**Architecture 324**
**Structures II**

# Cross-Laminated Timber
# CLT

# Kreuzlagenholz
# KLH

Material Properties
Structural Properties
Structural Design
Construction Details
Examples

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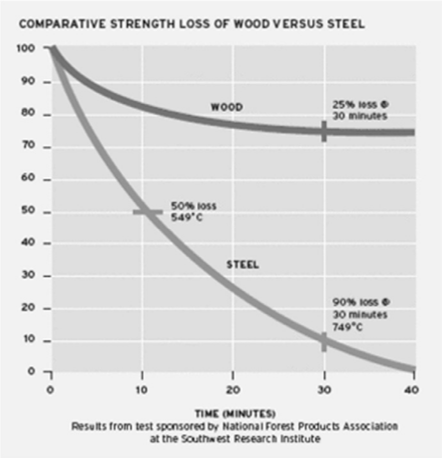
# Cross-Laminated Timber Characteristics

- large-scale solid wood panel
- prefabricated
- lightweight, yet very strong
- fast and easy to install
- low environmental impact
- superior acoustic, fire, seismic, and thermal performance

Highly advantageous alternative to conventional materials like concrete, masonry, or steel, especially in multi-family and commercial construction.

# Fire Resistance of Timber

- Timber generally chars at 1”/hour
- Flat panels burn slower than edges
- Maintain strength in heat better than steel
- Allowed heights by IBC
  Fully Protected Type IV-A 270’
  Partially Protected Type IV-B 180’
  Exposed Type IV-C 85’


COMPARATIVE STRENGTH LOSS OF WOOD VERSUS STEEL

Results from test sponsored by National Forest Products Association at the Southwest Research Institute

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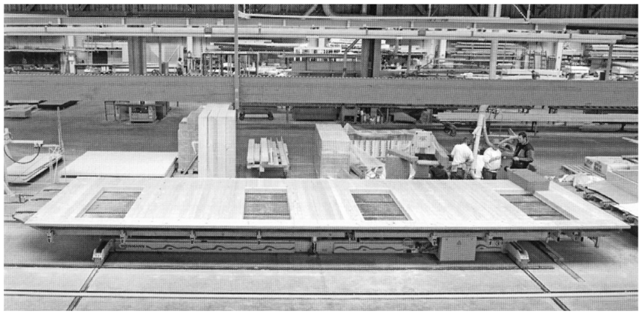
# Cross-Laminated Timber Composition

- several layers of kiln-dried lumber boards
- stacked in alternating directions
- bonded with structural adhesives
- pressed to form a solid, straight, rectangular panel
- odd number of layers – usually 3 to 7
- may be sanded or prefinished

# Cross-Laminated Timber Fabrication

- panels are cut to size
- pre-cut door and window openings
- often CNC routed
- panels are exceptionally stiff, strong, and stable
- structural load transfer on any side
- panels are typically 2 to 10 feet wide
- lengths up to 60 feet (max. 98 ft)
- thickness up to 20 inches
- widths up to 18 feet



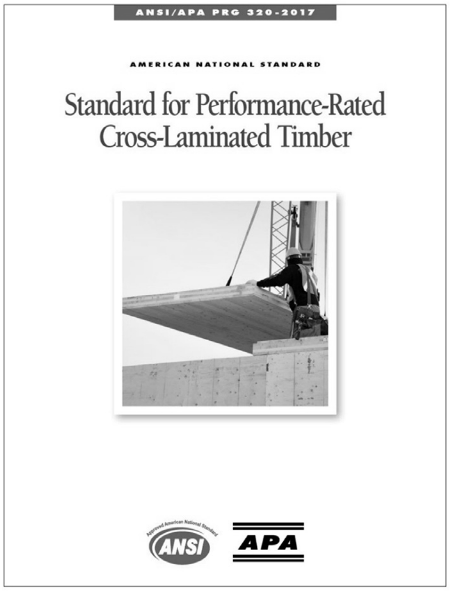
# Cross-Laminated Timber Performance Standards

- American National Standard ANSI / APA PRG 320-2019
- APA certification by APA member mills.
- designed to assure manufacture in conformance with APA performance standards

APA

V2 6 7/8"

MILL 0000 ANSI/APA PRG 320-2012



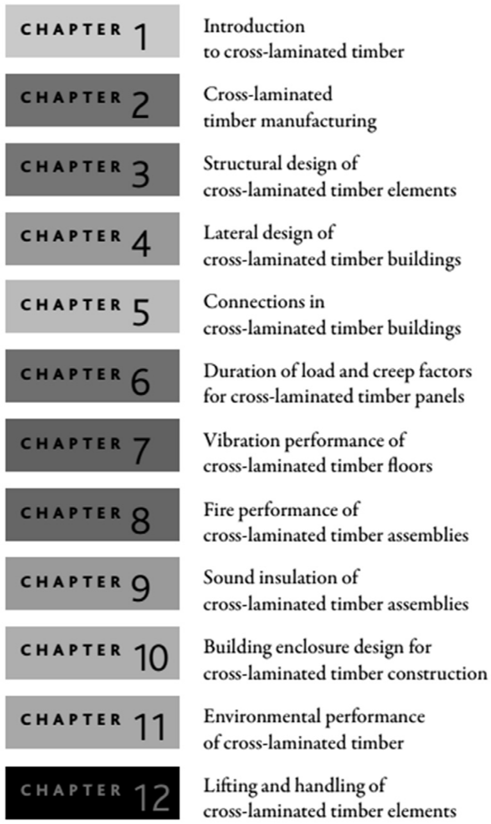
ANSI/APA PRG 320-2017

AMERICAN NATIONAL STANDARD

Standard for Performance-Rated Cross-Laminated Timber

APA PRG-320

# Cross-Laminated Timber



CHAPTER 1 Introduction to cross-laminated timber

CHAPTER 2 Cross-laminated timber manufacturing

CHAPTER 3 Structural design of cross-laminated timber elements

CHAPTER 4 Lateral design of cross-laminated timber buildings

CHAPTER 5 Connections in cross-laminated timber buildings

CHAPTER 6 Duration of load and creep factors for cross-laminated timber panels

CHAPTER 7 Vibration performance of cross-laminated timber floors

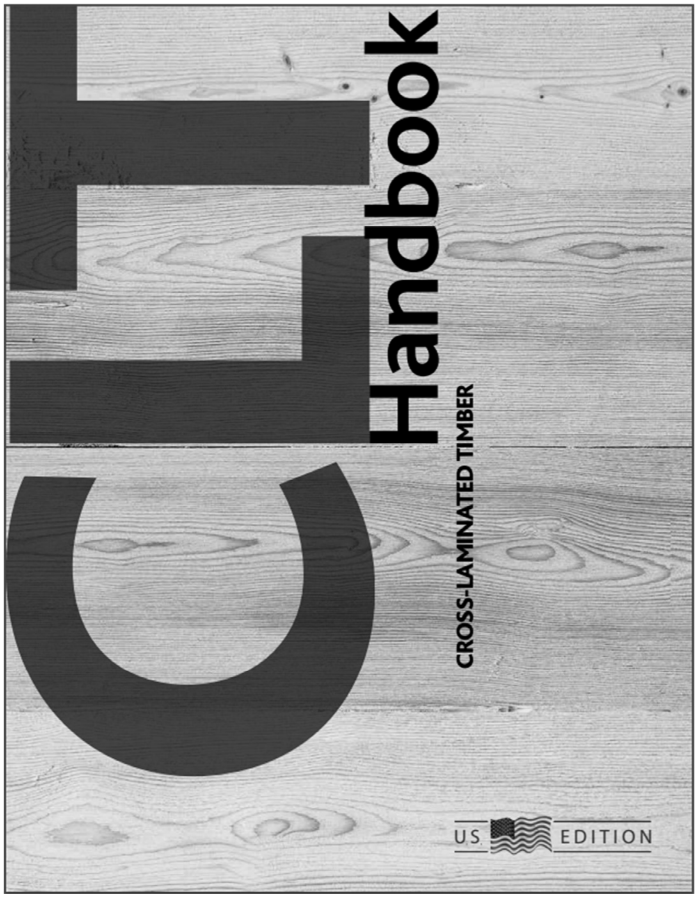
CHAPTER 8 Fire performance of cross-laminated timber assemblies

CHAPTER 9 Sound insulation of cross-laminated timber assemblies

CHAPTER 10 Building enclosure design for cross-laminated timber construction

CHAPTER 11 Environmental performance of cross-laminated timber

CHAPTER 12 Lifting and handling of cross-laminated timber elements



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# Cross-Laminated Timber
## Structural Properties

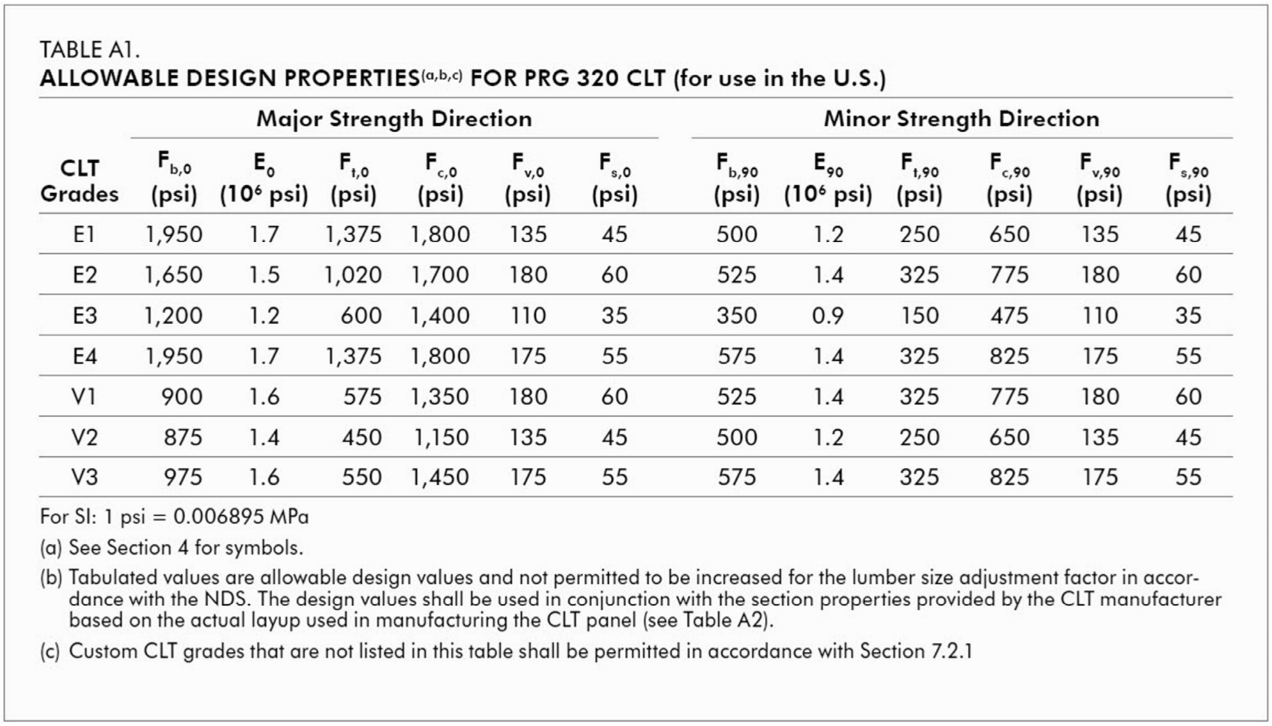


TABLE A1.
**ALLOWABLE DESIGN PROPERTIES**[a,b,c] **FOR PRG 320 CLT (for use in the U.S.)**

| | Major Strength Direction | | | | | | Minor Strength Direction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CLT Grades | $F_{b,0}$ (psi) | $E_0$ ($10^6$ psi) | $F_{t,0}$ (psi) | $F_{c,0}$ (psi) | $F_{v,0}$ (psi) | $F_{s,0}$ (psi) | $F_{b,90}$ (psi) | $E_{90}$ ($10^6$ psi) | $F_{t,90}$ (psi) | $F_{c,90}$ (psi) | $F_{v,90}$ (psi) | $F_{s,90}$ (psi) |
| E1 | 1,950 | 1.7 | 1,375 | 1,800 | 135 | 45 | 500 | 1.2 | 250 | 650 | 135 | 45 |
| E2 | 1,650 | 1.5 | 1,020 | 1,700 | 180 | 60 | 525 | 1.4 | 325 | 775 | 180 | 60 |
| E3 | 1,200 | 1.2 | 600 | 1,400 | 110 | 35 | 350 | 0.9 | 150 | 475 | 110 | 35 |
| E4 | 1,950 | 1.7 | 1,375 | 1,800 | 175 | 55 | 575 | 1.4 | 325 | 825 | 175 | 55 |
| V1 | 900 | 1.6 | 575 | 1,350 | 180 | 60 | 525 | 1.4 | 325 | 775 | 180 | 60 |
| V2 | 875 | 1.4 | 450 | 1,150 | 135 | 45 | 500 | 1.2 | 250 | 650 | 135 | 45 |
| V3 | 975 | 1.6 | 550 | 1,450 | 175 | 55 | 575 | 1.4 | 325 | 825 | 175 | 55 |

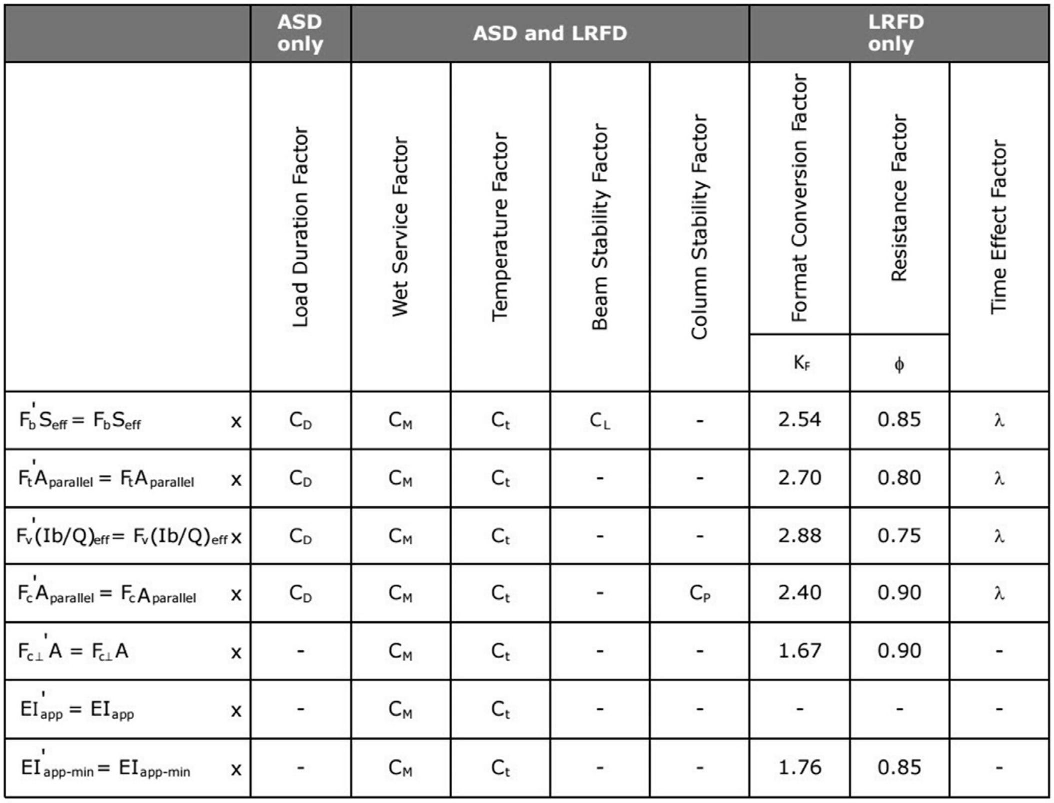
For SI: 1 psi = 0.006895 MPa

(a) See Section 4 for symbols.

(b) Tabulated values are allowable design values and not permitted to be increased for the lumber size adjustment factor in accordance with the NDS. The design values shall be used in conjunction with the section properties provided by the CLT manufacturer based on the actual layup used in manufacturing the CLT panel (see Table A2).

(c) Custom CLT grades that are not listed in this table shall be permitted in accordance with Section 7.2.1

# Cross-Laminated Timber
# Adjustment Factors



| | ASD only | ASD and LRFD | | | | LRFD only | | |
|---|---|---|---|---|---|---|---|---|
| | Load Duration Factor | Wet Service Factor | Temperature Factor | Beam Stability Factor | Column Stability Factor | Format Conversion Factor | Resistance Factor | Time Effect Factor |
| | | | | | | $K_F$ | $\phi$ | |
| $F_b' S_{eff} = F_b S_{eff}$ x | $C_D$ | $C_M$ | $C_t$ | $C_L$ | - | 2.54 | 0.85 | $\lambda$ |
| $F_t' A_{parallel} = F_t A_{parallel}$ x | $C_D$ | $C_M$ | $C_t$ | - | - | 2.70 | 0.80 | $\lambda$ |
| $F_v' (Ib/Q)_{eff} = F_v (Ib/Q)_{eff}$ x | $C_D$ | $C_M$ | $C_t$ | - | - | 2.88 | 0.75 | $\lambda$ |
| $F_c' A_{parallel} = F_c A_{parallel}$ x | $C_D$ | $C_M$ | $C_t$ | - | $C_P$ | 2.40 | 0.90 | $\lambda$ |
| $F_{c\perp}' A = F_{c\perp} A$ x | - | $C_M$ | $C_t$ | - | - | 1.67 | 0.90 | - |
| $EI_{app}' = EI_{app}$ x | - | $C_M$ | $C_t$ | - | - | - | - | - |
| $EI_{app-min}' = EI_{app-min}$ x | - | $C_M$ | $C_t$ | - | - | 1.76 | 0.85 | - |

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# Cross-Laminated Timber - Allowable Bending Capacity

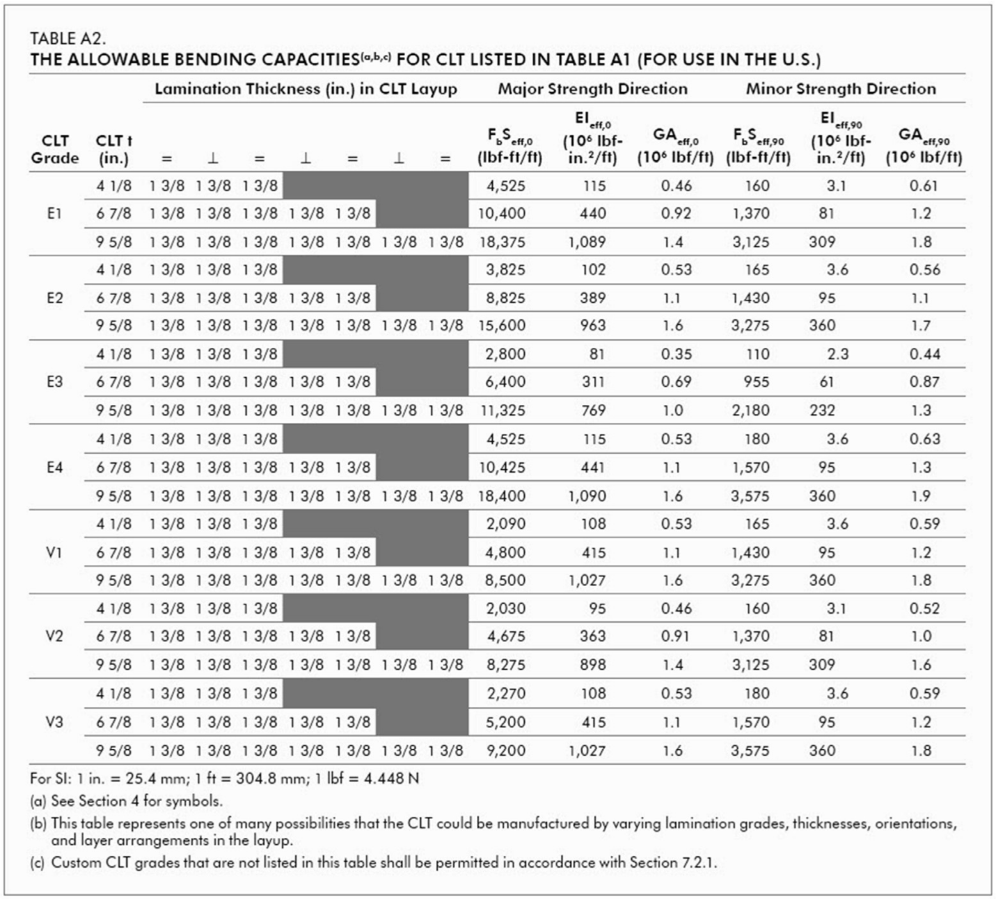


TABLE A2.
**THE ALLOWABLE BENDING CAPACITIES(a,b,c) FOR CLT LISTED IN TABLE A1 (FOR USE IN THE U.S.)**

| | | Lamination Thickness (in.) in CLT Layup | | | | | | | Major Strength Direction | | | Minor Strength Direction | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CLT Grade | CLT t (in.) | = | ⊥ | = | ⊥ | = | ⊥ | = | $F_bS_{eff,0}$ (lbf-ft/ft) | $EI_{eff,0}$ ($10^6$ lbf-in.$^2$/ft) | $GA_{eff,0}$ ($10^6$ lbf/ft) | $F_bS_{eff,90}$ (lbf-ft/ft) | $EI_{eff,90}$ ($10^6$ lbf-in.$^2$/ft) | $GA_{eff,90}$ ($10^6$ lbf/ft) |
| E1 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | | | 4,525 | 115 | 0.46 | 160 | 3.1 | 0.61 |
| | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | 10,400 | 440 | 0.92 | 1,370 | 81 | 1.2 |
| | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 18,375 | 1,089 | 1.4 | 3,125 | 309 | 1.8 |
| E2 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | | | 3,825 | 102 | 0.53 | 165 | 3.6 | 0.56 |
| | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | 8,825 | 389 | 1.1 | 1,430 | 95 | 1.1 |
| | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 15,600 | 963 | 1.6 | 3,275 | 360 | 1.7 |
| E3 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | | | 2,800 | 81 | 0.35 | 110 | 2.3 | 0.44 |
| | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | 6,400 | 311 | 0.69 | 955 | 61 | 0.87 |
| | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 11,325 | 769 | 1.0 | 2,180 | 232 | 1.3 |
| E4 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | | | 4,525 | 115 | 0.53 | 180 | 3.6 | 0.63 |
| | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | 10,425 | 441 | 1.1 | 1,570 | 95 | 1.3 |
| | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 18,400 | 1,090 | 1.6 | 3,575 | 360 | 1.9 |
| V1 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | | | 2,090 | 108 | 0.53 | 165 | 3.6 | 0.59 |
| | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | 4,800 | 415 | 1.1 | 1,430 | 95 | 1.2 |
| | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 8,500 | 1,027 | 1.6 | 3,275 | 360 | 1.8 |
| V2 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | | | 2,030 | 95 | 0.46 | 160 | 3.1 | 0.52 |
| | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | 4,675 | 363 | 0.91 | 1,370 | 81 | 1.0 |
| | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 8,275 | 898 | 1.4 | 3,125 | 309 | 1.6 |
| V3 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | | | 2,270 | 108 | 0.53 | 180 | 3.6 | 0.59 |
| | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | | | 5,200 | 415 | 1.1 | 1,570 | 95 | 1.2 |
| | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 9,200 | 1,027 | 1.6 | 3,575 | 360 | 1.8 |

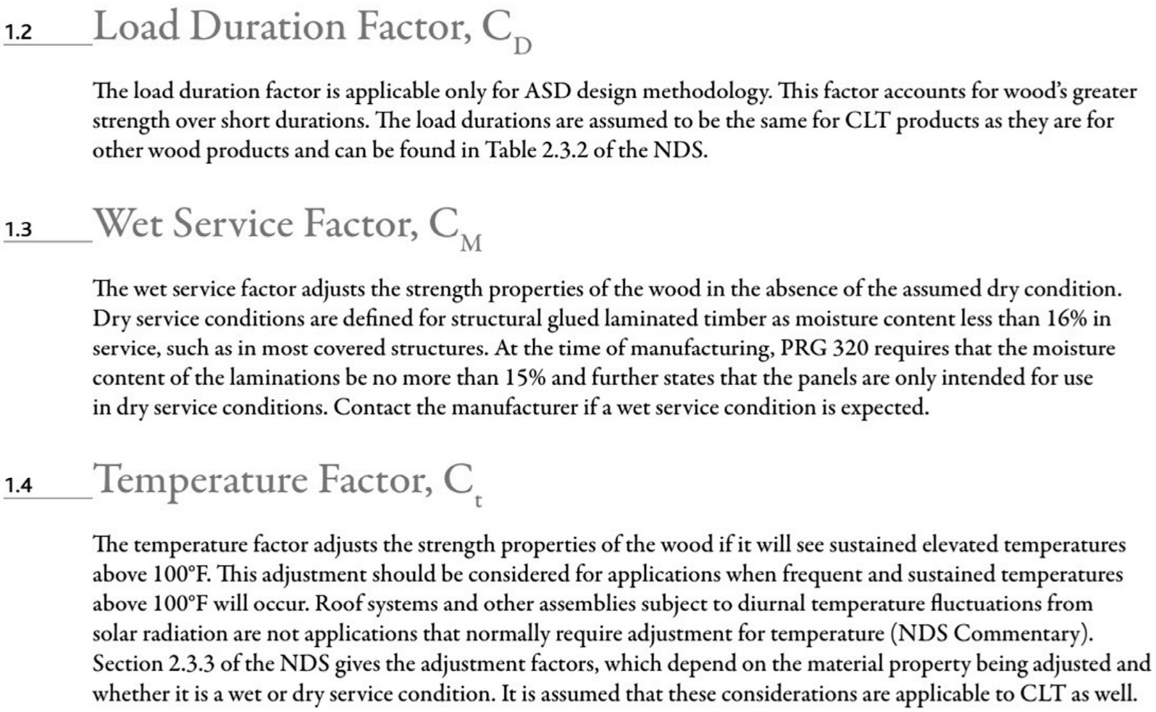
For SI: 1 in. = 25.4 mm; 1 ft = 304.8 mm; 1 lbf = 4.448 N

(a) See Section 4 for symbols.

(b) This table represents one of many possibilities that the CLT could be manufactured by varying lamination grades, thicknesses, orientations, and layer arrangements in the layup.

(c) Custom CLT grades that are not listed in this table shall be permitted in accordance with Section 7.2.1.

# Cross-Laminated Timber
# Adjustment Factors



## 1.2 Load Duration Factor, $C_D$

The load duration factor is applicable only for ASD design methodology. This factor accounts for wood's greater strength over short durations. The load durations are assumed to be the same for CLT products as they are for other wood products and can be found in Table 2.3.2 of the NDS.

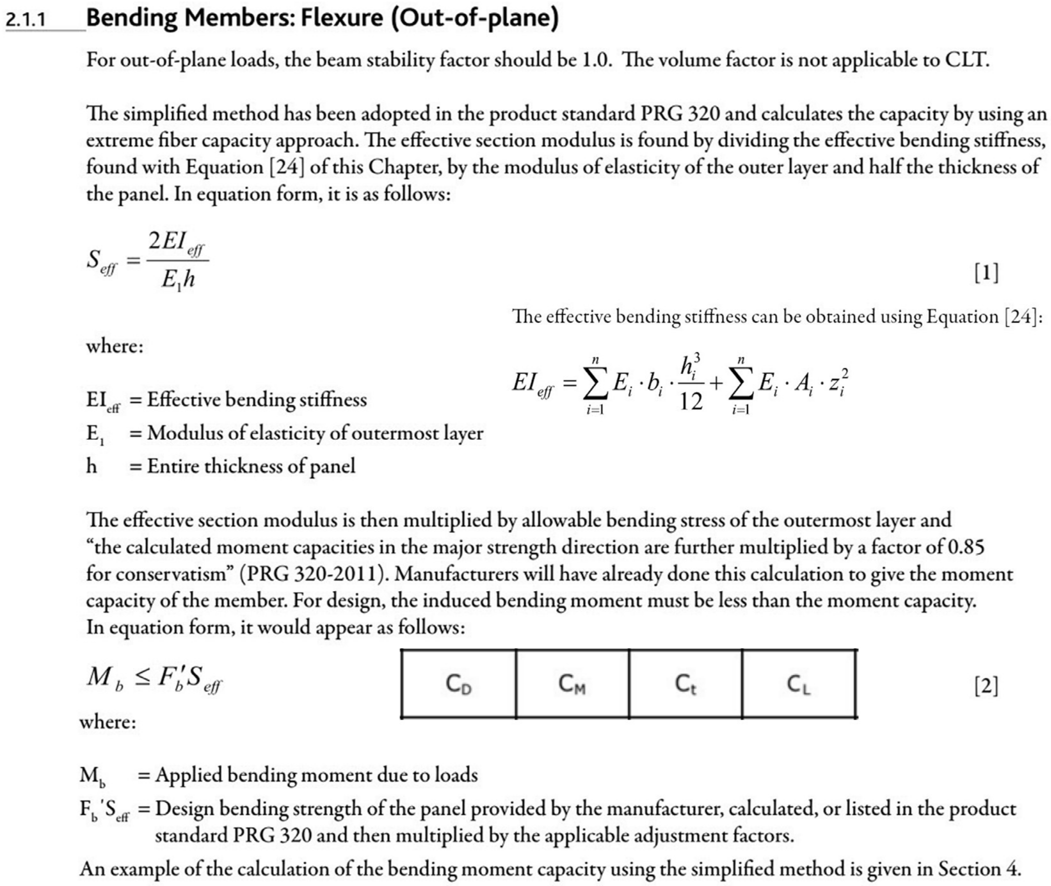
## 1.3 Wet Service Factor, $C_M$

The wet service factor adjusts the strength properties of the wood in the absence of the assumed dry condition. Dry service conditions are defined for structural glued laminated timber as moisture content less than 16% in service, such as in most covered structures. At the time of manufacturing, PRG 320 requires that the moisture content of the laminations be no more than 15% and further states that the panels are only intended for use in dry service conditions. Contact the manufacturer if a wet service condition is expected.

## 1.4 Temperature Factor, $C_t$

The temperature factor adjusts the strength properties of the wood if it will see sustained elevated temperatures above 100°F. This adjustment should be considered for applications when frequent and sustained temperatures above 100°F will occur. Roof systems and other assemblies subject to diurnal temperature fluctuations from solar radiation are not applications that normally require adjustment for temperature (NDS Commentary). Section 2.3.3 of the NDS gives the adjustment factors, which depend on the material property being adjusted and whether it is a wet or dry service condition. It is assumed that these considerations are applicable to CLT as well.

# Cross-Laminated Timber - Flexure



### 2.1.1 Bending Members: Flexure (Out-of-plane)

For out-of-plane loads, the beam stability factor should be 1.0. The volume factor is not applicable to CLT.

The simplified method has been adopted in the product standard PRG 320 and calculates the capacity by using an extreme fiber capacity approach. The effective section modulus is found by dividing the effective bending stiffness, found with Equation [24] of this Chapter, by the modulus of elasticity of the outer layer and half the thickness of the panel. In equation form, it is as follows:

$$S_{eff} = \frac{2EI_{eff}}{E_1 h} \qquad [1]$$

where:

$EI_{eff}$ = Effective bending stiffness

$E_1$ = Modulus of elasticity of outermost layer

h = Entire thickness of panel

The effective bending stiffness can be obtained using Equation [24]:

$$EI_{eff} = \sum_{i=1}^{n} E_i \cdot b_i \cdot \frac{h_i^3}{12} + \sum_{i=1}^{n} E_i \cdot A_i \cdot z_i^2$$

The effective section modulus is then multiplied by allowable bending stress of the outermost layer and "the calculated moment capacities in the major strength direction are further multiplied by a factor of 0.85 for conservatism" (PRG 320-2011). Manufacturers will have already done this calculation to give the moment capacity of the member. For design, the induced bending moment must be less than the moment capacity. In equation form, it would appear as follows:

$$M_b \le F_b' S_{eff} \qquad [2]$$

| | | | |
|---|---|---|---|
| $C_D$ | $C_M$ | $C_t$ | $C_L$ |

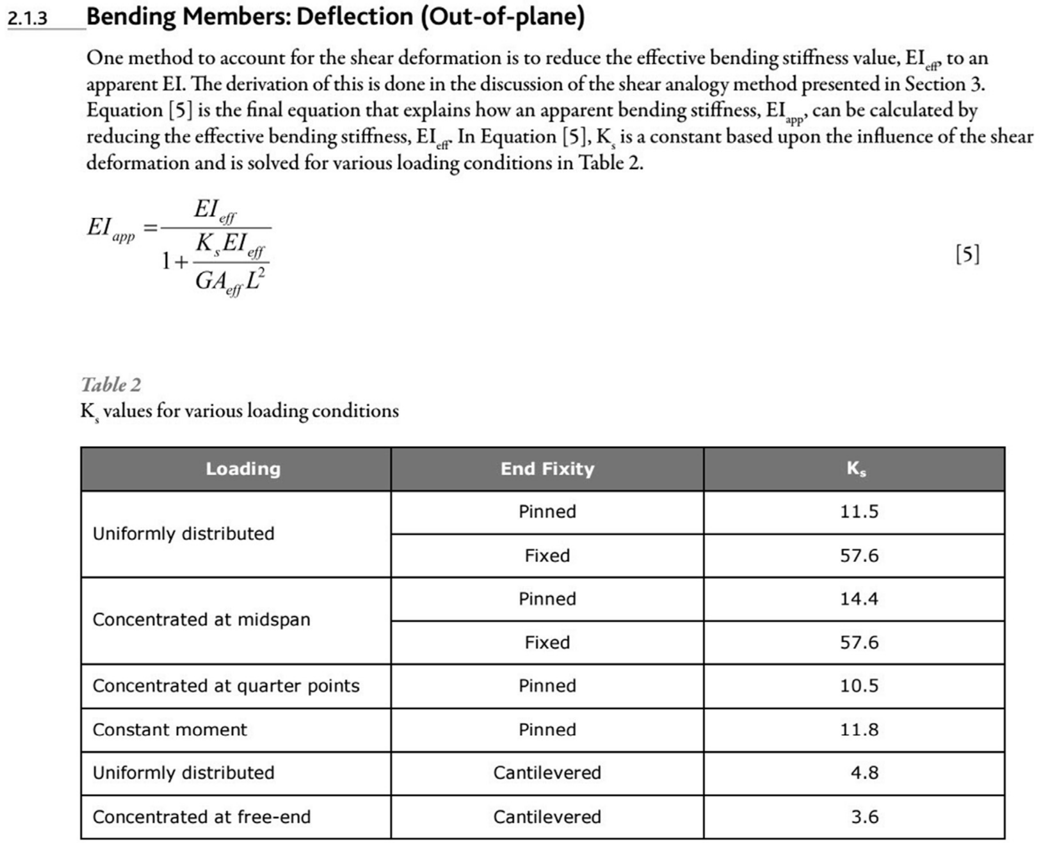
where:

$M_b$ = Applied bending moment due to loads

$F_b'S_{eff}$ = Design bending strength of the panel provided by the manufacturer, calculated, or listed in the product standard PRG 320 and then multiplied by the applicable adjustment factors.

An example of the calculation of the bending moment capacity using the simplified method is given in Section 4.

# Cross-Laminated Timber - Deflection



### 2.1.3 Bending Members: Deflection (Out-of-plane)

One method to account for the shear deformation is to reduce the effective bending stiffness value, $EI_{eff}$, to an apparent EI. The derivation of this is done in the discussion of the shear analogy method presented in Section 3. Equation [5] is the final equation that explains how an apparent bending stiffness, $EI_{app}$, can be calculated by reducing the effective bending stiffness, $EI_{eff}$. In Equation [5], $K_s$ is a constant based upon the influence of the shear deformation and is solved for various loading conditions in Table 2.

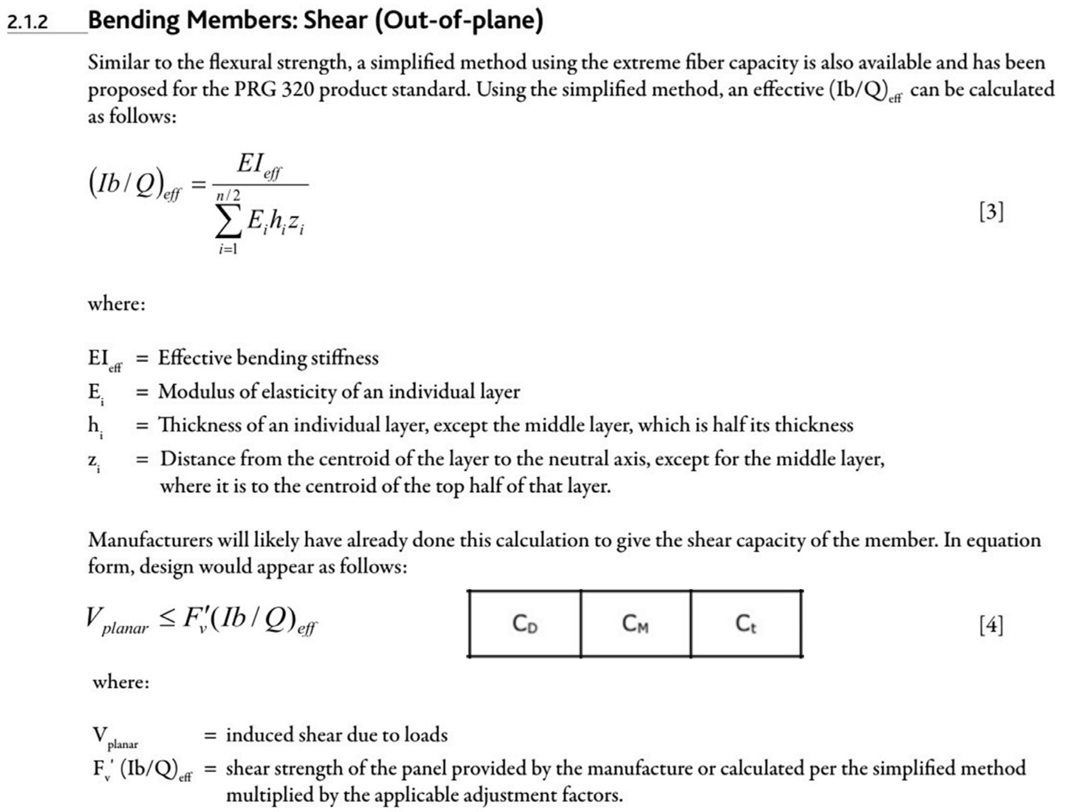
$$EI_{app} = \frac{EI_{eff}}{1 + \frac{K_s EI_{eff}}{GA_{eff} L^2}} \qquad [5]$$

*Table 2*

$K_s$ values for various loading conditions

| Loading | End Fixity | $K_s$ |
|---|---|---|
| Uniformly distributed | Pinned | 11.5 |
| | Fixed | 57.6 |
| Concentrated at midspan | Pinned | 14.4 |
| | Fixed | 57.6 |
| Concentrated at quarter points | Pinned | 10.5 |
| Constant moment | Pinned | 11.8 |
| Uniformly distributed | Cantilevered | 4.8 |
| Concentrated at free-end | Cantilevered | 3.6 |

# Cross-Laminated Timber - Shear



### 2.1.2 Bending Members: Shear (Out-of-plane)

Similar to the flexural strength, a simplified method using the extreme fiber capacity is also available and has been proposed for the PRG 320 product standard. Using the simplified method, an effective $(Ib/Q)_{eff}$ can be calculated as follows:

$$(Ib/Q)_{eff} = \frac{EI_{eff}}{\sum_{i=1}^{n/2} E_i h_i z_i} \qquad [3]$$

where:

$EI_{eff}$ = Effective bending stiffness
$E_i$ = Modulus of elasticity of an individual layer
$h_i$ = Thickness of an individual layer, except the middle layer, which is half its thickness
$z_i$ = Distance from the centroid of the layer to the neutral axis, except for the middle layer, where it is to the centroid of the top half of that layer.

Manufacturers will likely have already done this calculation to give the shear capacity of the member. In equation form, design would appear as follows:

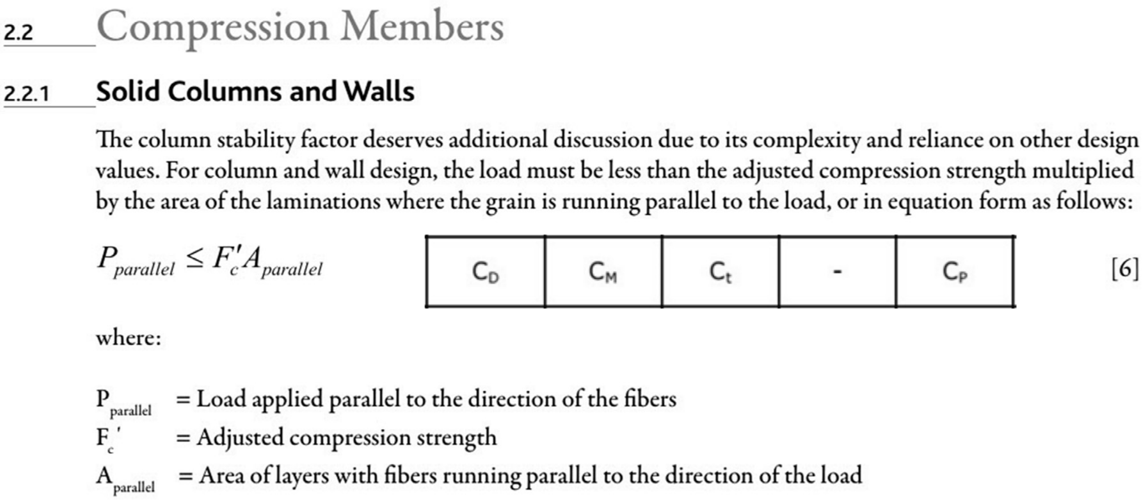
$$V_{planar} \le F_v'(Ib/Q)_{eff} \qquad [4]$$

| | | |
|---|---|---|
| $C_D$ | $C_M$ | $C_t$ |

where:

$V_{planar}$ = induced shear due to loads
$F_v'(Ib/Q)_{eff}$ = shear strength of the panel provided by the manufacture or calculated per the simplified method multiplied by the applicable adjustment factors.

# Cross-Laminated Timber - Compression



## 2.2 Compression Members

### 2.2.1 Solid Columns and Walls

The column stability factor deserves additional discussion due to its complexity and reliance on other design values. For column and wall design, the load must be less than the adjusted compression strength multiplied by the area of the laminations where the grain is running parallel to the load, or in equation form as follows:

$$P_{parallel} \le F'_c A_{parallel} \quad [6]$$

| | | | | |
|---|---|---|---|---|
| $C_D$ | $C_M$ | $C_t$ | - | $C_P$ |

where:

$P_{parallel}$ = Load applied parallel to the direction of the fibers
$F_c'$ = Adjusted compression strength
$A_{parallel}$ = Area of layers with fibers running parallel to the direction of the load

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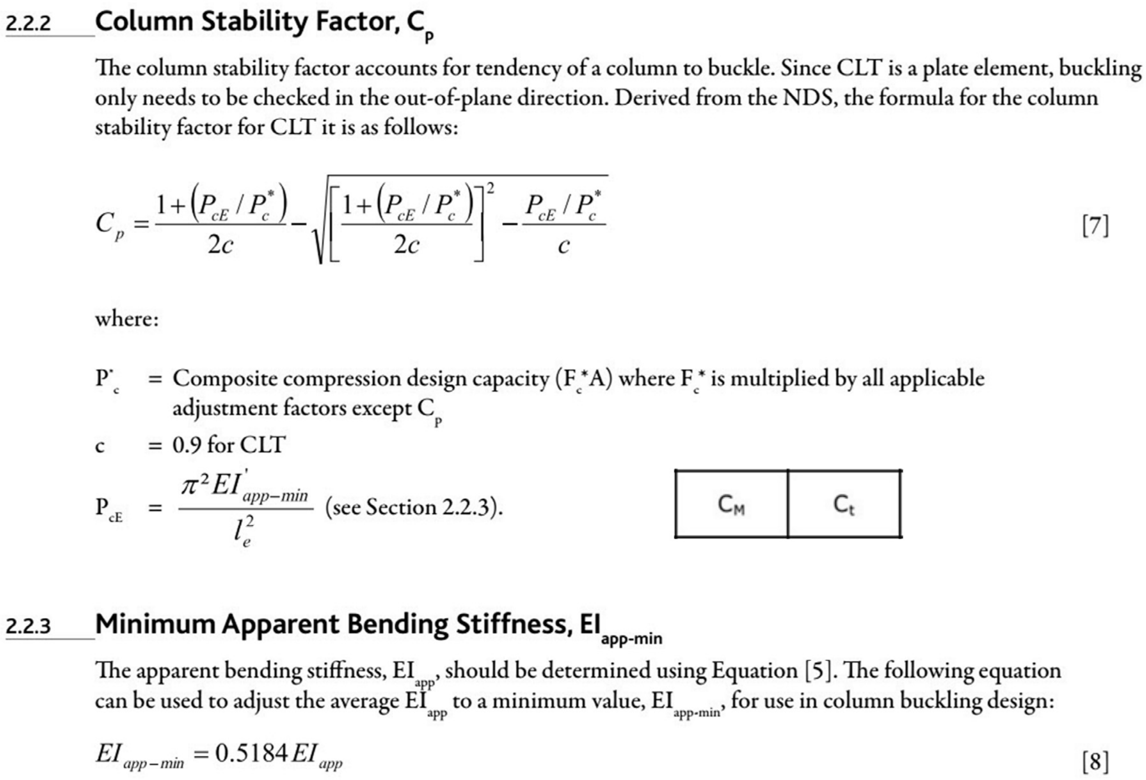
# Cross-Laminated Timber - Compression Adjustment Factors



### 2.2.2 Column Stability Factor, $C_P$

The column stability factor accounts for tendency of a column to buckle. Since CLT is a plate element, buckling only needs to be checked in the out-of-plane direction. Derived from the NDS, the formula for the column stability factor for CLT it is as follows:

$$C_p = \frac{1+\left(P_{cE}/P_c^*\right)}{2c} - \sqrt{\left[\frac{1+\left(P_{cE}/P_c^*\right)}{2c}\right]^2 - \frac{P_{cE}/P_c^*}{c}} \quad [7]$$

where:

$P^*_c$ = Composite compression design capacity ($F_c$*A) where $F_c$* is multiplied by all applicable adjustment factors except $C_p$
c = 0.9 for CLT
$P_{cE}$ = $\frac{\pi^2 EI'_{app-min}}{l_e^2}$ (see Section 2.2.3).

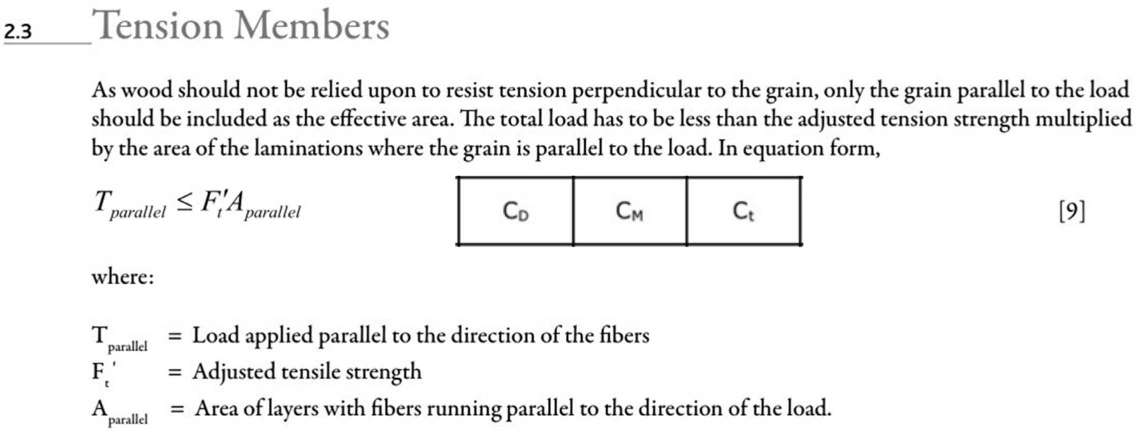
| | |
|---|---|
| $C_M$ | $C_t$ |

### 2.2.3 Minimum Apparent Bending Stiffness, $EI_{app-min}$

The apparent bending stiffness, $EI_{app}$, should be determined using Equation [5]. The following equation can be used to adjust the average $EI_{app}$ to a minimum value, $EI_{app-min}$, for use in column buckling design:

$$EI_{app-min} = 0.5184\, EI_{app} \quad [8]$$

# Cross-Laminated Timber - Tension



## 2.3 Tension Members

As wood should not be relied upon to resist tension perpendicular to the grain, only the grain parallel to the load should be included as the effective area. The total load has to be less than the adjusted tension strength multiplied by the area of the laminations where the grain is parallel to the load. In equation form,

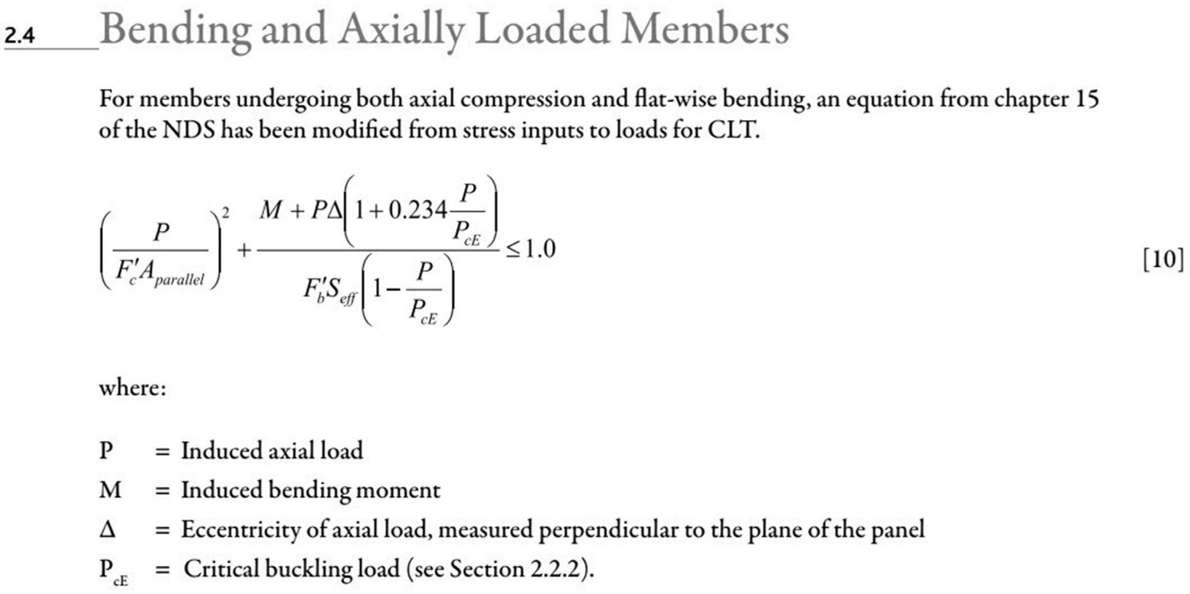
$$T_{parallel} \le F_t' A_{parallel} \qquad [9]$$

| | | |
|---|---|---|
| $C_D$ | $C_M$ | $C_t$ |

where:

$T_{parallel}$ = Load applied parallel to the direction of the fibers
$F_t'$ = Adjusted tensile strength
$A_{parallel}$ = Area of layers with fibers running parallel to the direction of the load.

# Cross-Laminated Timber - Adjustment Factors



## 2.4 Bending and Axially Loaded Members

For members undergoing both axial compression and flat-wise bending, an equation from chapter 15 of the NDS has been modified from stress inputs to loads for CLT.

$$\left(\frac{P}{F_c' A_{parallel}}\right)^2 + \frac{M + P\Delta\left(1+0.234\frac{P}{P_{cE}}\right)}{F_b' S_{eff}\left(1-\frac{P}{P_{cE}}\right)} \le 1.0 \qquad [10]$$

where:

P = Induced axial load
M = Induced bending moment
$\Delta$ = Eccentricity of axial load, measured perpendicular to the plane of the panel
$P_{cE}$ = Critical buckling load (see Section 2.2.2).

# Cross-Laminated Timber - Adjustment Factors

## 2.5 Bearing of Members

### 2.5.1 Perpendicular to the Grain

The bearing area factor for CLT is 1.0, so is not included in Table 1. The design equation is as follows:

$$P \le F'_{c\perp} A \qquad [11]$$

| $C_M$ | $C_t$ |
|---|---|

where:

P = Load applied

$F'_{c\perp}$ = Adjusted compression perpendicular to grain design value.

### 2.5.2 Parallel to the Grain

For bearing parallel to the grain or with a combination of parallel and perpendicular to grain, such as the bottom of a wall, parallel to the grain will dominate over perpendicular. The design equation is the following:

$$P_{parallel} \le F_c^* A_{parallel} \qquad [12]$$

where:

$P_{parallel}$ = Load applied parallel to the direction of the fibers

$F_c^*$ = Reference compression parallel to grain design value multiplied by all applicable adjustment factors except the column stability factor, Cp

$A_{parallel}$ = Area of layers with fibers running parallel to the direction of the load.

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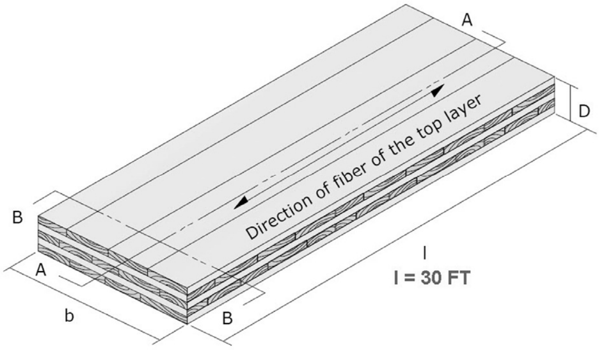
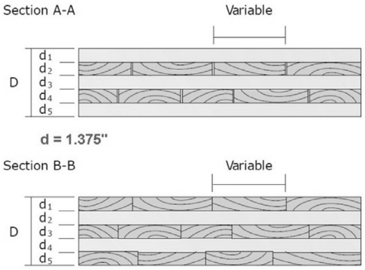
# Cross-Laminated Timber - Flexure Example

Given: Span = 30 ft.
CLT PRG 320 E1
5 layer, h = 6.875 in

Find: Load capacity





# Cross-Laminated Timber - Flexure Example

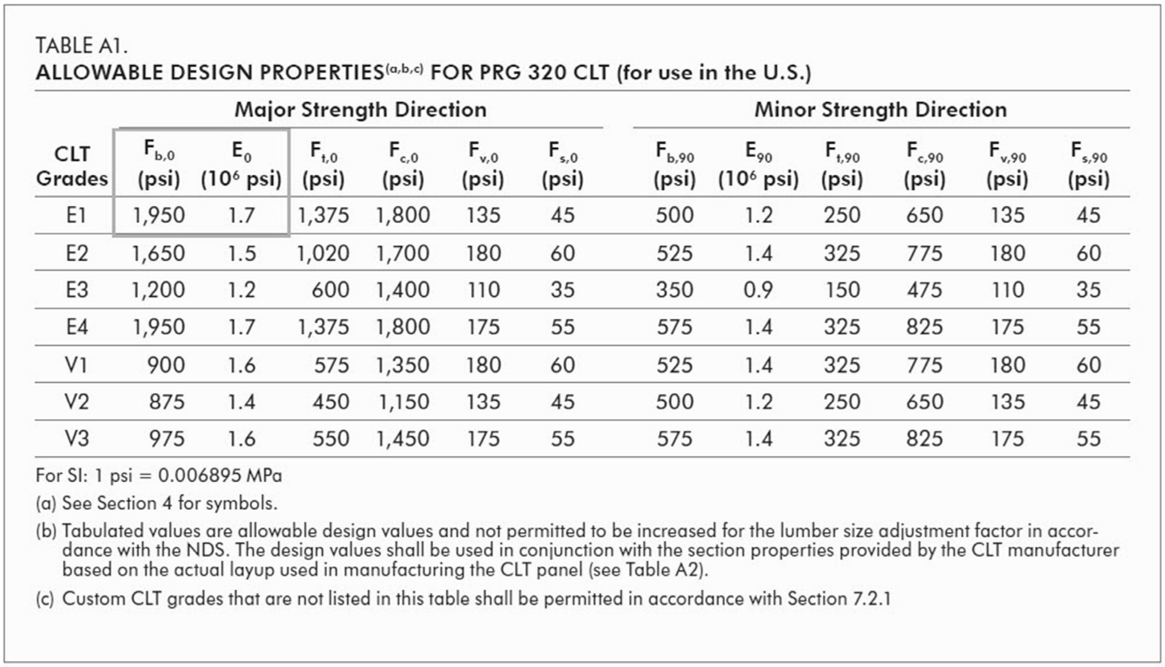


TABLE A1.

**ALLOWABLE DESIGN PROPERTIES$^{(a,b,c)}$ FOR PRG 320 CLT (for use in the U.S.)**

| CLT Grades | Major Strength Direction | | | | | | Minor Strength Direction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F_{b,0}$ (psi) | $E_0$ ($10^6$ psi) | $F_{t,0}$ (psi) | $F_{c,0}$ (psi) | $F_{v,0}$ (psi) | $F_{s,0}$ (psi) | $F_{b,90}$ (psi) | $E_{90}$ ($10^6$ psi) | $F_{t,90}$ (psi) | $F_{c,90}$ (psi) | $F_{v,90}$ (psi) | $F_{s,90}$ (psi) |
| E1 | 1,950 | 1.7 | 1,375 | 1,800 | 135 | 45 | 500 | 1.2 | 250 | 650 | 135 | 45 |
| E2 | 1,650 | 1.5 | 1,020 | 1,700 | 180 | 60 | 525 | 1.4 | 325 | 775 | 180 | 60 |
| E3 | 1,200 | 1.2 | 600 | 1,400 | 110 | 35 | 350 | 0.9 | 150 | 475 | 110 | 35 |
| E4 | 1,950 | 1.7 | 1,375 | 1,800 | 175 | 55 | 575 | 1.4 | 325 | 825 | 175 | 55 |
| V1 | 900 | 1.6 | 575 | 1,350 | 180 | 60 | 525 | 1.4 | 325 | 775 | 180 | 60 |
| V2 | 875 | 1.4 | 450 | 1,150 | 135 | 45 | 500 | 1.2 | 250 | 650 | 135 | 45 |
| V3 | 975 | 1.6 | 550 | 1,450 | 175 | 55 | 575 | 1.4 | 325 | 825 | 175 | 55 |

For SI: 1 psi = 0.006895 MPa

(a) See Section 4 for symbols.

(b) Tabulated values are allowable design values and not permitted to be increased for the lumber size adjustment factor in accordance with the NDS. The design values shall be used in conjunction with the section properties provided by the CLT manufacturer based on the actual layup used in manufacturing the CLT panel (see Table A2).

(c) Custom CLT grades that are not listed in this table shall be permitted in accordance with Section 7.2.1

---

# Cross-Laminated Timber - Flexure Example

To find S = **I**/c = 2 **I**/h, first find **I** ( or E **I** eff )

Calculation of section stiffness – E **I** eff

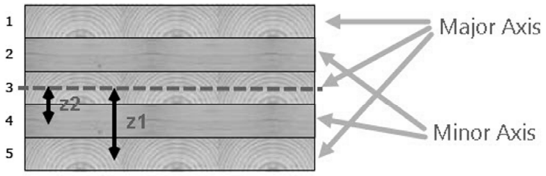
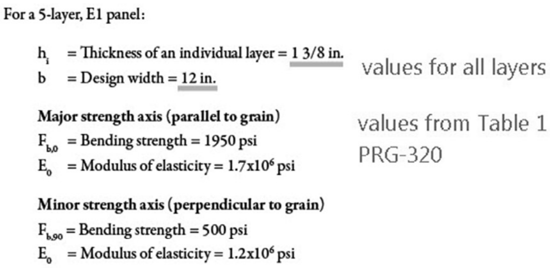


*Figure 6*

Cross-section of a 5-layer CLT panel



For a 5-layer, E1 panel:

$h_i$ = Thickness of an individual layer = 1 3/8 in.

b = Design width = 12 in.

values for all layers

**Major strength axis (parallel to grain)**

$F_{b,0}$ = Bending strength = 1950 psi

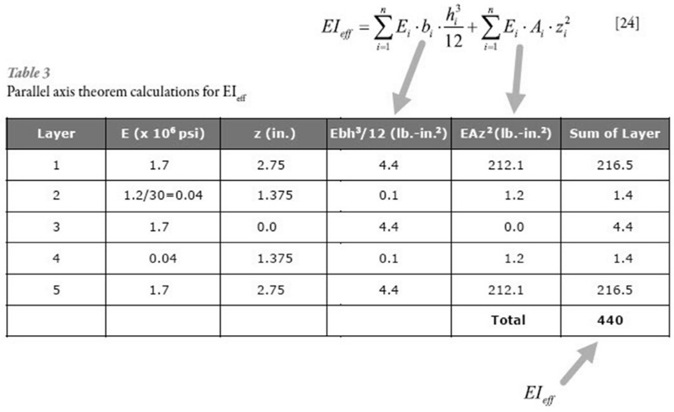
$E_0$ = Modulus of elasticity = 1.7x$10^6$ psi

values from Table 1 PRG-320

**Minor strength axis (perpendicular to grain)**

$F_{b,90}$ = Bending strength = 500 psi

$E_0$ = Modulus of elasticity = 1.2x$10^6$ psi



$$EI_{eff} = \sum_{i=1}^{n} E_i \cdot b_i \cdot \frac{h_i^3}{12} + \sum_{i=1}^{n} E_i \cdot A_i \cdot z_i^2 \qquad [24]$$

*Table 3*

Parallel axis theorem calculations for $EI_{eff}$

| Layer | E (x $10^6$ psi) | z (in.) | $Ebh^3/12$ (lb.-in.$^2$) | $EAz^2$ (lb.-in.$^2$) | Sum of Layer |
|---|---|---|---|---|---|
| 1 | 1.7 | 2.75 | 4.4 | 212.1 | 216.5 |
| 2 | 1.2/30=0.04 | 1.375 | 0.1 | 1.2 | 1.4 |
| 3 | 1.7 | 0.0 | 4.4 | 0.0 | 4.4 |
| 4 | 0.04 | 1.375 | 0.1 | 1.2 | 1.4 |
| 5 | 1.7 | 2.75 | 4.4 | 212.1 | 216.5 |
| | | | | **Total** | **440** |

$EI_{eff}$

# Cross-Laminated Timber - Flexure Example

Calculation of section modulus:
S eff

$$S_{eff} = \frac{2EI_{eff}}{E_1 h} = \frac{2 \times 440}{1.7 \times 6.875} = 75.29\ in.^3$$

Calculation of bending moment :
M = F’$_b$ S$_{eff}$

safety factor

Fb

S eff

$$F_b S_{eff} = \frac{0.85 \times 1950 \times 75.29}{12} = 10{,}400\ lb. - ft.$$

in/ft

moment capacity

For a uniform beam loading per foot:

$$M = \frac{w\,l^2}{8} = 10400 \text{ ft-lbs}$$

|  |  |  |  |
|---|---|---|---|
| $C_D$ | $C_M$ | $C_t$ | $C_L$ |

$$w = \frac{10400 \times 8}{30^2} = 92 \text{ psf}$$

---

# Cross-Laminated Timber - Allowable Bending Capacity

CLT PRG 320 E1
5 layer, h = 6.875 in.

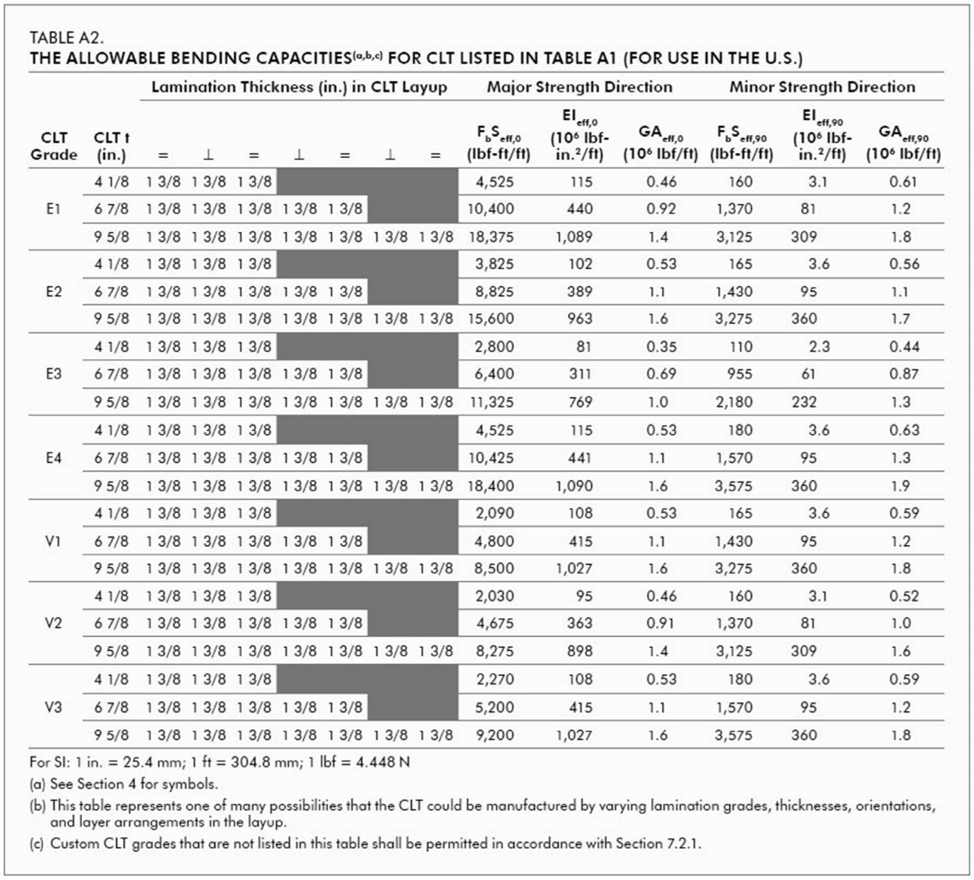


TABLE A2.
**THE ALLOWABLE BENDING CAPACITIES[a,b,c] FOR CLT LISTED IN TABLE A1 (FOR USE IN THE U.S.)**

|  |  | Lamination Thickness (in.) in CLT Layup |  |  |  |  |  |  | Major Strength Direction |  |  | Minor Strength Direction |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CLT Grade | CLT t (in.) | = | ⊥ | = | ⊥ | = | ⊥ | = | $F_bS_{eff,0}$ (lbf-ft/ft) | $EI_{eff,0}$ ($10^6$ lbf-in.$^2$/ft) | $GA_{eff,0}$ ($10^6$ lbf/ft) | $F_bS_{eff,90}$ (lbf-ft/ft) | $EI_{eff,90}$ ($10^6$ lbf-in.$^2$/ft) | $GA_{eff,90}$ ($10^6$ lbf/ft) |
| E1 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  |  |  | 4,525 | 115 | 0.46 | 160 | 3.1 | 0.61 |
|  | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  | 10,400 | 440 | 0.92 | 1,370 | 81 | 1.2 |
|  | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 18,375 | 1,089 | 1.4 | 3,125 | 309 | 1.8 |
| E2 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  |  |  | 3,825 | 102 | 0.53 | 165 | 3.6 | 0.56 |
|  | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  | 8,825 | 389 | 1.1 | 1,430 | 95 | 1.1 |
|  | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 15,600 | 963 | 1.6 | 3,275 | 360 | 1.7 |
| E3 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  |  |  | 2,800 | 81 | 0.35 | 110 | 2.3 | 0.44 |
|  | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  | 6,400 | 311 | 0.69 | 955 | 61 | 0.87 |
|  | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 11,325 | 769 | 1.0 | 2,180 | 232 | 1.3 |
| E4 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  |  |  | 4,525 | 115 | 0.53 | 180 | 3.6 | 0.63 |
|  | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  | 10,425 | 441 | 1.1 | 1,570 | 95 | 1.3 |
|  | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 18,400 | 1,090 | 1.6 | 3,575 | 360 | 1.9 |
| V1 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  |  |  | 2,090 | 108 | 0.53 | 165 | 3.6 | 0.59 |
|  | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  | 4,800 | 415 | 1.1 | 1,430 | 95 | 1.2 |
|  | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 8,500 | 1,027 | 1.6 | 3,275 | 360 | 1.8 |
| V2 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  |  |  | 2,030 | 95 | 0.46 | 160 | 3.1 | 0.52 |
|  | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  | 4,675 | 363 | 0.91 | 1,370 | 81 | 1.0 |
|  | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 8,275 | 898 | 1.4 | 3,125 | 309 | 1.6 |
| V3 | 4 1/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  |  |  | 2,270 | 108 | 0.53 | 180 | 3.6 | 0.59 |
|  | 6 7/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 |  |  | 5,200 | 415 | 1.1 | 1,570 | 95 | 1.2 |
|  | 9 5/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 1 3/8 | 9,200 | 1,027 | 1.6 | 3,575 | 360 | 1.8 |

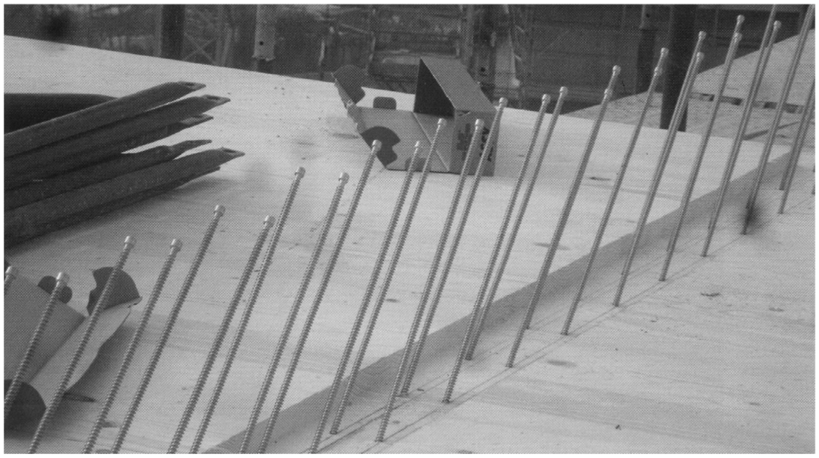
For SI: 1 in. = 25.4 mm; 1 ft = 304.8 mm; 1 lbf = 4.448 N

(a) See Section 4 for symbols.

(b) This table represents one of many possibilities that the CLT could be manufactured by varying lamination grades, thicknesses, orientations, and layer arrangements in the layup.

(c) Custom CLT grades that are not listed in this table shall be permitted in accordance with Section 7.2.1.

# Cross-Laminated Timber
## connections



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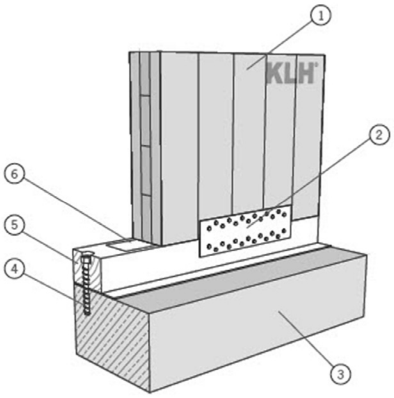
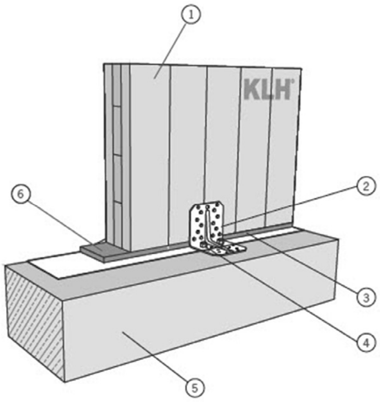
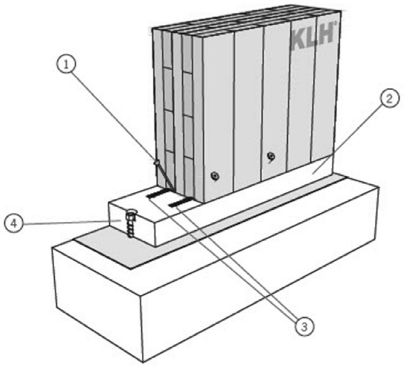
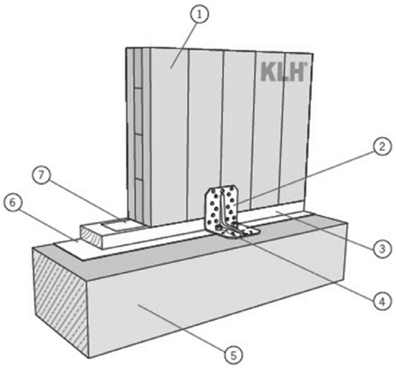
# Cross-Laminated Timber
# Wall to Foundation Details

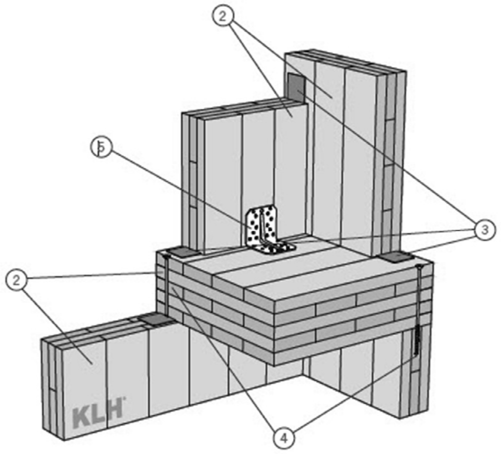


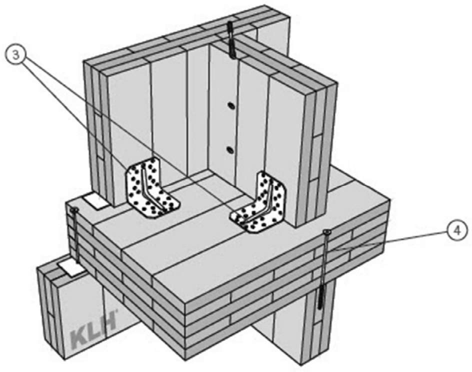


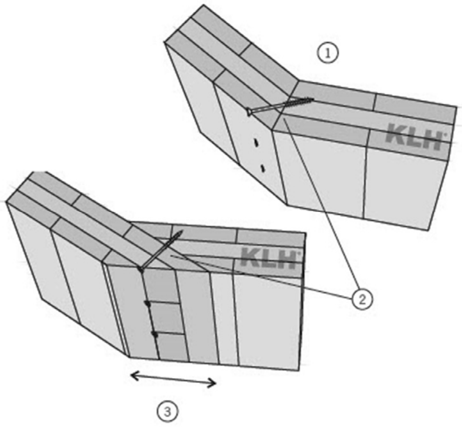


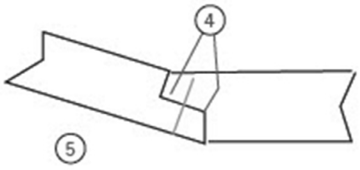


# Cross-Laminated Timber
# Wall to Wall Details









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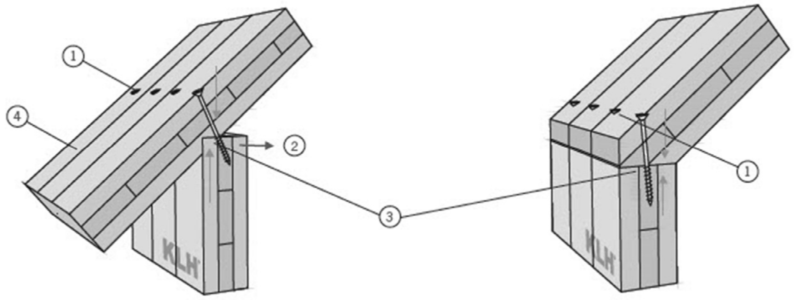
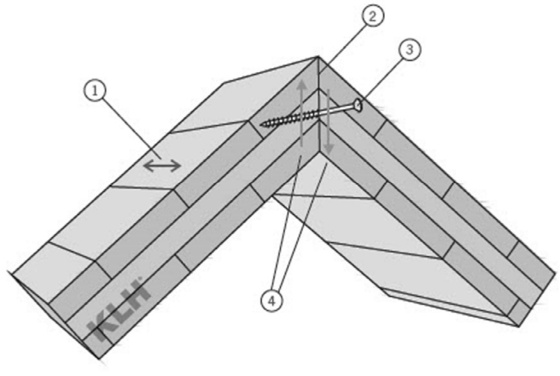
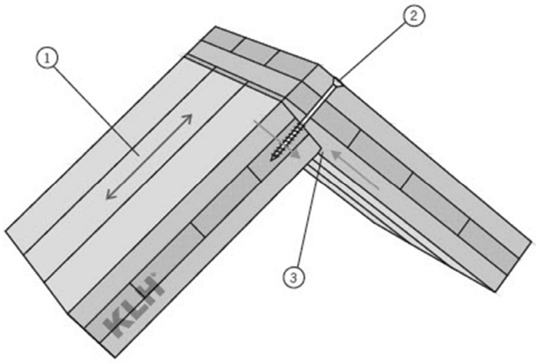
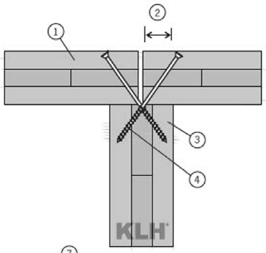
# Cross-Laminated Timber
# Wall to Roof Details

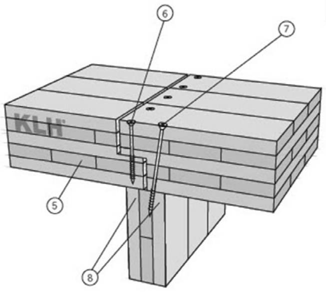


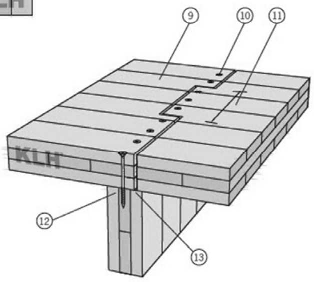


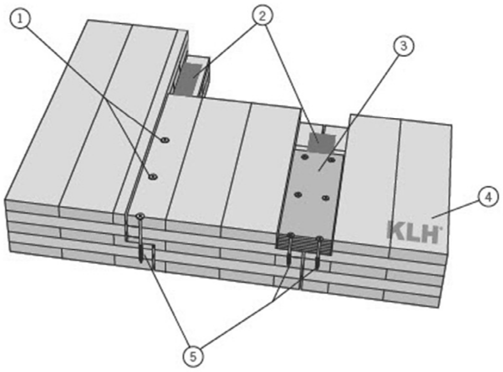


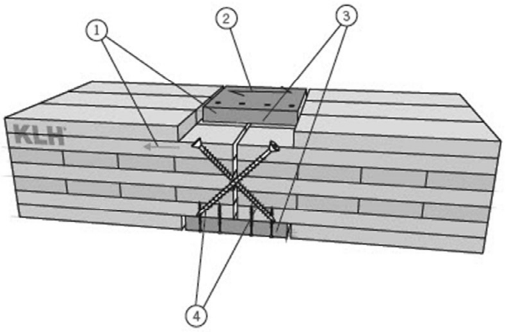
# Cross-Laminated Timber
## Floor Details











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# Cross-Laminated Timber
## Construction Sequence - Slab to Roof in 2 Weeks


Bodenplatte in Panoramaansicht

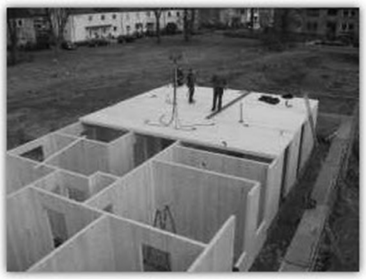

Die ersten Seitenteile stehen


Alle Wände im EG stehen

**R&S Münsterländer Holz & Elementbau GmbH,** Lüdinghausen, Germany

## R&S Münsterländer Holz & Elementbau GmbH End of Week 1




Beginn des Ausbaus 1. EG



Innenansicht

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## R&S Münsterländer Holz & Elementbau GmbH Week 2


Dachstuhl








**R&S Münsterländer Holz & Elementbau GmbH** **End of Week 2**

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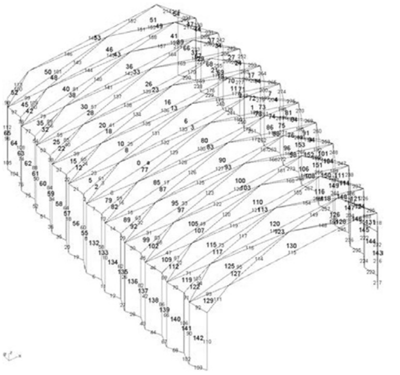
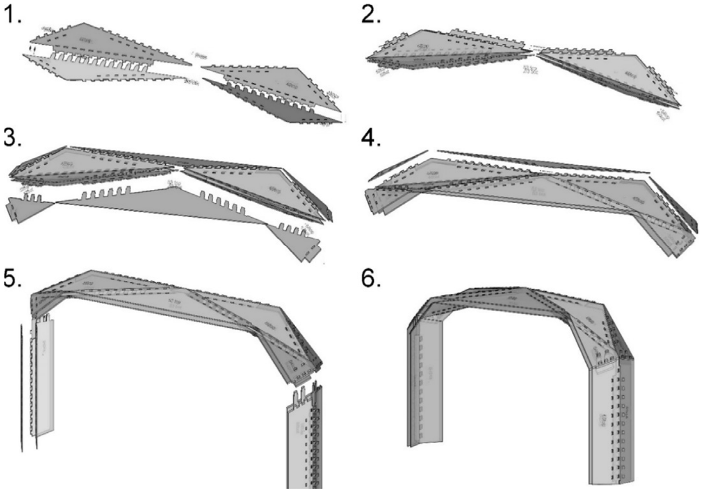
# THÉÂTRE VIDY LAUSANNE:
# A DOUBLE-LAYERED TIMBER FOLDED PLATE STRUCTURE

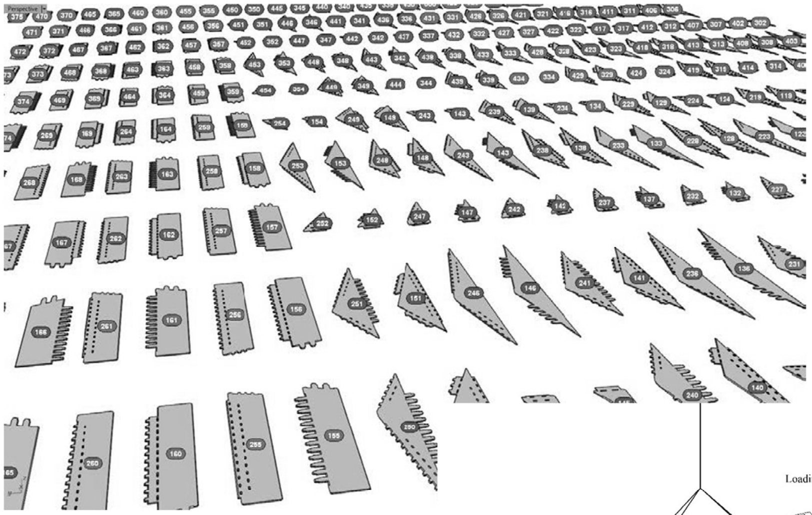


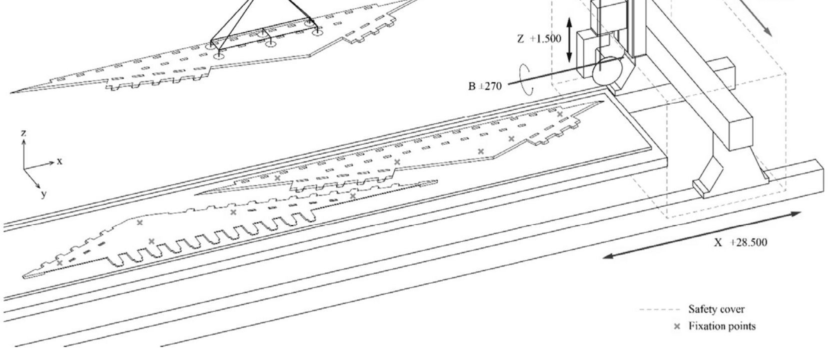


Six step fabrication and erection. Steps 1-4 prefabricated. Step 5 assembly at site..

Double layer folded plate assembly with through tenons.

# THÉÂTRE VIDY LAUSANNE





Details of CNC 5-axis routing of tenons

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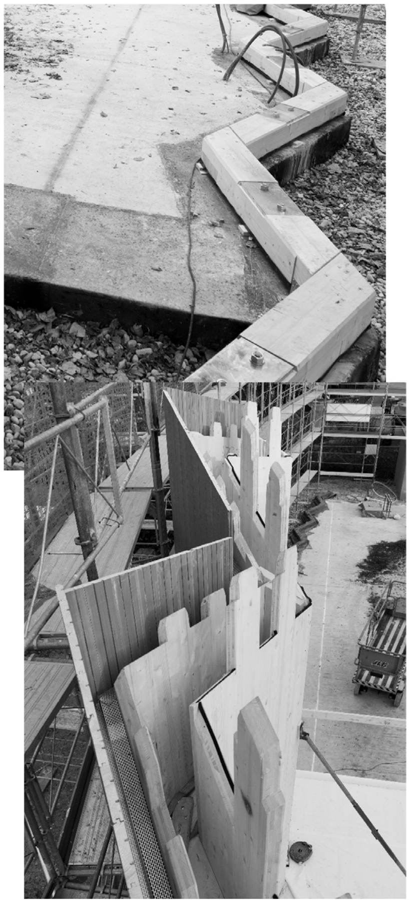
# THÉÂTRE VIDY LAUSANNE

Shell assembly at fabrication shop

# THÉÂTRE VIDY LAUSANNE

Transport and site assembly



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# Cross-Laminated Timber Examples

**Kindergarten Josef-Felderstr. 29, Augsburg**
Architektur: Hiendl & Partner Architekten, Passau

# Cross-Laminated Timber Examples

**Kindergarten Josef-Felderstr. 29, Augsburg**
Architektur: Hiendl & Partner Architekten, Passau

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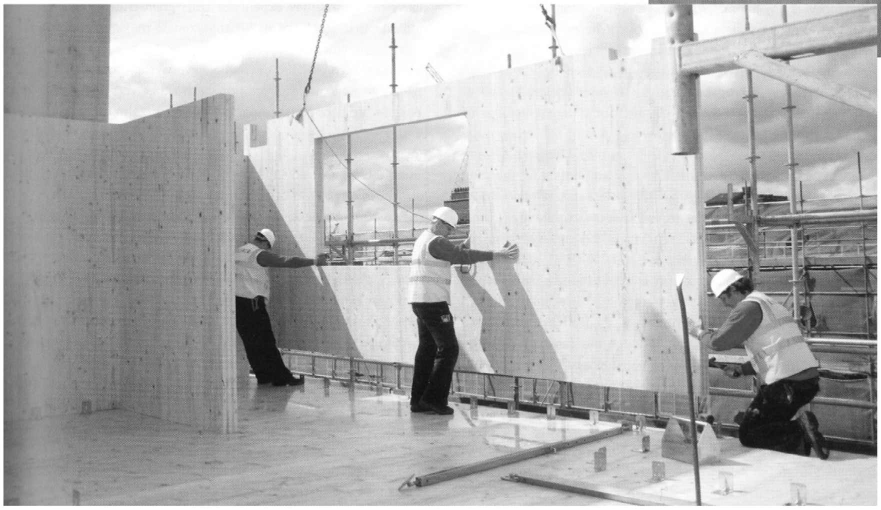
# Cross-Laminated Timber Examples

**Forte Apartments**
**Australia, Docklands**

# Cross-Laminated Timber Examples



**“Honeycomb” construction in UK**

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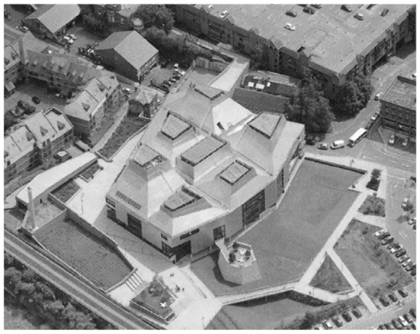
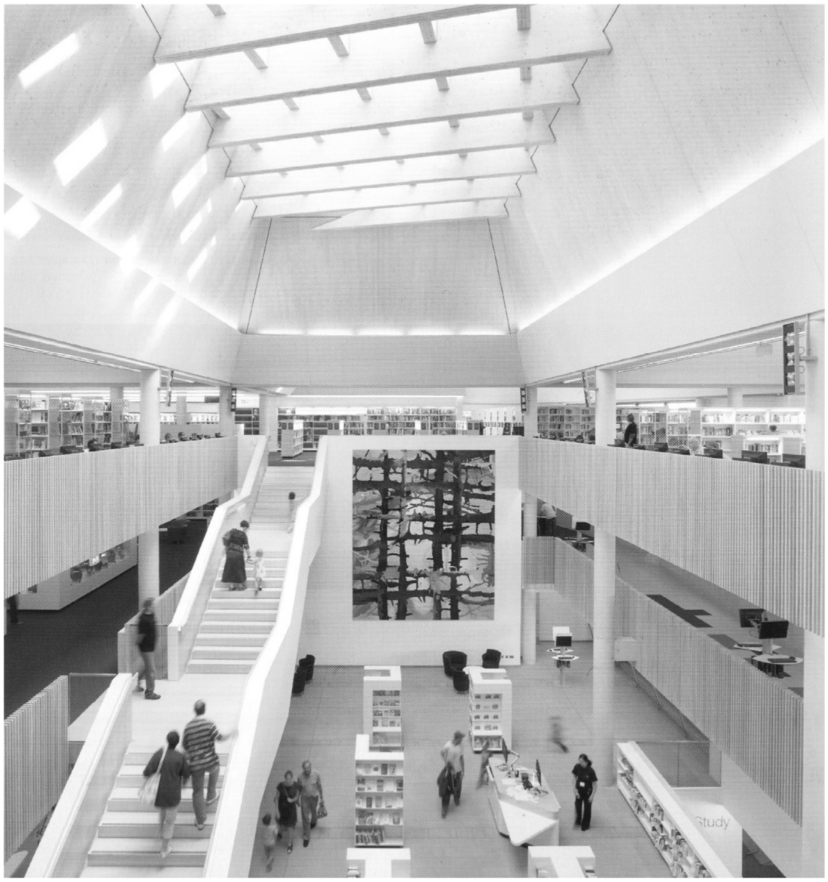
# Cross-Laminated Timber

**Worcester Library and History Center “The Hive”**

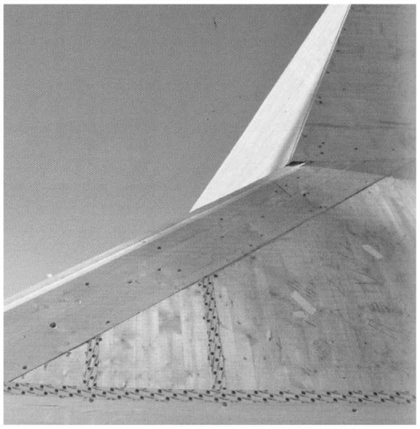
**Architect: Feilden Clegg Bradley Studios**

**Engineer: Hyder Consulting**





# Cross-Laminated Timber
“The Hive”



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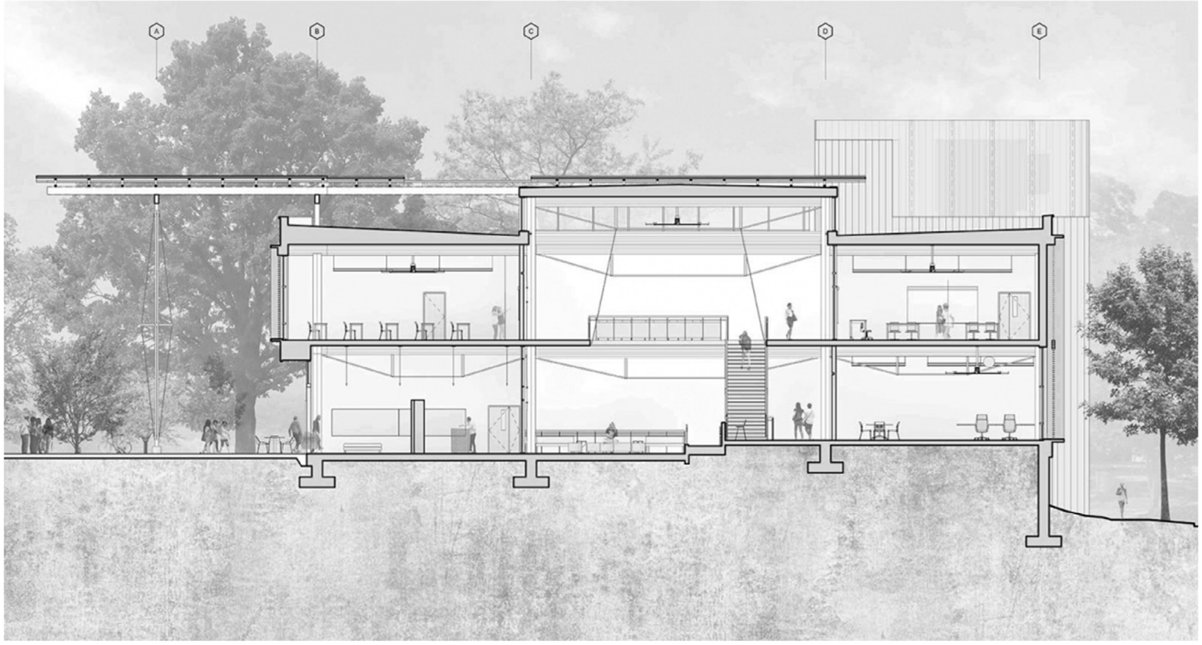
# The Kendeda Building – Atlanta, Georgia – 2018/19

https://mobile.twitter.com/KendedaBuilding/status/1247976305909354496



The Kendeda Building for Innovative Sustainable Design, Georgia Tech, Atlanta

# The Kendeda Building

Atlanta, Georgia – 2018/19