WoodWorks

The Case for Cross Laminated Timber: Part 2

Opportunities and Challenges for a New Class of Timber Product

Presented by
Regional Director
WoodWorks for Non-residential Construction

Learning Objectives

1. Review answers to common questions regarding the design and construction of CLT structures, including those related to cost and designing for exposed conditions.
2. Evaluate the fire characteristics of CLT, including the benefits of charring, effects of lamination, flame spread and more.
3. Discuss current seismic approaches that can be used for CLT buildings as well as the future of seismic testing.
4. Consider the acoustic and moisture performance of CLT assemblies and how they inform the design of a project.

Copyright Materials

Outline

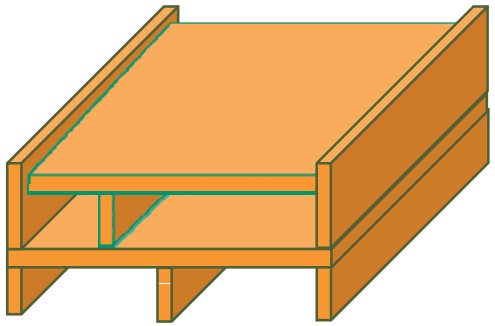
- CLT Design
  - Fire
  - Lateral
  - Acoustic
  - Building Enclosure
- Including…..
  - Information available in the CLT Handbook
  - Information from additional resources
  - Answers to Frequently Asked Questions

Fire Design

- Fire Design
  - Building Types
  - Fire Resistance
  - Interior Finish
  - Connections

Fire and Life Safety – Building Types

- **Type V** are generally combustible such as wood although V permits any material permitted by code



All structural elements can be combustible construction:

- Exterior walls
- Floor
- Roof
- Interior walls

Fire and Life Safety – Building Types

- **Type VB** is unprotected construction and requires no fire rating on any building elements.

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f, g] Interior	3 3[a]	2 2[a]	1 1	0 0	2 1	2 0	2 1/HT	1 1	0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	1½[b]	1[b, c]	1[b, c]	0[c]	1[b, c]	0	HT	1[b, c]	0

Fire and Life Safety – Building Types

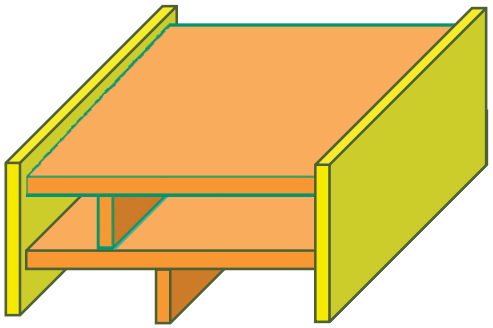
- **Type VA** is protected construction and requires a 1hr rating for all structural elements with some exceptions for roofs.

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f, g] Interior	3 3[a]	2 2[a]	1 1	0 0	2 1	2 0	2 1/HT	1 1	0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	1½[b]	1[b, c]	1[b, c]	0[c]	1[b, c]	0	HT	1[b, c]	0

Fire and Life Safety – Building Types

- **Type III** is noncombustible exterior and combustible interior. Fire-retardant-treated wood framing is permitted in the exterior walls.



Structural elements that can be CLT:

- Floor
- Roof
- Interior walls

Fire and Life Safety – Building Types

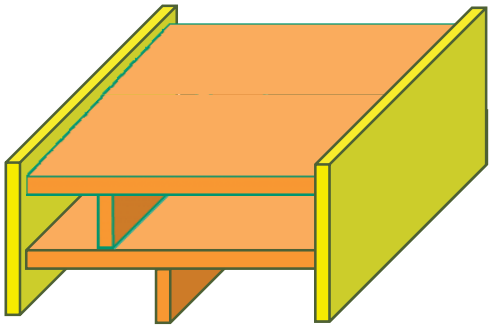
- **Type III** requires a 2hr fire rating at exterior walls for both protected and unprotected construction, 1hr rated most everywhere else for **IIIA** and no where else for **IIIB**.

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f,g] Interior	3 3[a]	2 2[a]	1 1	0 0	2 1	2 0	2 1/HT	1 1	0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	1½[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

Fire and Life Safety – Building Types

- **Type IV** are generally combustible with the exception of the exterior walls and requires that there are no concealed spaces.

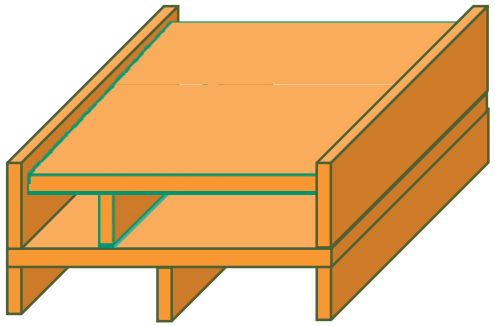


Structural elements that can be CLT:

- Floor
- Roof
- Interior walls

Fire and Life Safety – Building Types

- **Type IV** are generally combustible with the exception of the exterior walls that can be CLT or FRT when the rating is 2hr or less.



Structural elements that can be CLT under 2015 IBC:

- Floor
- Roof
- Interior walls
- Exterior walls

Fire and Life Safety – Building Types

- Type IV - Fire resistance requirements do NOT apply to HT Construction except at the Exterior Walls

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I A	TYPE I B	TYPE II A[d]	TYPE II B	TYPE III A[d]	TYPE III B	TYPE IV HT	TYPE V A[d]	TYPE V B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f,g]	3	2	1	0	2	2	2	1	0
Interior	3[a]	2[a]	1	0	1	0	1/HT	1	0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	1½[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	IIT	1[b,c]	0

Fire and Life Safety – Building Types

TABLE 503
ALLOWABLE BUILDING HEIGHTS AND AREAS[a,b]
Building height limitations shown in feet above grade plane. Story limitations shown as stories above grade plane.
Building area limitations shown in square feet, as determined by the definition of "Area, building," per story

GROUP		TYPE I A	TYPE I B	TYPE II A	TYPE II B	TYPE III A	TYPE III B	TYPE IV HT	TYPE V A	TYPE V B
	HEIGHT (feet)	UL	160	65	55	65	55	65	50	40
		STORIES (S) AREA (A)								
A-1	S	UL	11	4	2	3	2	3	2	1
	A	UL	UL	25,000	15,500	19,000	14,000	28,500	11,500	6,500
A-2	S	UL	11	4	2	3	2	3	2	1
	A	UL	UL	25,000	15,500	19,000	14,000	28,500	11,500	6,000
A-3	S	UL	11	4	2	3	2	3	2	1
	A	UL	UL	25,000	15,500	19,000	14,000	28,500	11,500	6,000
A-4	S	UL	11	4	2	3	2	3	2	1
	A	UL	UL	25,000	15,500	19,000	14,000	28,500	11,500	6,000
A-5	S	UL	UL	UL	UL	UL	UL	UL	UL	UL
	A	UL	UL	UL	UL	UL	UL	UL	UL	UL
B	S	UL	11	5	3	5	3	5	3	2
	A	UL	UL	37,500	23,000	28,500	19,000	36,000	18,000	9,000
E	S	UL	11	4	2	3	2	3	1	1
	A	UL	UL	25,000	15,500	23,500	14,500	26,500	18,500	9,500
F-1	S	UL	11	4	2	3	2	4	2	1
	A	UL	UL	25,000	15,500	19,000	12,000	33,500	14,000	8,500
F-2	S	UL	11	5	3	4	3	5	3	2
	A	UL	UL	37,500	23,000	28,500	18,000	50,500	21,000	13,000

BUSINESS
Business Occupancy
NFPA 13 Sprinklers IBC 903.3.1.1 Modifications
6 stories
85 feet
135,000 sq. ft./floor max
405,000 sq. ft. total max.
No Fire walls

Fire and Life Safety – Building Types

TABLE 503—continued
ALLOWABLE BUILDING HEIGHTS AND AREAS[a,b]

GROUP		TYPE I A	TYPE I B	TYPE II A	TYPE II B	TYPE III A	TYPE III B	TYPE IV HT	TYPE V A	TYPE V B
	HEIGHT (feet)	UL	160	65	55	65	55	65	50	40
		STORIES (S) AREA (A)								
R	S	UL	5	4	2	4	2	4	3	1
	A	UL	35,500	19,000	8,500	18,500	12,500	20,500	14,000	9,000
R	S	UL	5	4	2	4	2	4	3	2
	A	UL	35,500	19,000	8,500	24,000	16,000	20,500	12,000	7,000
R	S	UL	5	4	2	4	2	4	3	2
	A	UL	35,500	19,000	8,500	24,000	16,000	20,500	12,000	7,000
R	S	UL	5	4	2	4	4	4	3	3
	A	UL	35,500	19,000	8,500	UL	UL	UL	UL	UL
R	S	UL	5	4	2	4	2	4	3	2
	A	UL	35,500	19,000	8,500	24,000	16,000	20,500	12,000	7,000
S	S	UL	5	4	2	3	2	4	3	1
	A	UL	35,500	19,000	8,500	26,000	17,500	25,500	14,000	9,000
S	S	UL	5	4	2	4	3	5	4	2
	A	UL	35,500	19,000	8,500	39,000	26,000	38,500	21,000	13,500
U	S	UL	5	4	2	3	2	4	2	1
	A	UL	35,500	19,000	8,500	14,000	8,500	18,000	9,000	5,500

RESIDENTIAL
R-2 Occupancy
NFPA 13 Sprinklers IBC 903.3.1.1 Modifications
5 stories
85 feet
76,875 sq. ft./floor max
230,625 sq. ft. total max.
No Fire walls

Fire and Life Safety - AMMR

[A] 104.11 Alternative materials, design and methods of construction and equipment. The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been *approved*. An alternative material, design or method of construction shall be *approved* where the *building official* finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, *fire resistance*, durability and safety.

Fire and Life Safety – AMMR

[A] 104.11.2 Tests. Whenever there is insufficient evidence of compliance with the provisions of this code, or evidence that a material or method does not conform to the requirements of this code, or in order to substantiate claims for alternative materials or methods, the *building official* shall have the authority to require tests as evidence of compliance to be made at no expense to the jurisdiction. Test methods shall be as specified in this code or by other recognized test standards. In the absence of recognized and accepted test methods, the *building official* shall approve the testing procedures. Tests shall be performed by an *approved agency*. Reports of such tests shall be retained by the *building official* for the period required for retention of public records.

[A] 104.11.1 Research reports. Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, shall consist of valid research reports from *approved* sources.

Fire Resistance

Fire protection based on

- ASTM E119 test performed by AWC or test reports from FPInnovations, OR…
- Calculate fire resistance per NDS Ch. 16

ASTM E119 Fire Endurance Test

- 5-Ply CLT (approx. 7” thick)
- 5/8” Type X GWB each side
- Sought 2 hour rating
- RESULTS: 3 hours 6 minutes

Fire Resistance Testing

Full Scale E119 Testing was done to prove min 2hr resistance to allow CLT as an exception in Type IV construction.

http://www.awc.org/Code-Officials/2012-IBC-Challenges/NGC-CLT-Report.pdf

Fire Resistance Calculation

Full Scale E119 Testing was done to prove the calculation methods.

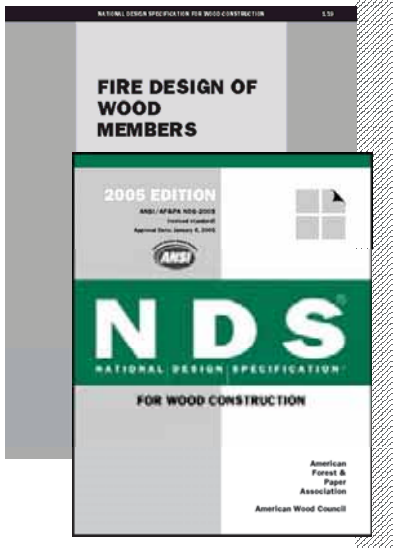
The advantage to a calculated method is versatility (not relying on a UL assembly to include your exact assembly).

http://www.awc.org/Code-Officials/2012-IBC-Challenges/Preliminary-CLT-Fire-Test-Report-FINAL-July2012.pdf

Fire Resistance

SECTION 721
CALCULATED FIRE RESISTANCE

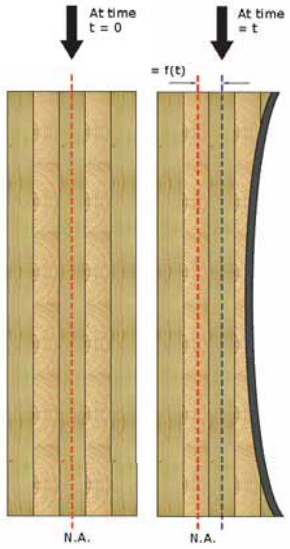
721.1 General. The provisions of this section contain procedures by which the *fire resistance* of specific materials or combinations of materials is established by calculations. These procedures apply only to the information contained in this section and shall not be otherwise used. The calculated *fire resistance* of concrete, concrete masonry and clay masonry assemblies shall be permitted in accordance with ACI 216.1/TMS 0216. The calculated *fire resistance* of steel assemblies shall be permitted in accordance with Chapter 5 of ASCE 29. The calculated *fire resistance* of exposed wood members and wood decking shall be permitted in accordance with Chapter 16 of ANSI/AF&PA *National Design Specification for Wood Construction (NDS)*.



Fire Resistance

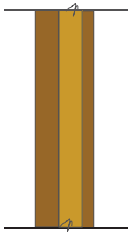
Chapter 16 NDS

- Charring Rate and Char Depth



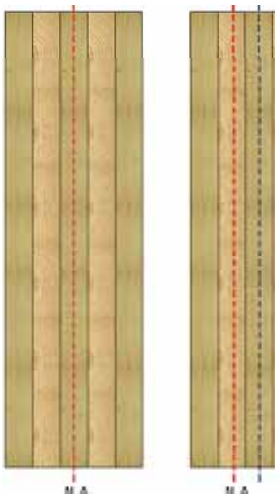
Fire Resistance

Net section properties



Typical one foot section

Plan



Section

Interior Finish

Wood Interior Finish – Flame spread

- Building occupancy
- Location of the material in the building
- Sprinklers or no sprinklers

ASTM E84 or UL 723 Test Method

IBC 803.1.1

Table 8
Flame spread classes according with IBC

Class	Flame Spread Index	Smoke Development Index
A	0-25	0-450
B	26-75	0-450
C	76-200	0-450

Interior Finish

Table 9
Flame spread indices for softwood lumber

Species	Flame Spread Index
Cedar, Alaska yellow	50
Cedar, Pacific Coast yellow	78
Cedar, Port Orford	60
Cedar, Western Red	70-75
Cypress	145-150
Douglas-fir	70-100
Douglas-fir flooring, ¾ in.	83-98
Fir, Amabilis (Pacific Silver)	68
Fir, California Red	63
Fir, Grand	60
Fir, White	45
Hemlock, Eastern	85
Hemlock, Western	72
Larch, Western	98
Pine, Eastern White	130-215
Pine, Lodgepole	105-230
Pine, Ponderosa	142
Pine, Southern Yellow	130-195
Pine, Sugar	95
Redwood	70
Spruce, Engelmann	55
Spruce, Northern	65
Spruce, Sitka	74

Classification in Codes are:

Class	Flame Spread Range	Example Locations
I or A	0-25	Enclosed vertical exits
II or B	26-75	Exit access corridors
III or C	76-200	Other rooms and areas

Interior Finish

TABLE 803.9
INTERIOR WALL AND CEILING FINISH REQUIREMENTS BY OCCUPANCY[k]

GROUP	SPRINKLERED[l]			NONSPRINKLERED		
	Interior exit stairways, interior exit ramps and exit passageways[a, b]	Corridors and enclosure for exit access stairways and exit access ramps	Rooms and enclosed spaces[c]	Interior exit stairways, interior exit ramps and exit passageways[a, b]	Corridors and enclosure for exit access stairways and exit access ramps	Rooms and enclosed spaces[c]
A-1 & A-2	B	B	C	A	A[d]	B[e]
A-3[f], A-4, A-5	B	B	C			
B, E, M, R-1	B	C	C			
R-4	B	C	C			
F	C	C	C			
H	B	B	C[g]			
I-1	B	C	C			
I-2	B	B	B[h, i]			
I-3	A	A[j]	C			
I-4	B	B	B[h, i]			
R-2	C	C	C			
R-3	C	C	C			
S	C	C	C	B	B	C
U	No restrictions			No restrictions		

803.3 Heavy timber exemption. Exposed portions of structural members complying with the requirements for buildings of Type IV construction in Section 602.4 shall not be subject to *interior finish* requirements.

Connections

Structural requirements and……

Fire requirements

- HT doesn't identify specific protection requirements
- connection protection must be equivalent to construction type requirements

Metal Connectors

- strength compromised
- Reduced capacity in heated zone
- Thermal conductivity of connector itself

Connections

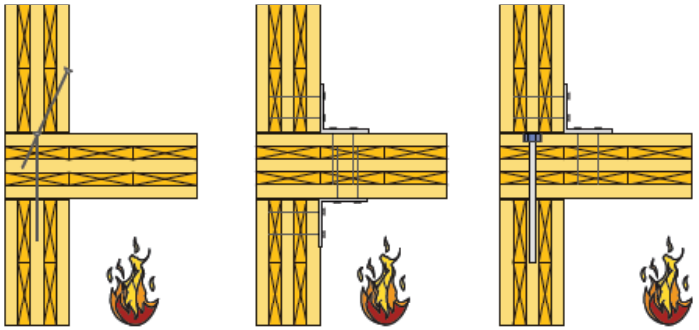


Figure 12
Examples of connections seen in CLT platform construction

Connections

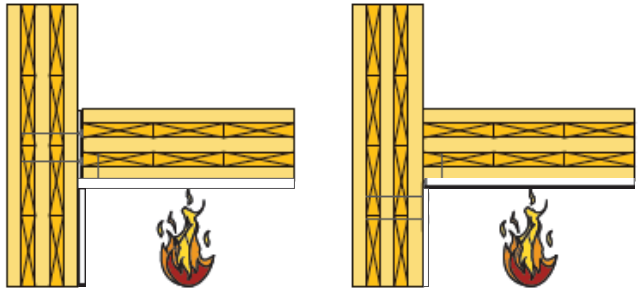


Figure 13
Examples of connections seen in CLT balloon construction

Connections

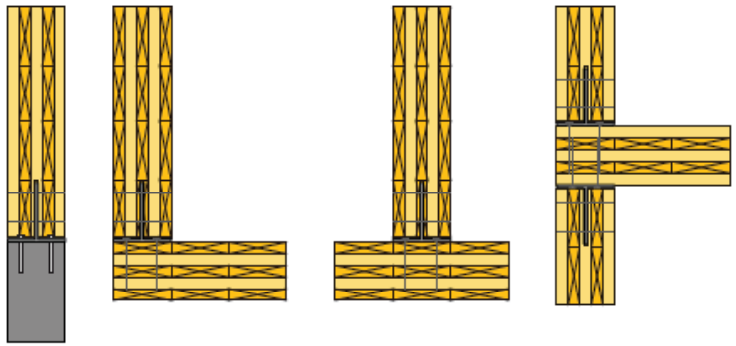


Figure 14
Concealed metal plates

Connections

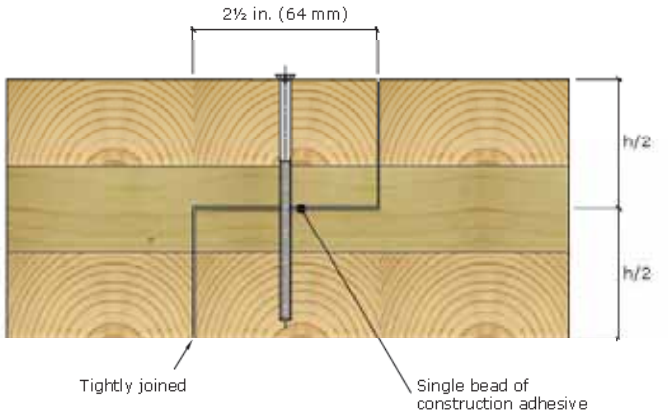


Figure 9
CLT panel-to-panel half-lapped joint detail

Connections

www.awc.org

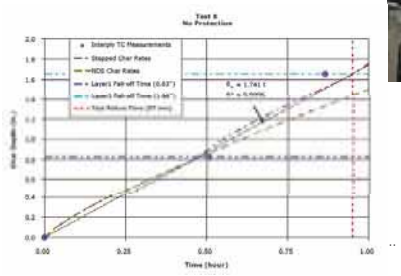
Fire ratings for connections are established by the fire rating of the system.

Type IV Construction does not have fire ratings for connections.

IBC 722.6.3.3 - 1hr of protection = 1-1/2" wood covering

Chapter 8 - Fire

- IBC Height and Areas
- ASTM E119 Test
- ASTM E84 Test
- Design Examples



Frequently Asked Questions:

1. What Building Type should I specify?
2. How tall can I go with CLT?
3. Can I expose CLT?
4. Are there approved fire rated assemblies?

Frequently Asked Questions:

1. What Building Type should I specify?
   - This will depend on the height and area you require and if your threshold for fire walls.
   - Types III, IV and V will all allow CLT to some degree.
   - The 2015 IBC holds an opportunity for expanded use that may be accessed by utilizing 104.10
2. How tall can I go with CLT?
3. Can I expose CLT?
4. Are there approved fire rated assemblies?

Frequently Asked Questions:

1. What Building Type should I specify?
2. How tall can I go with CLT?
   - Depends on occupancy, use of sprinklers and structural design parameters
   - 6 Story Office Type IV or III
   - 6 Story S-2 (parking) – Type IV
   - 5 Story Retail & Residential – Type IV or III
   - Possibly taller with performance based design
3. Can I expose CLT?
4. Are there approved fire rated assemblies?

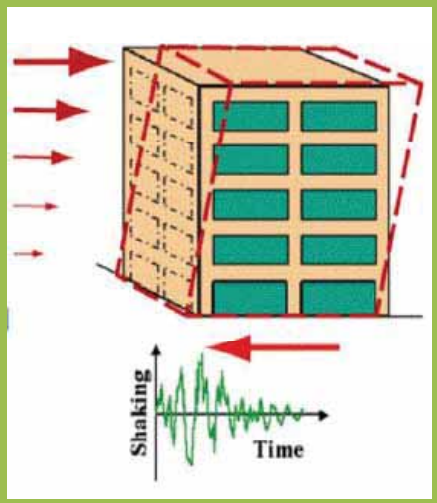
Frequently Asked Questions:

1. What Building Type should I specify?
2. How tall can I go with CLT?
3. Can I expose CLT?
   - Additional sacrificial laminations may be required to accommodate required fire resistance rating.
   - Most exposed CLT will have a Class B or C finish rating.
   - Type IV members are not subject to interior finish requirements.
4. Are there approved fire rated assemblies?

Frequently Asked Questions:

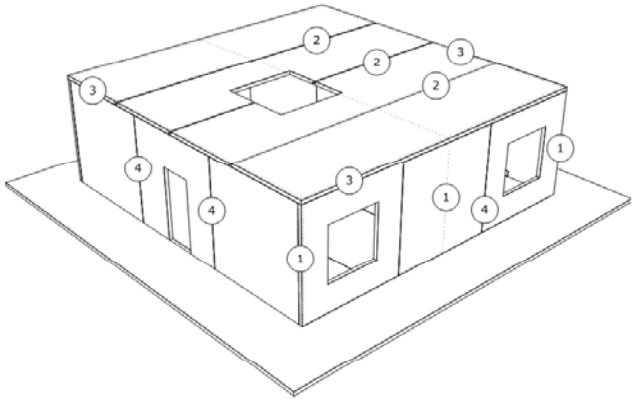
1. What Building Type should I specify?
2. How tall can I go with CLT?
3. Can I expose CLT?
4. Are there approved fire rated assemblies?
   - A calculated method has been established for fire ratings of Cross Laminated Timber.
   - The calculated method has been justified with full scale E119 fire tests.
   - Not having set approved fire assemblies gives designers more flexibility with their assemblies but may require more explanation with a building dept.

Lateral Design



CLT in Lateral Force Resisting Systems

CLT Panels can be used as structural diaphragms and shear walls.



Source: A Ceccotti in the US CLT Handbook

CLT in Lateral Force Resisting Systems

CLT Panels have a very high in-plane shear strength.

CrossLam In-Plane Shear Loading				
Panel d (in)	SLT3 3.90	SLT5 6.65	SLT7 9.41	SLT9 12.17
	Vr (lbs/ft			
	6510	13019	19529	26038

Source: *The Cross Laminated Timber Design Guide* from Structurlam

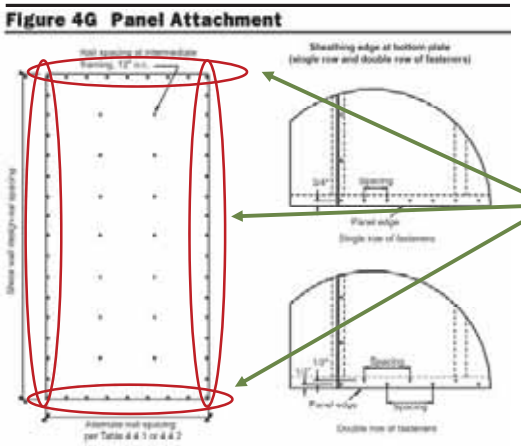
CLT in Lateral Force Resisting Systems

Product	Nordic X-Lam						
Application	Wall Panels and Lintels						
Appearance grades	Industrial or Architectural						
Stress grade	E1 (L 1950F_b and T No. 3/Stud)						
Layup Combinations	78-3s	105-3s	131-5s	175-5s	220-7s	244-7l	314-9l
Loaded to major strength direction	3	4	5	7	9	10	12
Compression, P_0 (10^3 lbf/ft)	44	59	66	89	119	149	178
Tension, T_0 (10^3 lbf/ft)	34	45	50	68	91	113	136
Effective area, A_{eff} ($in.^2$/ft)	24	33	37	50	66	83	99
Effective inertia, I_{eff} ($in.^4$/ft)	28	68	108	257	498	824	1638
Radius of gyration, r_{eff} (in./ft)	1.0	1.4	1.7	2.3	2.7	3.2	4.1
In-plane shear, V_0 (lbf/in.)	304	396	597	792	912	1188	1584
Loaded to minor strength direction							
Compression, P_{90} (10^3 lbf/ft)	8,2	11	16	21	25	21	32
Tension, T_{90} (10^3 lbf/ft)	3,2	4,1	6,3	8,3	9,5	8,3	12
Effective area, A_{eff} ($in.^2$/ft)	12	17	25	33	38	33	50
Effective inertia, I_{eff} ($in.^4$/ft)	1,0	2,6	30	68	153	68	257
Radius of gyration, r_{eff} (in./ft)	0,3	0,4	1,1	1,4	2,0	1,4	2,3
In-plane shear, V_{90} (lbf/in.)	304	396	597	792	912	1188	1584

Source: Nordic CLT Guide

Connections Determine Lateral Strength

Similar to Wood Structural Panel Shear Walls

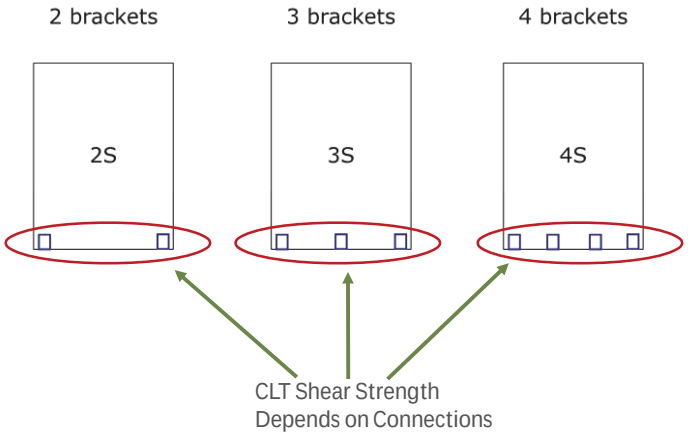


Light frame shear wall strength is dependent on perimeter (edge) nailing

Source: *SDPWS 2008*

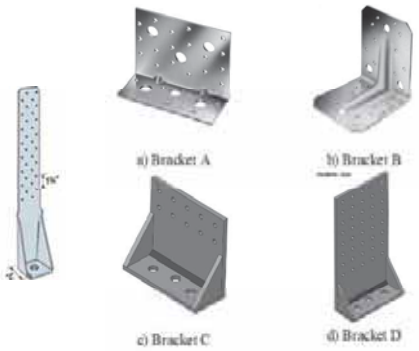
Connections Determine Lateral Strength

Similar to Wood Structural Panel Shear Walls



Source: US CLT Handbook

Fasteners and Brackets



Frequently Asked Questions:

1. How do you design connections for CLT?.

CLT connections should adhere to the *National Design Specification® for Wood Construction (NDS®)* just like other wood connections. The NDS has specific provisions for commodity fasteners, which can be found in Appendix K – L. The NDS does not yet include information on how to apply its dowel bearing equations regarding grain direction to CLT. However, the existing NDS design provisions can be applied with some modification, assuming that the CLT dowel bearing strength is based on the species-specific gravity of the face ply and the loading direction relative to the grain angle of the face ply.

Commercial Products

Figure 1: ABR105 – CLT Panel Connection

Figure 2: AE116 – CLT to Concrete

Table 1: Allowable Stress Design Values – CLT Panel Connection

Model ID	Gauge	Dimensions (in.)			Fastener Schedule				Allowable Load (lbs.), C_D = 1.60			
		W_1	W_2	L	Horizontal Leg		Vertical Leg		F_1	F_2	F_3	F_4
					Quantity	Type	Quantity	Type				
ABR302U	14	3 1/16	3 1/16	2 7/16	10	CNA4x60	10	CNA4x60	1085	780	1330	590
					10	SD10212	10	SD10212	1480	1200	1330	1010
ABR105	11	4 1/4	4 1/4	3 1/16	14	CNA4x60	10	CNA4x60	1350	835	2300	1020
					14	SD10212	10	SD10212	1880	1235	2300	1475
AE116	11	3 1/16	1 1/4	4 1/16	7	CNA4x60	18	CNA4x60	1720	1225	1550	650
					7	SD10212	18	SD10212	1850	1445	1850	1035

For SI: 1 inch = 25.4 mm; 1 lbf = 4.45 N.

1. The allowable loads are based on the use of SPF Grade 2 Cross Laminated Timber (CLT) material conforming to APA PRG-320.
2. Installation and fastener schedule assume platform framing, i.e., install vertical leg at bottom edge of CLT wall panel, and horizontal leg on CLT floor panel with 3⅛ in. min. edge distance.
3. Allowable loads have been increased for wind or earthquake loading with no further increase allowed. Reduce for other load durations as required by code.
4. **Nails:** CNA4x60 = 4 mm diameter x 60 mm long proprietary ring-shank nail.
5. **Screws:** SD10212 = 0.162 in. shank diameter x 2.5 in. long Simpson Strong-Drive® wood screw.

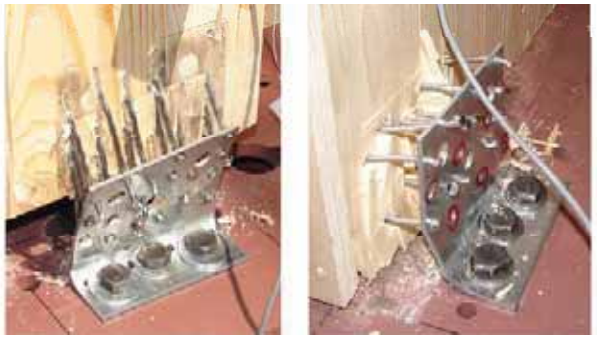
Frequently Asked Questions:

1. What type of connections are recommended/approved for CLT?.

- Self-tapping screws will likely be the most common connector used in CLT construction. These are proprietary connectors and design values and requirements would be specified by the manufacturer. The manufacturer will be responsible for providing lateral and withdrawal connection values and any information needed to explain how to use provisions of the NDS (e.g. dowel bearing strength adjustments, dowel bending strengths of the self-tapping screws, and specific application of the NDS yield equations).
- Design values for proprietary fasteners and information on their approved use are available in Evaluation Reports or the manufacturer's literature.

Seismic Design

To provide ductile seismic resistance, CLT connections in seismic force resisting systems should be governed by fastener yielding and wood crushing NOT brittle failures.



Wind Design

- Wind design uses linear-elastic analysis methods
- Design resistance can be derived using standard methods
- Design is fairly straight forward

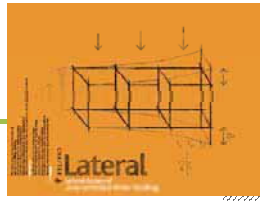
Seismic Design

Available design approaches:

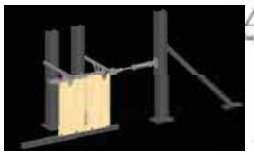
Alternative Means until CLT system code recognized.

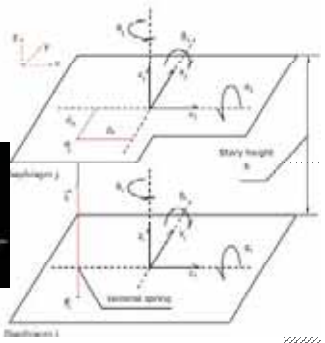
- ELF Seismic Performance Factors; R, Omega, Cd.
    - (under development)
    - (CLT handbook provides values considered to be conservative)
- Performance Based Seismic Design

CLT Handbook -Chapter 4

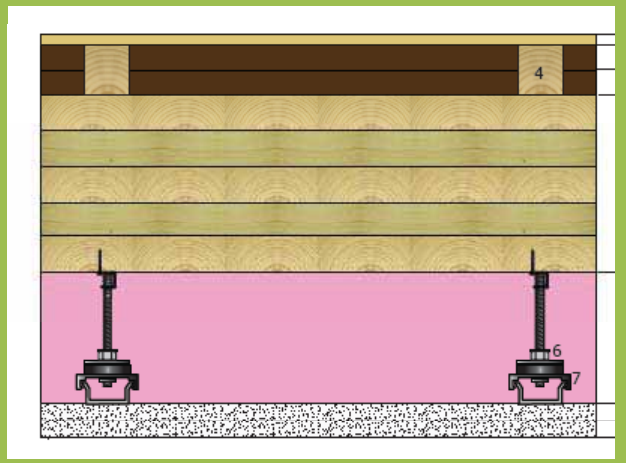


- Shear wall Performance
  - Prescribed vs. principles of mechanics
  - Based on connection design - fasteners should yield
- Seismic design
  - Coefficients (R, Ωo, Cd)
  - Performance Based Design Pathways
- Literature review
- Numerical modeling
- Examples –
  - allowable capacity
  - system simulation
- R=2 conservative recommendation





Acoustic Design



Acoustics

Essential Knowledge – Principle for Good Sound Insulation Design

- Sufficient mass
- Soft surface of floor finishing
- Floating topping and finishing
- Suspended drywall ceiling
- Decouple

FPInnovations

Acoustics

Perceivable sound pressure differential is 3dB

Important rule for the development of cost-effective solutions!

FPInnovations

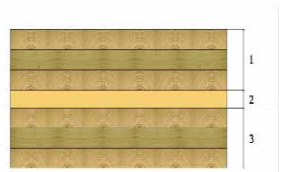
Acoustics

Sound Insulation of Bare CLT Floors and Walls

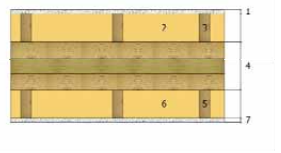
Number of layers	Thickness (in.)	Assembly type	STC	IIC
3	3-3/4 to 4-1/2	Wall	32-34	N.A.
5	5-1/3	Floor	39	23
5	5-3/4	Floor	39	24
Measured on field bare CLT wall and floor				
Number of layers	Thickness in.	Assembly type	FSTC	FIIC
3	4-1/8	Wall	28	N.A.
7	8-1/5	Floor	N.A	25-30

Acoustics

Design Examples for >50 STC Walls



- STC 50:
1 and 3 = 4-1/2 in. CLT; 2=1-1/8 in. Mineral wool in the gap
- STC 55:
Adding 5/8 in. gypsum board directly to both sides
- STC 60:
with the gypsum boards and double the thickness of the gap and mineral wool



- STC 58:
1 and 7 = 5/8 in. gypsum boards
3 and 5 = 2 in. by 3 in. wood studs at least 16 in. o.c.
2 and 6 = 2.5 in. mineral wool
4 = 4-1/2 in. CLT

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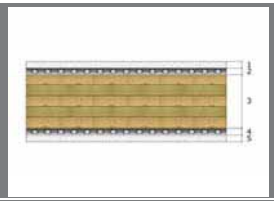
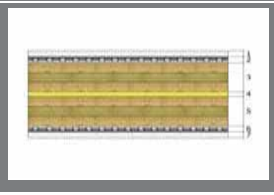
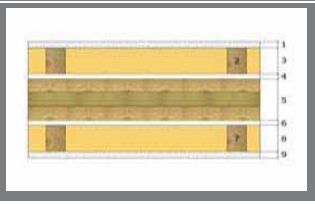
Acoustics

Design Examples for >45 FSTC Walls

Top view of cross-section	Wall detail	FSTC
	1 & 5 = 5/8" Gypsum board 2 & 4 = Resilient channels at 24" o.c. 3. 5-layer CLT of 7-1/4"	46
	1 & 7 = 5/8" Gypsum board 2 & 6 = Resilient channels at 24" o.c 3 & 5 = 3-layer CLT of 3.07" 4 = 1" air gap filled with mineral wool	47

Acoustics

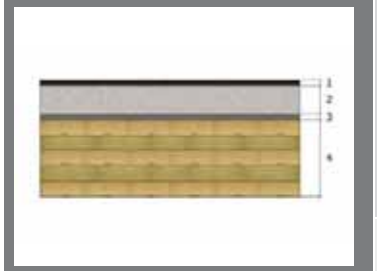
Design Examples for >45 FSTC Walls

Top view of cross-section	Wall detail	FSTC
	1 = 3-layer CLT of 4-1/8" 2 = 1/2" air gap 3 = 2" by 3" wood studs at 16" o.c. 4 = 2-1/2" mineral wool 5 = 5/8" gypsum board	47
	1 & 9 = 5/8" gypsum board 2 & 7 = 2" by 3" wood studs at 16" o.c. 3 & 8 = 2-1/2" mineral wool 4 & 6 = 1/2" air gap 5 = 3-layer CLT of 4-1/8"	50

FPInnovations

Acoustics

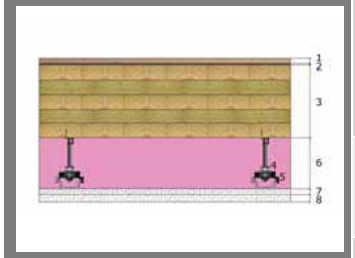
Design Examples for >45 FSTC and FIIC Floors

End view of cross-section	Floor detail	FSTC	FIIC
	1 = Carpet, or floating flooring about 2/5" on 1/8" resilient underlayment of 0.16 to 0.37 lb./ft.² 2 = At least 5.12 lb./ft.² dry topping, e.g. 0.8-1" gypsum board, cement fibreboard 3 = Resilient underlayment, e.g. 2/5" rubber mat of 0.84 lb./ft.² , ¾" texture felt of 0.27 lb./ft.² , ½" low density wood fibreboard of 0.73lb./ft.² 4 = 5-layer CLT of 6-7/8"	~45	~45
	- Replace the dry topping by wet topping, e.g. 1.5" concrete of at least 15.6 lb./ft.²	~50	~50

FPInnovations

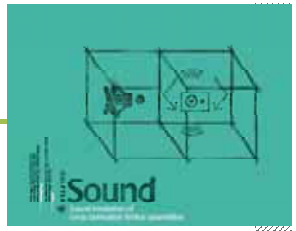
Acoustics

Design Examples for >45 FSTC and FIIC Floors

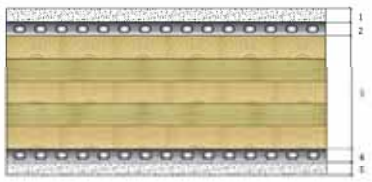
End view of cross-section	Floor detail	FSTC	FIIC
	1 = Carpet, or flooring about 2/5" 2 = 1/8" resilient underlayment of 0.16 to 0.37 lb./ft.² 3 = 5-layer CLT of 6-7/8" 4 = Sound Isolation Clips of 4" high 5 = Metal hat channel at 16" o.c. 6 = Sound absorption material (such as glass fibre) of 4" 7 = Gypsum board of 5/8" 8 = Gypsum board of 5/8"	~50	~50
	- Replace 1) by hardwood flooring nailed to ¾" plywood - Replace 2) by thick resilient underlayment, e.g. 2/5" rubber mat of 0.84 lb./ft.² , ¾" texture felt of 0.27 lb./ft.² , ½" low-density wood fibre board of 0.73 lb./ft.²	~53	~53
	- Replace 1) by ceramic tile glued to ½" and ¾" plywood - Replace 2) by thick resilient underlayment, e.g. 2/5" rubber mat of 0.84 lb./ft.² , ¾" texture felt of 0.27 lb./ft.² , ½" low-density wood fibreboard of 0.73lb./ft.²	~53	~53

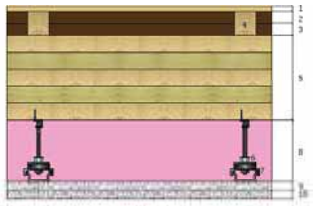
FPInnovations

Chapter 9 - Sound



- Acoustic properties of CLT
- STC and IIC rated assemblies
- FSTC and FIIC rated assemblies
- Recommendations for meeting IBC requirements





Frequently Asked Question:

1. Are their any substitutions for more common acoustic assembly materials?

yes

Fermacell can be replaced with cement –fiber board as long as it has the same or higher density (32kg/m2).

Isover is very similar to Roxul (Rock wool).

Frequently Asked Question:

1. Are there more tested assemblies available?

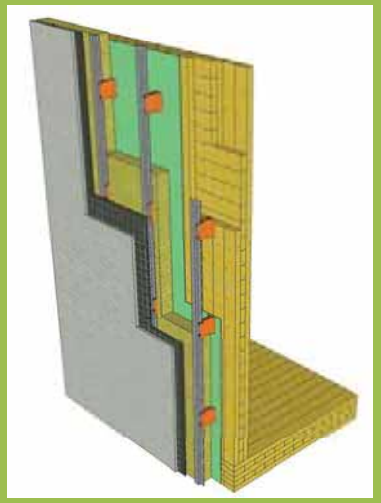
yes

NRC has data on assemblies beyond those in the Handbook

Additional assemblies may be tested

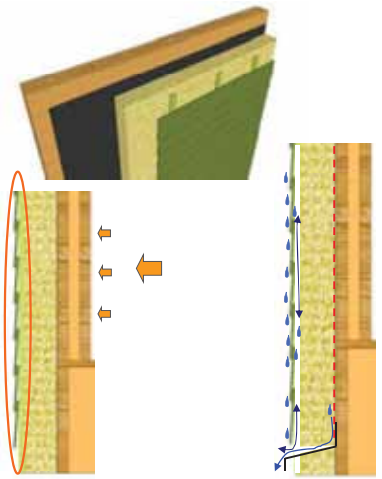
Acousticians can estimate sound performance based on sound test data

Building Enclosure Design



Building Enclosure Design

- CLT wall assemblies should be built “breathable”
- Prevent rain infiltrations
- Wetting during transportation, construction and service should be minimized
- Studies show that in heating climate that no vapor barrier will be required at interior



Moisture Management

- Rain screen
  - cavity directly behind the cladding
  - allows improved drying
  - Openings in cladding at top and bottom
- Drained wall
  - Requires WRB
  - 1/16” air gap suggested
  - Drainage wrap recommended with foam insulation
  - OR groves cut in back side of foam insulation

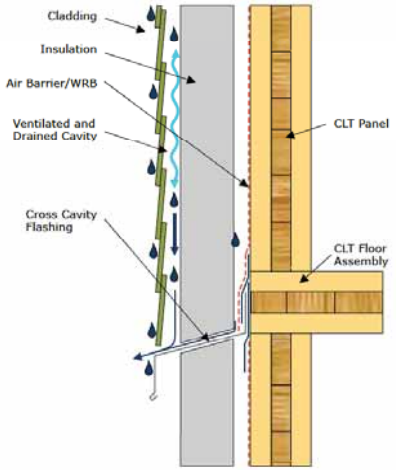
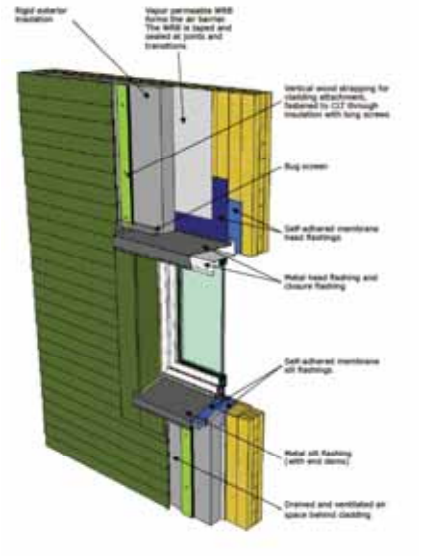


Figure 5
Best practice rainwater management strategy for CLT wall assembly

Moisture Management

- Water Resistive Barrier
  - Essential part
  - Properly overlapped in a shingle fashion
  - integrate with flashings
  - Sealed at all penetrations



Energy Performance

Exterior Insulation

- Provides continuity (no break at floors)
- Shields CLT and air barrier from temp (less expansion and contraction)
- Capitalizes more thermal mass benefit
- Keeps it warmer (in cold climates)
- Lowers surface relative humidity
- Keeps it dryer (in hot humid)

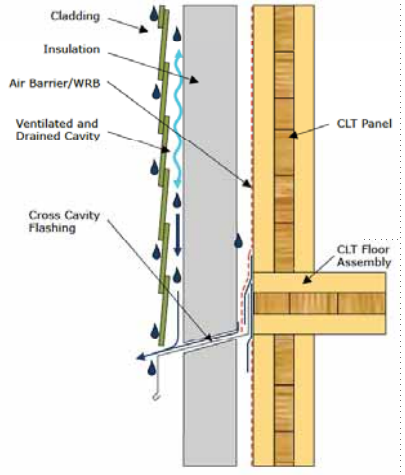
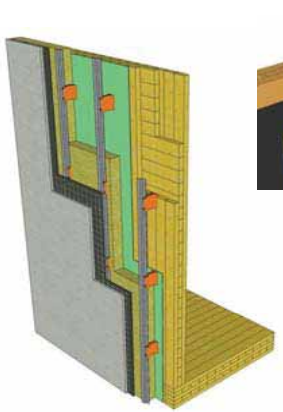
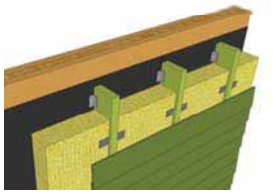
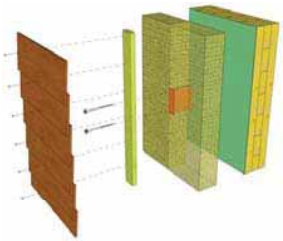


Figure 5
Best practice rainwater management strategy for CLT wall assembly

Energy Performance







Rigid shear block type connection through insulation, cladding to vertical strapping

Energy Performance

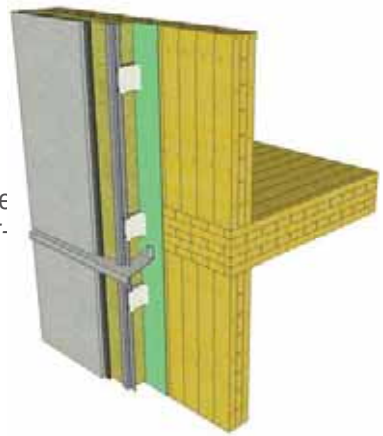
Air-tight as a material, but not as a system

Recommend

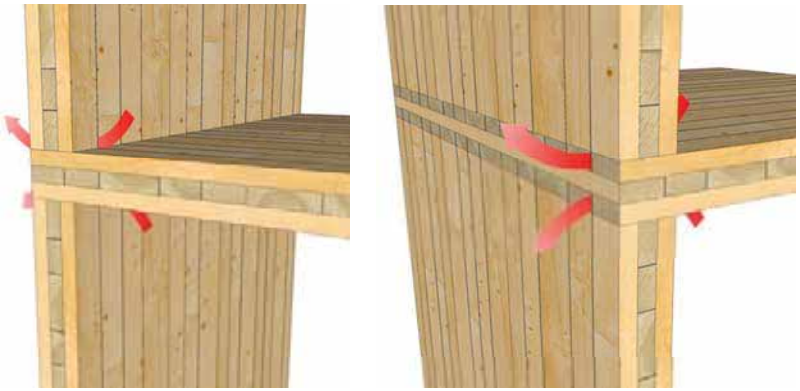
- self-adhered sheet product air barrier membranes
- or thick liquid applied membrane on exterior of panels *(exterior air-barrier approach)*

Not recommended

- loose-applied sheets (House-wraps)



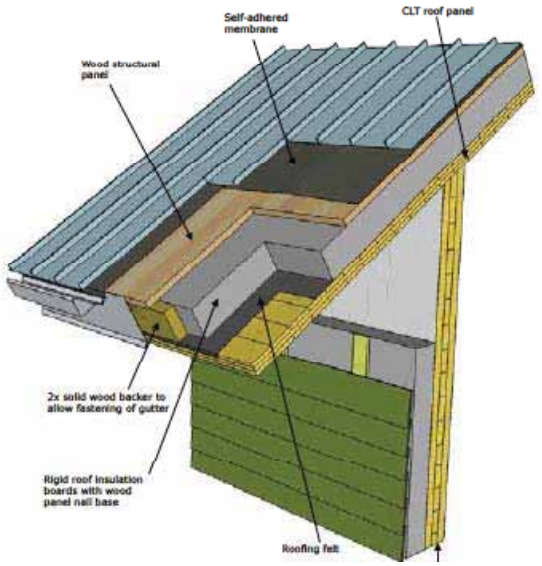
Energy Performance



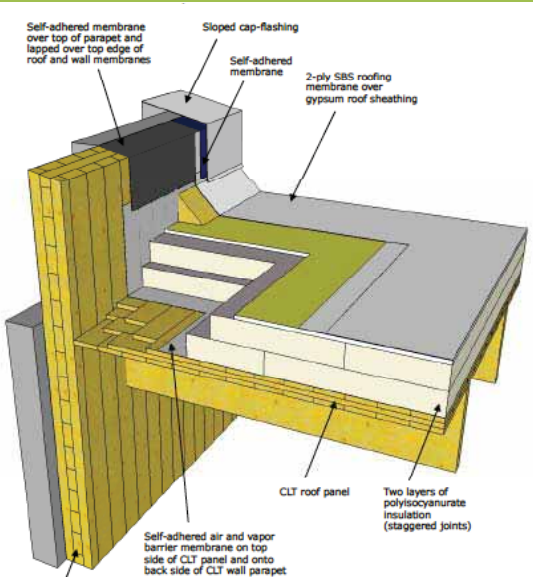
Sealants, tapes, & membranes applied on either side can't address this type of airflow path through the CLT lumber gaps

Airflow path more convoluted – lower leakage rates, but still a consideration

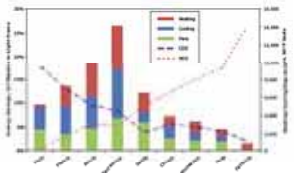
Roof Assemblies



Roof Assemblies



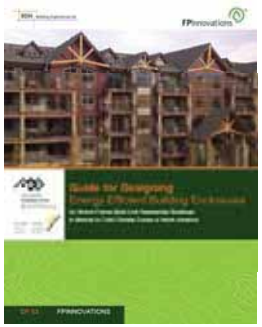
CLT Handbook -Chapter 10

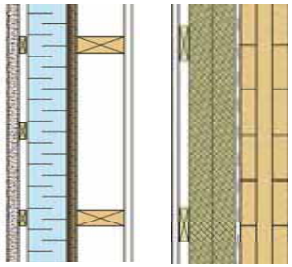


- Properties of CLT
  - Water vapor sorption
  - Permeability
  - Liquid water absorption
  - Heat storage/transfer
  - Air permeability
- Approaches to exterior water management
- Recommended Assemblies
- Moisture Control During Construction
- Preservative Treatment

Resources

Buildings in Marine to Cold Climate Zones in North America





2x4 (or 2x6) stud wall

CLT/mass timber

Exterior-insulated wall assemblies

http://www.fpinnovations.ca/ResearchProgram/AdvancedBuildingSystem/designing-energy-efficient-building-enclosures.pdf

Resources

Buildings in Marine to Cold Climate Zones in North America

Chapter 3: Moisture, Air and Thermal Control

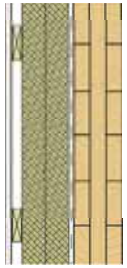
- Building as a System
- Climate Zones
- Interior Climate, HVAC Interaction
- Critical Barrier Concept
- Control of Rainwater Penetration
- Control of Air Flow
- Controlling Condensation
- Construction Moisture
- Controlling Heat Flow and Insulation
- Whole Building Energy Efficiency
- Computer Simulation Considerations for Wood-framed Enclosures

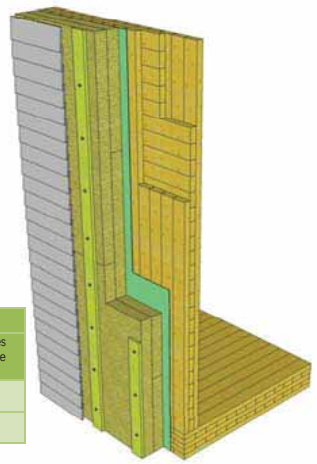
Resources

Buildings in Marine to Cold Climate Zones in North America

Chapter 4 – Energy Efficient Walls Exterior Insulated

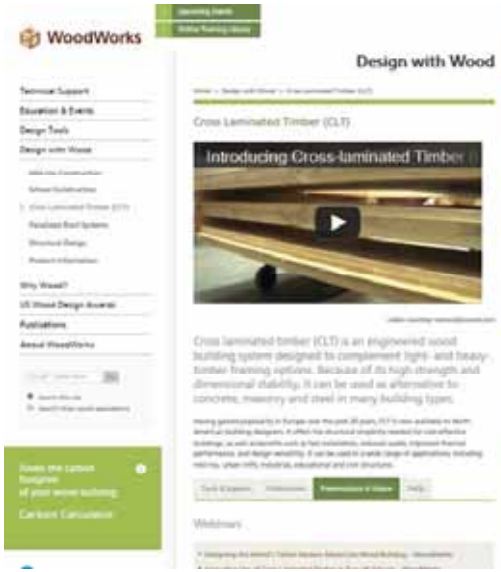
- Material selection & guidance
- Control Functions
- Critical Barriers
- Effective R-value Tables





Wood framing	Exterior insulation [R-value/inch (RSI/cm)]	Exterior insulation thickness					
		3 inches R-value (RSI)]	4 inches [R-value (RSI)]	5 inches [R-value (RSI)]	6 inches [R-value (RSI)]	7 inches [R-value (RSI)]	8 inches [R-value (RSI)]
3½-inch-thick CLT panels	**R-4/inch (0.28/cm)**	17.2 (3.0)	20.9 (3.7)	24.4 (4.3)	27.9 (4.9)	31.6 (5.6)	35.0 (6.2)
	R-5/inch (0.34/cm)	19.8 (3.5)	24.4 (4.3)	28.7 (5.1)	32.9 (5.8)	37.3 (6.6)	41.5 (7.3)

WoodWorks –Portal to CLT Information



Questions?

[contact info]

Project Assistance also available at help@woodworks.org