2 - Summary															
Span	3.6	m		European CLT - 120 L3s				UK CLT - 120 L3s				UK CLT - 140 L5s			
Dead Load	2.1	kN/m²		Normal Conditions		Fire Conditions		Normal Conditions		Fire Conditions		Normal Conditions		Fire Conditions	
Live Load	1.5	kN/m²	Strength	26.9%	PASS			24.4%	PASS	68.4%	PASS	19.0%	PASS	20.6%	PASS
Service class	1		Shear	15.3%	PASS			9.6%	PASS	5.5%	PASS	8.3%	PASS	4.4%	PASS
Shortest term action duration	Medium		Deflections	82.7%	PASS			97.5%	PASS			65.5%	PASS		
			Vibrations (Min 8 Hz)	8.30	PASS			7.69	FAIL			9.34	PASS		

Residential Building - Medium span

Design Example 3 - Summary															
Span	5	m		European CLT - 160 L5s				UK CLT - 160 L5s				UK CLT - 180 L5s			
Dead Load	1	kN/m²		Normal Conditions		Fire Conditions		Normal Conditions		Fire Conditions		Normal Conditions		Fire Conditions	
Live Load	1.5	kN/m²	Strength	25.0%	PASS	17.5%	PASS	22.2%	PASS	15.3%	PASS	19.1%	PASS	13.2%	PASS
Service class	1		Shear	11.6%	PASS	5.8%	PASS	7.7%	PASS	3.5%	PASS	6.8%	PASS	3.1%	PASS
Shortest term action duration	Medium		Deflections	70.9%	PASS			84.8%	PASS			66.1%	PASS		
			Vibrations (Min 8 Hz)	8.11	PASS			7.53	FAIL			8.46	PASS		

- For a UK CLT to compete with a European CLT, panel thickness must be increased by at least one standard product size (limiting property – Vibration)

6. Design and Analysis / Pilot Project

- ❑ Applying test results to building scenarios
- ❑ Detailing in accordance with BS
- ❑ Structural performance modelling
- ❑ Identifying best end use
- ❑ Trial Mass Timber product on a pilot project
- ❑ Full process appraisal

Pilot Project: DLT from home grown Larch - Munro Harvesting House at Deer Park, Knockmuir Brea, Avoch (North Scotland)

UK Timber species used: *Larch*

DLT Manufactured by: *MAKAR*

Building element: *Suspended immediate floor*

DLT panel specification:
- *140mm deep by 300mm wide and 4190mm long*
- *Joined together with 20mm diameter Beech dowels at 300mm centres*

Total DLT floor area: *20 m^2*

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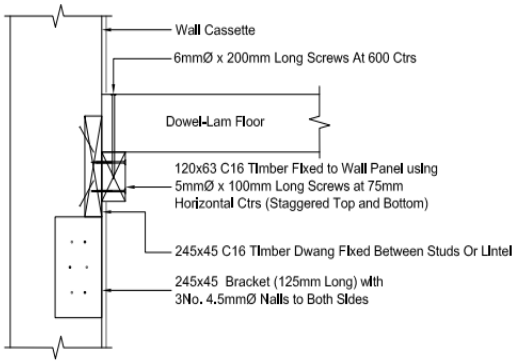
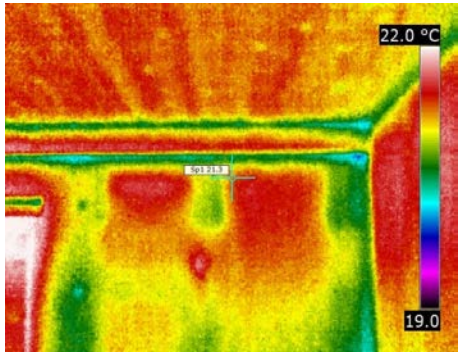
Pilot Project: DLT from home grown Larch - Munro Harvesting House at Deer Park, Knockmuir Brea, Avoch (North Scotland)



DLT structural detailing

- In platform frame construction the DLT floor can simply bear directly onto the head of a panel
- The timber walling can be built directly from it
- A rim beam can be used on the outer edge of the panel to form a cavity that can be filled with insulation.

(Consultations: SER engineers)



DLT Infra-red thermography analysis

- Infra-red thermograms revealed consistency in the junction between the floor and the wall cassette
- Internally there aren't any low surface temperatures that would reveal thermal bridging or heat loss

(Testing by: Scottish Energy Centre)

DLT Air permeability

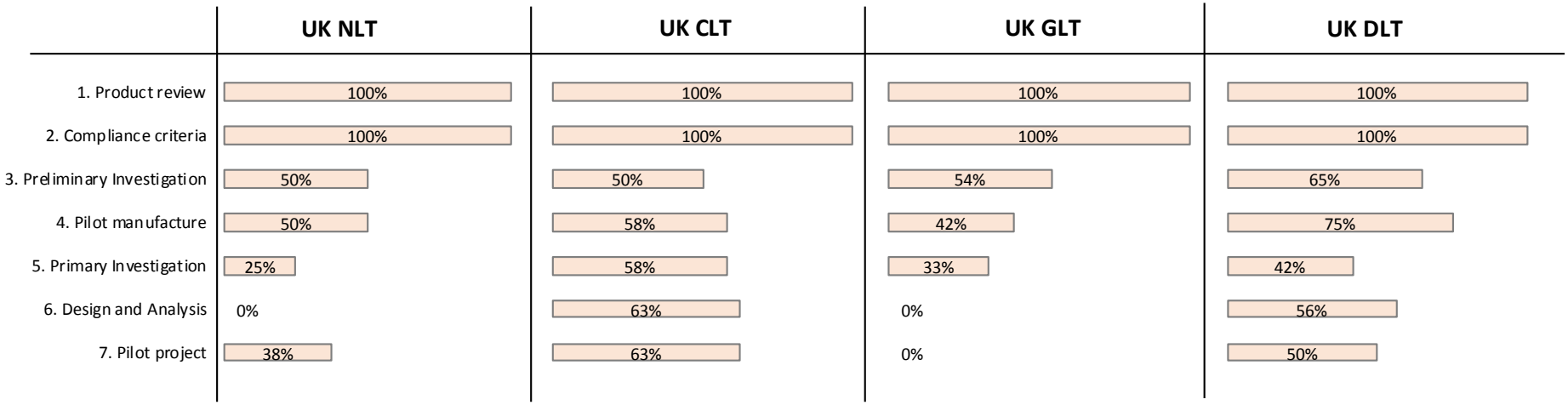
The air permeability tests performed revealed an average result of 5.25 m3/m2.h@50Pa – in compliance with The Building Regulations

(Testing by: Scottish Energy Centre)

7. Summary and Future Work

- ❑ Further product development
- ❑ Identifying and overcoming barriers
- ❑ Support with product certification
- ❑ Promotion

Estimated status of research carried out on home grown Mass Timber systems:



Recommendations for future work include:

- Update on market review and potential manufacturers
- Development of calculation methods for deriving the properties based on the layup and properties of the boards
- Finding optimum lamella layup/geometry, best suited for the UK market
- Further showcasing the feasibility of utilising home grown Mass Timber systems

Edinburgh Napier UNIVERSITY

Scottish Forestry
Coilltearachd na h-Alba

CONSTRUCTION SCOTLAND INNOVATION CENTRE

"Mass Timber commercialisation in the UK"

'The project aims to fully understand the feasibility and therefore potential costs, benefits and constraints of a mass timber manufacturing facility within Scotland'

Work Package 1: Review

- Parametric analysis of mass timber products
- Design and analysis utilising research data
- Development of technical details

Work Package 2: Market assessment

- Costs comparison
- Demand for mass timber products

Work Package 3: Manufacturing feasibility

- Potential mass timber manufacturers
- Suppliers and equipment needed
- Manufacturing scenarios for Scotland

Work Package 4: Manufacturing feasibility

- Identification of most realistic form(s) of mass timber product for fabrication
- Identification of a pilot project to best demonstrate home-grown mass timber production

Work Package 5: Mass Timber Alliance

- Final reporting and creation of outreach literature: *'Mass Timber from UK/Scotland resource - Manufacture and use of solid timber products and systems in Scotland'*
- Formation of industry advisory group, who will potentially facilitate supply chain integration with view to full commercialisation of the project findings

Thank you for your attention.

Questions and discussion welcome.

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