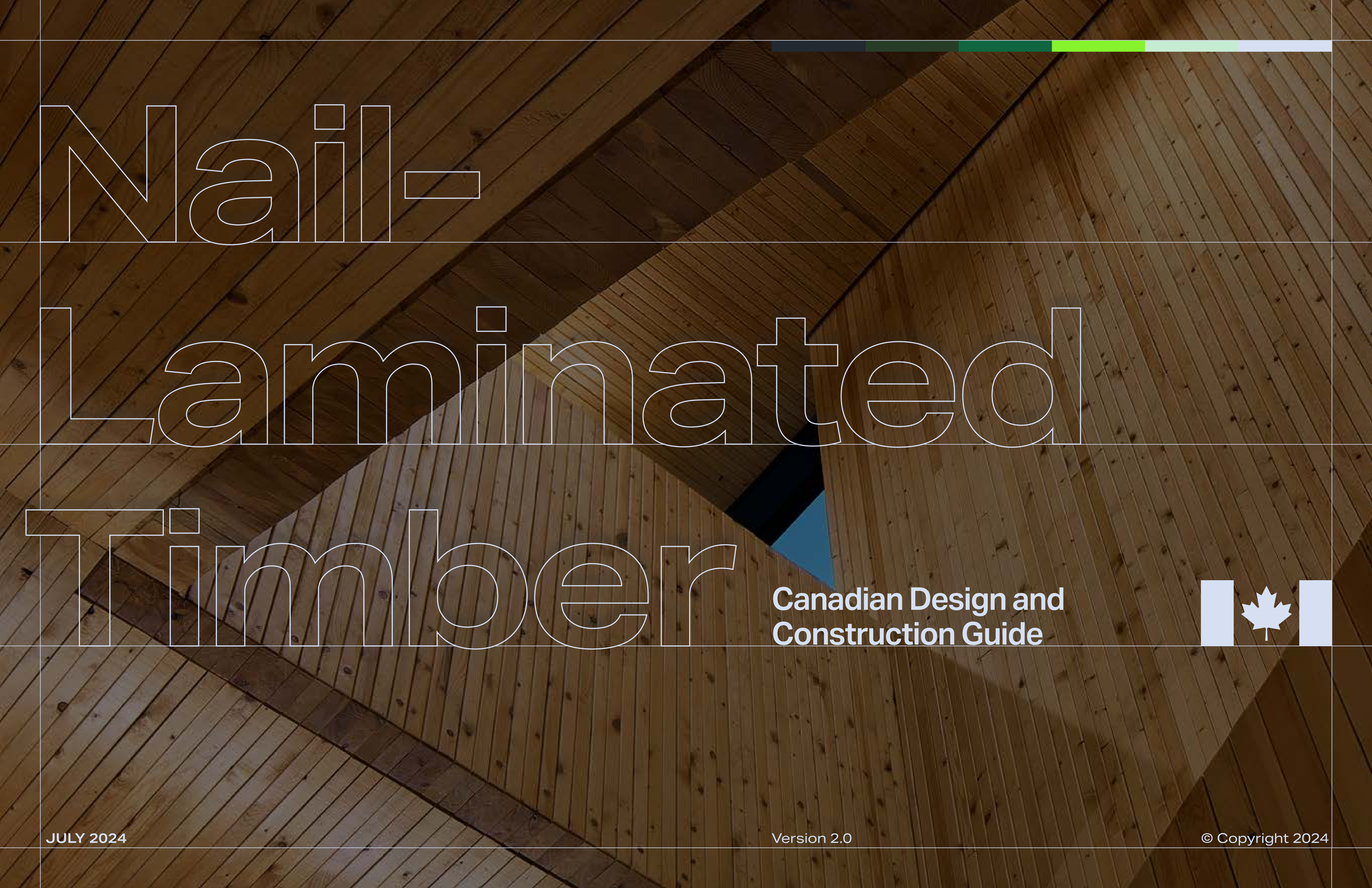

Nail-Laminated Timber

Canadian Design and Construction Guide

JULY 2024

Version 2.0

naturally:wood®
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Forestry Innovation Investment

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This guide was conceived and prepared by skilled practitioners who are each extraordinarily dedicated to advancing high-quality timber construction across industries, typologies, and geographies.

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Table of contents

Table of contents continued

List of figures

List of figures continued

List of tables

1.0 Introduction

2.0 Architecture

3.0 Fire

4.0 Structure

5.0 Enclosure

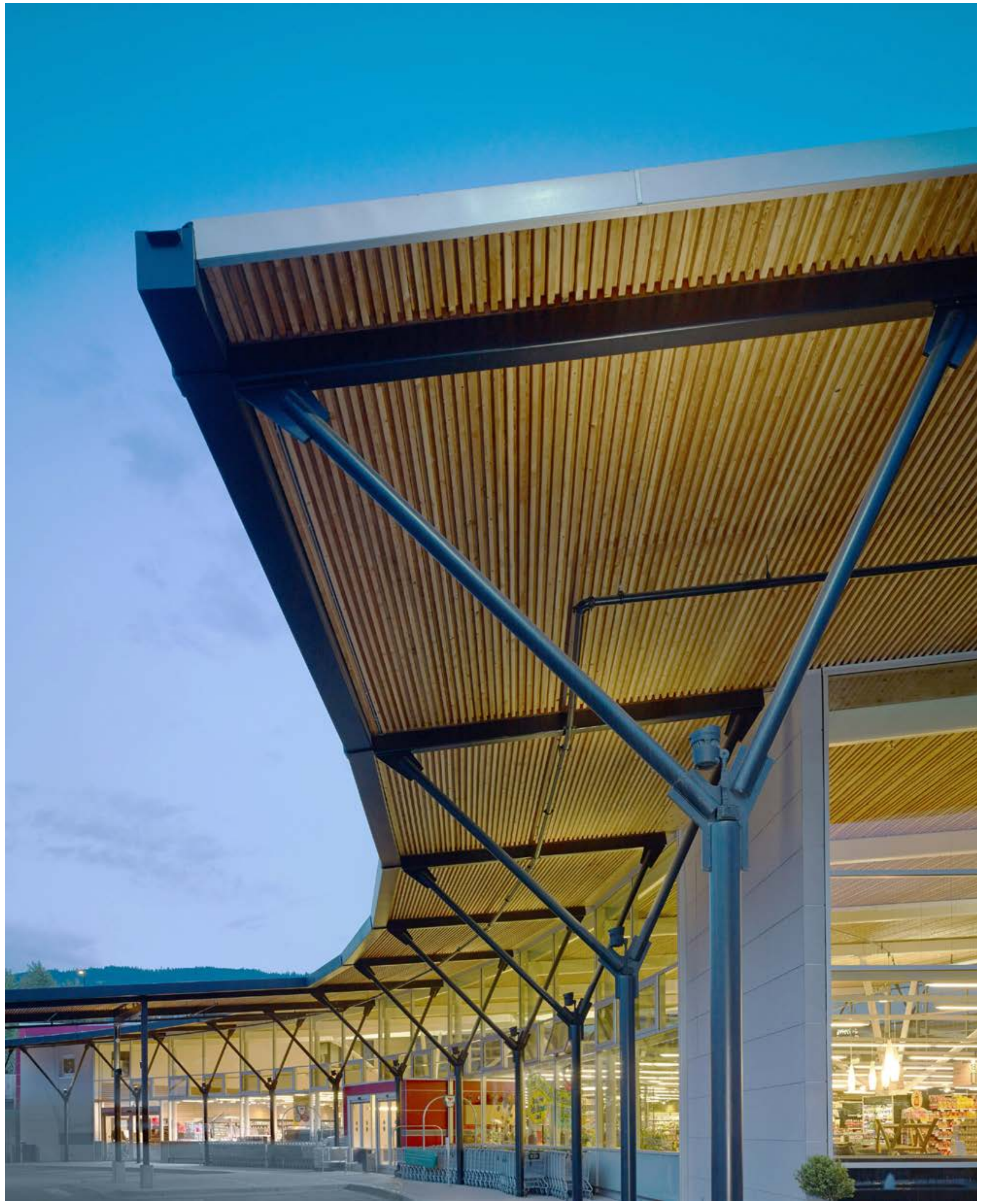
7.0 Fabrication

8.0 Construction and installation

9.0 Erection engineering

Preface

Below Askew's Uptown Market, Salmon Arm, BC
Architecture by Allen + Maurer Architects *Photo credit* Martin Knowles *Photo courtesy of* NaturallyWood



Version 1.0 of this Design and Construction Guide published in 2017 was the first of its kind to provide the Canadian design and construction industry with support and guidance on safe, predictable, and economical use of nail-laminated timber (NLT) for roofs, floors, and walls. It offered practical strategies, advice, and guidance, transferring knowledge and lessons learned from those with experience. This update and refresh builds on the intention of v1.0, incorporating new relevant building code updates, evolved best practices, new knowledge, and feedback from the market to advance high quality NLT design and construction. Substantive changes include incorporating new provisions for tall timber construction in the National Building Code of Canada (NBC), known as Encapsulated Mass Timber Construction (EMTC), and new manufacturing standards (CSA O125) and associated updates to the wood design standard (CSA O86). The guide has also been expanded to provide broader guidance for NLT used in walls.

All guidance provided here focuses on design and construction considerations for floor, roof, and wall systems pertaining to current Canadian construction practice and standards. The information included here is supplemental to wood design and construction best practices and is specific to the application of NLT. Built examples are included to illustrate real application and visual reference as much as possible.

This Guide is consistent with the following codes and standards, and these should be referenced as accompanying documents:

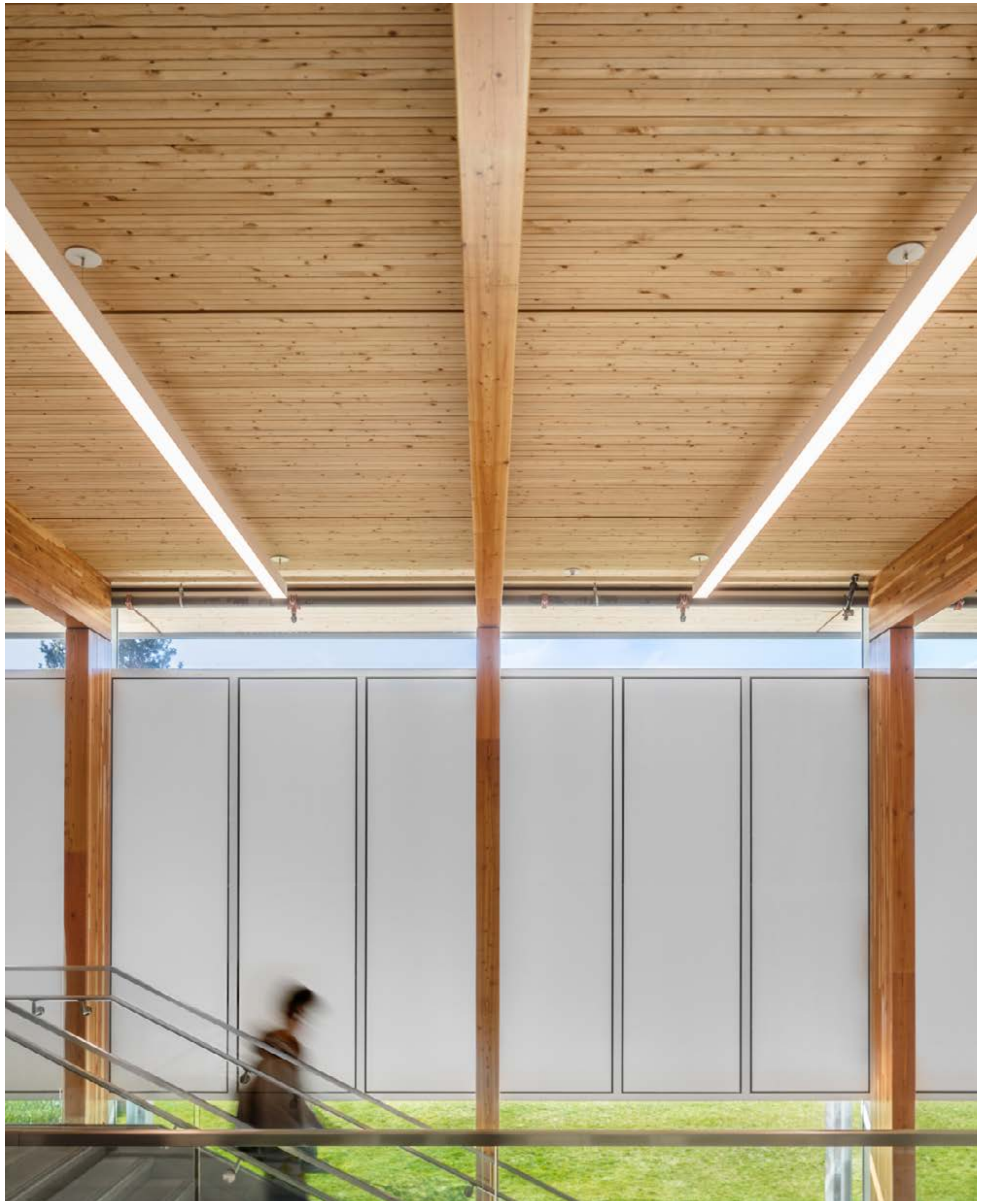
- The National Building Code of Canada 2020 (NBC) [01]
- CSA O86:24 Engineering Design in Wood [02]
- CSA O125:23 Mechanically laminated timber – Production and qualification specifications [03]

Other relevant resources are referenced throughout as necessary for more details.

1.0 Introduction

1.0 Introduction

Below Orchard Commons, UBC, Vancouver, BC
Architecture by Perkins&Will *Photo credit* Michael Elkan



Nail-laminated Timber (NLT) is an old method of construction with a range of modern opportunities to create compelling architecture. Used in many historic applications, it has evolved as one of many modern mass timber products available to designers and builders. Lightweight, low-carbon, and very compatible with high-performance buildings, NLT is increasingly used in large and small-scale buildings and infrastructure across sectors and around the world.

Mechanically laminated to create a solid structural element, NLT is created by placing dimension lumber, 38 mm, 64 mm, or 89 mm (2x, 3x, or 4x) width and 89 mm to 286 mm (nominal 4 in. to 12 in.) depth, on edge and fastening the individual laminations together with nails. Typically used as floors and roofs, panels can also be used for walls, elevator shafts, and stair shafts. Plywood/OSB added to one face provides in-plane shear capacity, allowing the product to be used as a shear wall or diaphragm.

NLT is part of the family of mass timber panel products. Mass timber panels are thick, compressed layers of wood, creating strong, structural load-bearing elements that can be constructed into panelized components. The mass timber product range available in North America includes Glued-laminated Timber (GLT), Cross-laminated Timber (CLT), Dowel-laminated Timber (DLT) and Nail-laminated Timber (NLT). Structurally composite materials such as Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), and Parallel Strand Lumber (PSL) are also considered mass timber products.

This range of products affords many options for specific design applications, and each has different design opportunities, challenges, performance characteristics, and construction advantages. NLT is significant in the range of available mass timber options given the relative ease of fabrication and access to material; NLT requires no necessarily unique manufacturing facility and can be fabricated with local dimension lumber for use in applications across sectors and structure types.

To understand appropriate and optimal application of NLT relative to other mass timber products, it is useful to compare product attributes and opportunities and constraints of each product. Refer to Table 1.1 on the following pages.

Products such as GLT and CLT have established modern fabrication standards, publications, and resources to assist designers and builders with specification, detailing, and installation. NLT is historically a product relying on prescriptive design methods or engineering judgement and built with minimal automation and no specific fabrication standard. This is the basis on which version 1.0 of this guide was published in 2017.

Now, a new fabrication standard, CSA O125 [03], has been established for mechanically-laminated timber (MLT), with QA/QC and certification body oversight, like CLT and GLT. CSA O125 typically coincides with highly automated fabrication of mechanically-laminated timber, which includes NLT when fabricated accordingly. MLT products are defined by CSA O86 as follows:

Mechanically-laminated timber (MLT): a prefabricated engineered wood product made of parallel laminations of graded lumber that are connected by mechanical fasteners inserted through the wide face of the laminations and that meets the requirements of CSA O125, such as:

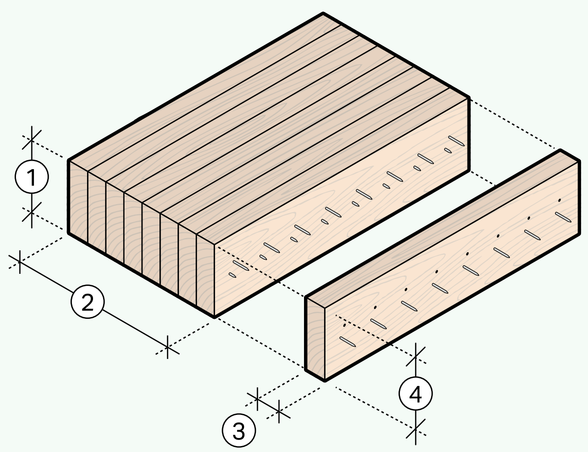
- **Dowel-laminated timber (DLT):** a type of MLT where the mechanical fasteners are wood dowels that are inserted in predrilled holes through the face of laminations.
- **Nail-laminated timber (NLT):** a type of MLT where the mechanical fasteners are nails or spikes driven through the face of the laminations.

NLT may be manufactured and certified in accordance with CSA O125 or not. In this guide, where direction is specific to NLT per the definition of mechanically-laminated timber, and certified in accordance to CSA O125, it is denoted as M-NLT. Many factors contribute to when and how a project might apply M-NLT, which are discussed at length throughout the guide. The wood design standard, CSA O86 [02], provides paths for either application:

- For the application of M-NLT, refer to CSA O86 CL 8.2, and
- For the application of NLT, refer to CSA O86 CL 6.5.10.3 (referred to as “nail laminated decking” in the standard).

For the purposes of this guide the "panel depth" (d) and the "lamination depth" (d_l) are considered alongside the "panel width" (b_0) and "lamination width" (b_{lam}), refer to **Figure 1.1**. In most cases the lamination width will be 38 mm (1.5 in.) and the panel width with the cumulative width of each of the lamination widths in the panel.

Figure 1.1
NLT reference dimensions



1. Panel depth (d)
2. Panel width (b_0)
3. Lamination width (b_{lam})
4. Lamination depth (d_l)

Below Rosemary Brown Arena, Burnaby, BC
Architecture by hcma *Photo credit* Ema Peter

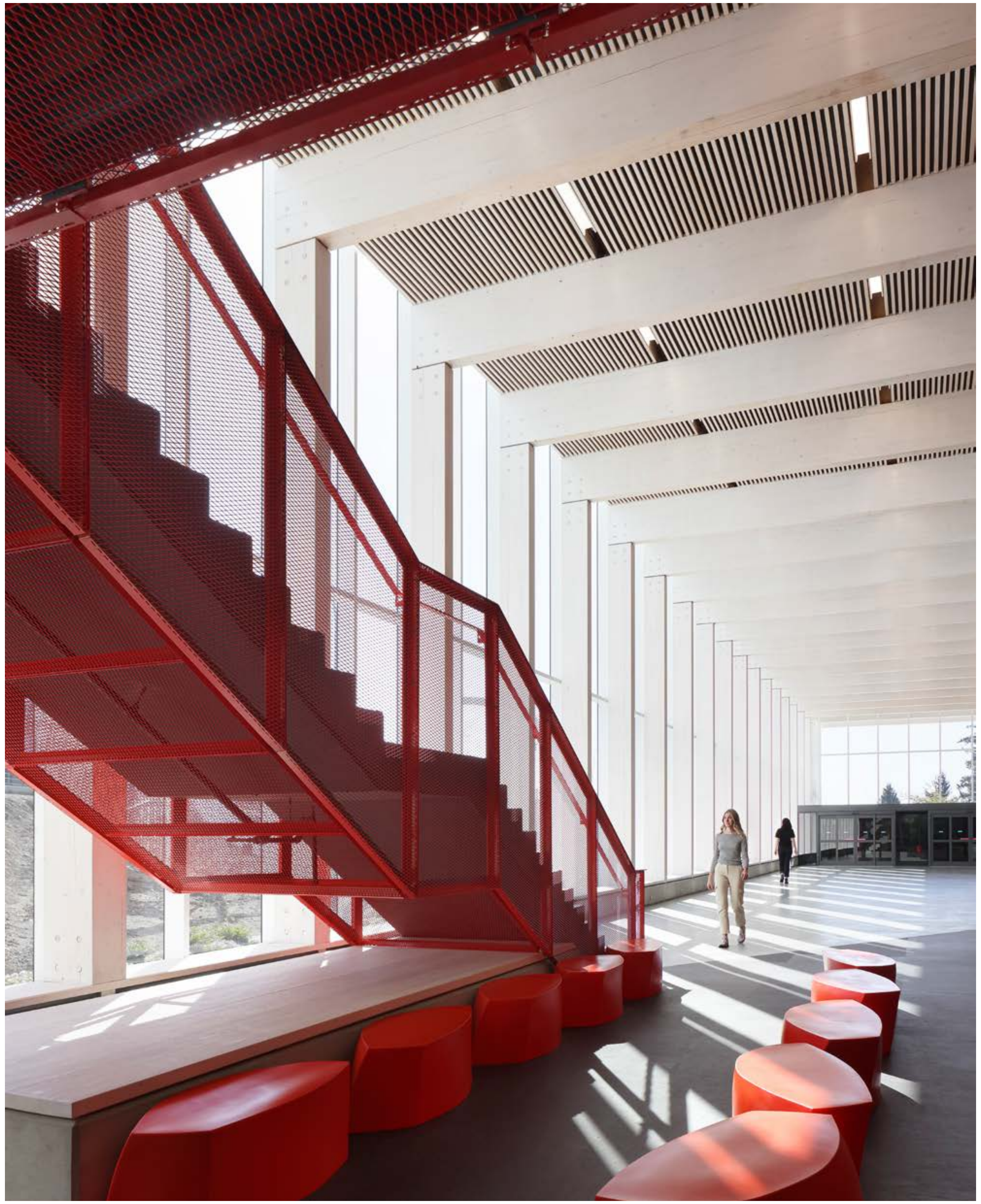


Table 1.1 Select mass timber product attributes

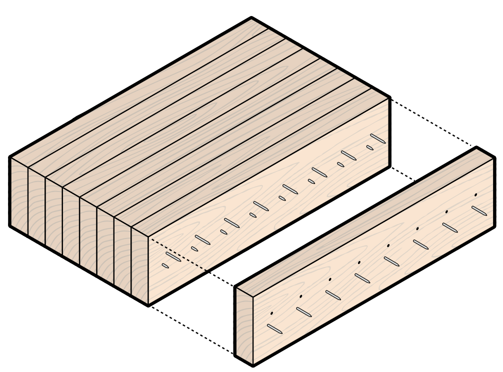
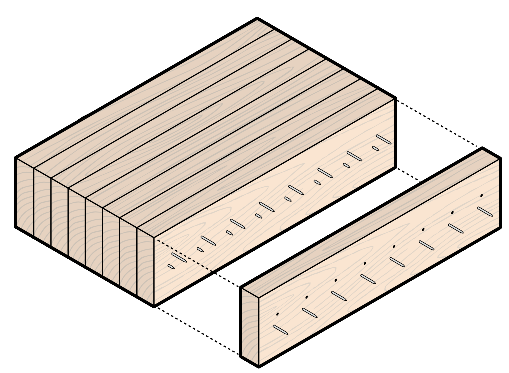
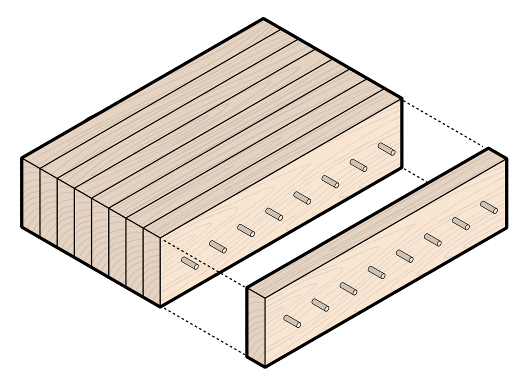
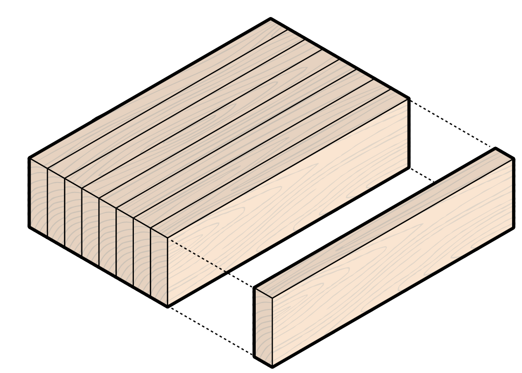
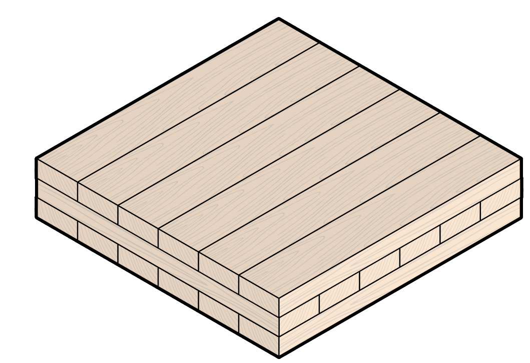
	NLT	MLT	DLT	GLT	CLT
Definition	**Nail-laminated timber** is a solid wood structural element consisting of dimension lumber on edge fastened together with nails.	**Mechanically laminated timber** is a prefabricated wood product made of parallel laminations of graded lumber that are connected by mechanical fasteners inserted through the wide face of the laminations and that meets the requirements of CSA O125, such as: **Mechanical nail-laminated timber (M-NLT):** a type of MLT where the mechanical fasteners are nails or spikes driven through the face of lumber laminations.	**Dowel-laminated timber** is a solid wood structural panel, created by placing dimension softwood lumber (nominal 2x, 4x, etc., thickness) on edge and friction-fastening laminations together with hardwood dowels.	**Glued-laminated timber** is a solid wood structural element composed of individual sawn lumber laminations, specifically selected, and positioned based on their performance characteristics and then bonded together with durable, moisture-resistant adhesives. The grain of all laminations run parallel with the length of the member.	**Cross-laminated timber** is a solid structural panel consisting of three, five, seven, or nine layers of sawn lumber oriented at right angles to one another, and then glued.
Use	Can be used for floors, roofs, and walls.	Can be used for floors, roofs, and walls.	Can be used for floors, roofs, and walls.	Can be used for floors, roofs, and walls.	Can be used for floors, roofs, and walls.
Span	One way-spanning  Has the lowest weak axis strength of all mass timber.	One-way spanning  Has the lowest weak axis strength of all mass timber.	One-way spanning  Weak axis bend strength and stiffness is limited by the continuous would dowels.	One-way spanning  Weak axis bend strength and stiffness is limited by the perpendicular-to-grain strength and stiffness. Large deformations weak axis could result in panel splitting.	Two-way spanning  The strong direction corresponding with the grain direction of the outer laminations.
Panel size	**NLT-1 and -2**, panel size is limited by available lumber lengths unless finger jointed lumber is available. **NLT-3, and -4**, panel size is usually limited by lifting and erection constraints, with the length also impacted by shipping length constraints.	**M-NLT-1 and -2**, panel size may be limited by available lumber lengths unless the manufacturing process has integrated finger jointing into the approach. **M-NLT-3, and -4**, panel size is usually limited by lifting and erection constraints, with the length also impacted by shipping length constraints.	Finger jointed DLT, panel size is usually limited by lifting and erection constraints, with the length also impacted by shipping length constraints	Limited by glulam press depth and length. Length may be limited by shipping and lifting constraints. Width may be limited by lifting constraints.	Limited by press sizes. Typical from 4-12 ft. wide and 40-60 ft. long. Largest presses align with common shipping limitations.

Table 1.1 continued Select mass timber product attributes

	NLT	MLT	DLT	GLT	CLT
1D char rate	0.8 mm/min *Based on NRC fire tests* [01] *Dependent on quality of construction and the presence of a top membrane of floors or protection at one or both sides of walls.*	0.8 mm/min or manufacturer specific char rate *Based on NRC fire tests* [01]	0.8 mm/min or manufacturer specific char rate.	0.65 mm/min *Refer to Annex B of CSA O86*	0.65 mm/min *Refer to Annex B of CSA O86*
Strength and stiffness	NLT/M-NLT/DLT typically have the same strength and stiffness for similar layups and lumber.	NLT/M-NLT/DLT typically have the same strength and stiffness for similar layups and lumber.	NLT/M-NLT/DLT typically have the same strength and stiffness for similar layups.	GLT strength and stiffness is set based on the wood fiber type.	CLT is slightly weaker than the one-way spanning systems for equivalent material grade and panel depth because some grain is not oriented in the primary direction.
	Strength and stiffness limited by strength of lumber and layup type (NLT-1 and -2 are stronger and stiffer than NLT-3 and -4).	Strength and stiffness limited by strength of lumber and layup type (NLT-1 and -2 are stronger and stiffer than NLT-3 and -4).	Strength and stiffness limited by strength of lumber and layup type (NLT-1 and -2 are stronger and stiffer than NLT-3 and -4).	Typically has the same strength and stiffness as NLT-1 or -2 for equivalent base material.	
Dimensional stability	Subject to overall panel width change due to swelling. Shrinkage will result in an increase in gap size between laminations.	Subject to overall panel width change due to swelling. Shrinkage will result in an increase in gap size between laminations. Due to pressing during fabrication these gaps will generally be smaller than for NLT.	Subject to overall panel width change due to swelling. Shrinkage will result in an increase in gap size between laminations. Due to pressing during fabrication these gaps will generally be smaller than for NLT.	Subject to overall panel width change due to swelling or shrinkage.	Cross laminations provide dimensional stability in the length and width of the panel.
	Subject to panel depth change due to swelling or shrinkage.	Subject to panel depth change due to swelling or shrinkage.	Subject to panel depth change due to swelling or shrinkage.	Subject to panel depth change due to swelling or shrinkage.	Subject to panel depth change due to swelling or shrinkage.

Preface and Chapter 1.0 references

[01] Canadian Commission on Building and Fire Codes, and National Research Council of Canada. 2020. *National Building Code of Canada, 2015*. Ottawa, Ont: National Research Council Canada.

[02] Canadian Standards Associations (CSA). 2024. CSA O86 – *Engineering Design in Wood.* CSA.

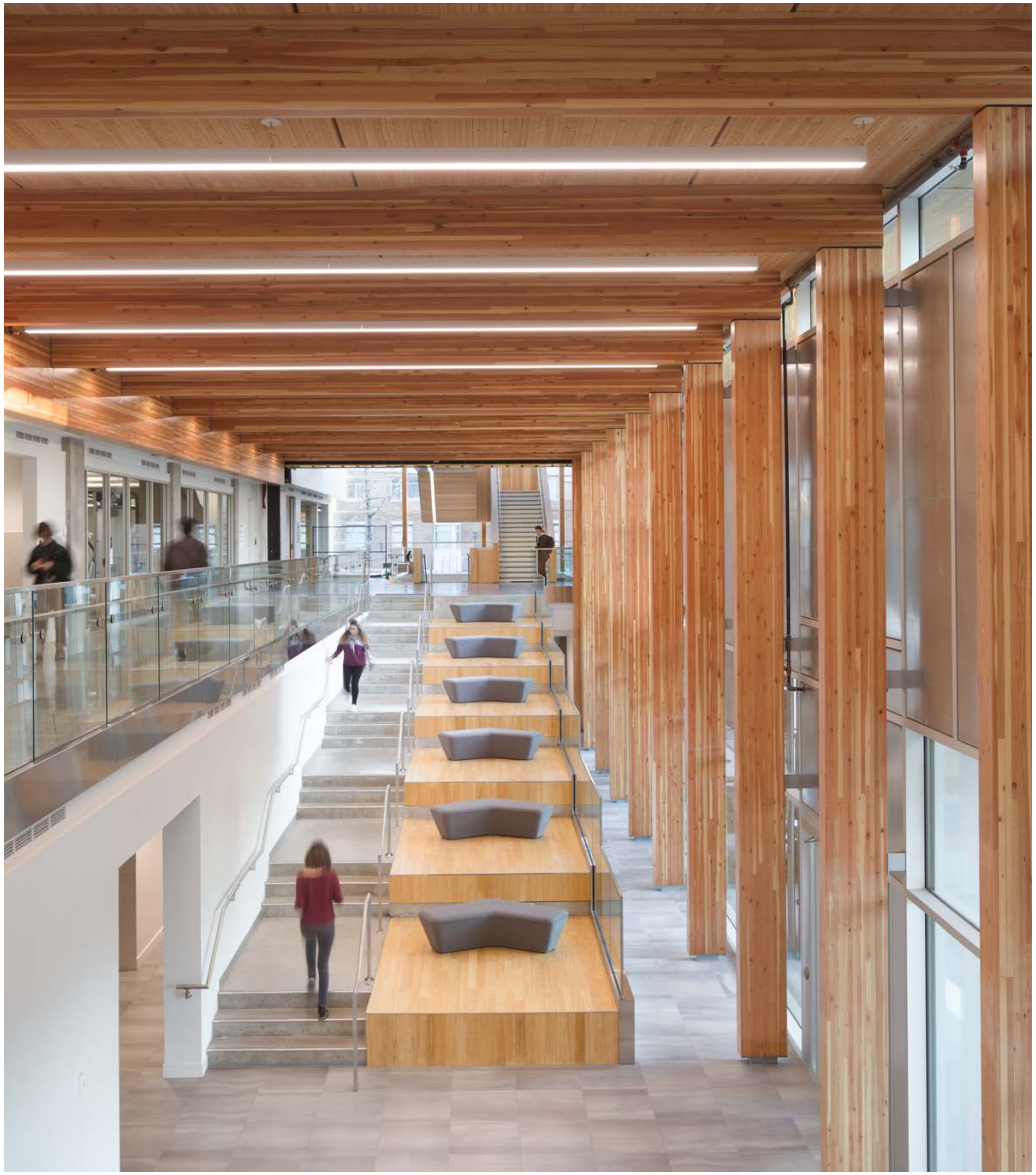
[03] Canadian Standards Associations (CSA). 2023. CSA 125 – *Mechanically laminated timber – Production and qualification specifications.* CSA.

Below Algonquin College DARE District, Ottawa, ON
Architecture by Diamond Schmitt *Photo credit* Doublespace Photography

Below Algonquin College DARE District, Ottawa, ON
Architecture by Diamond Schmitt *Photo courtesy of* Diamond Schmitt

2.0 Architecture

2.0 Architecture



2.1 Conceptual considerations

Nail Laminated Timber (NLT) can be used in nearly all building types in a wide variety of applications in modern construction. In many cases a strong desire to expose wood to building interiors drives the use of NLT, but with new provisions for taller mass timber construction in the building code, concealed uses of NLT are also gaining traction alongside other mass timber products.

Projects may opt for NLT for many reasons. In some instances, it may be lower cost owing to ease of fabrication and ease of procurement. NLT can also benefit from and contribute to regional industry where local labour forces are available to build it and material can be sourced nearby. NLT may also offer advantages for installation in applications where a specific feature or aesthetic is desired, particularly where NLT is built on site rather than panelized.

Right Orchard Commons, UBC, Vancouver, BC
Architecture by Perkins&Will *Photo credit* Wade Comer Photography
Photo courtesy of NaturallyWood

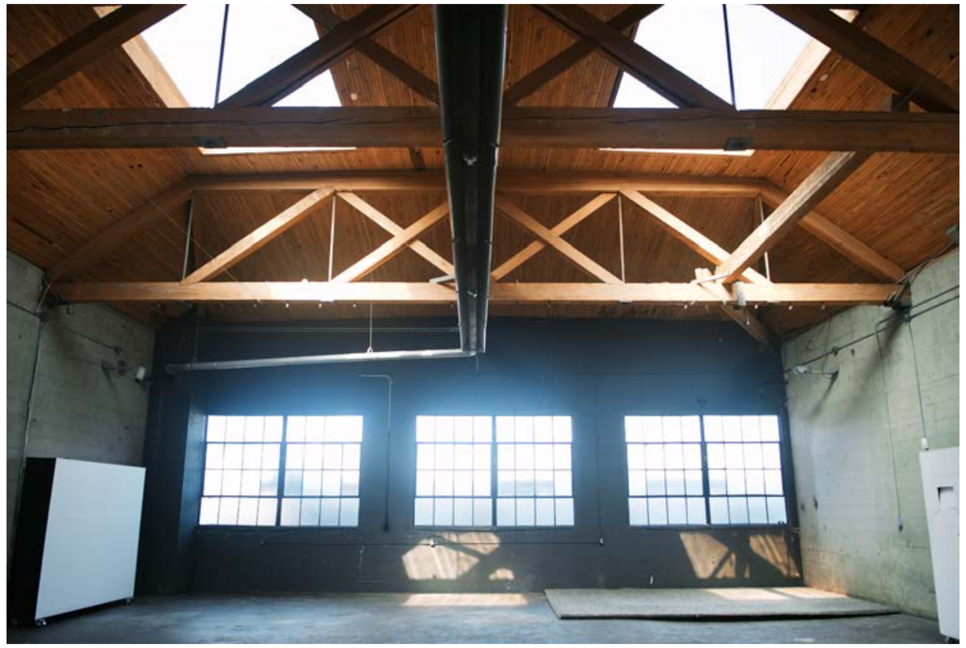
2.1.1 Form

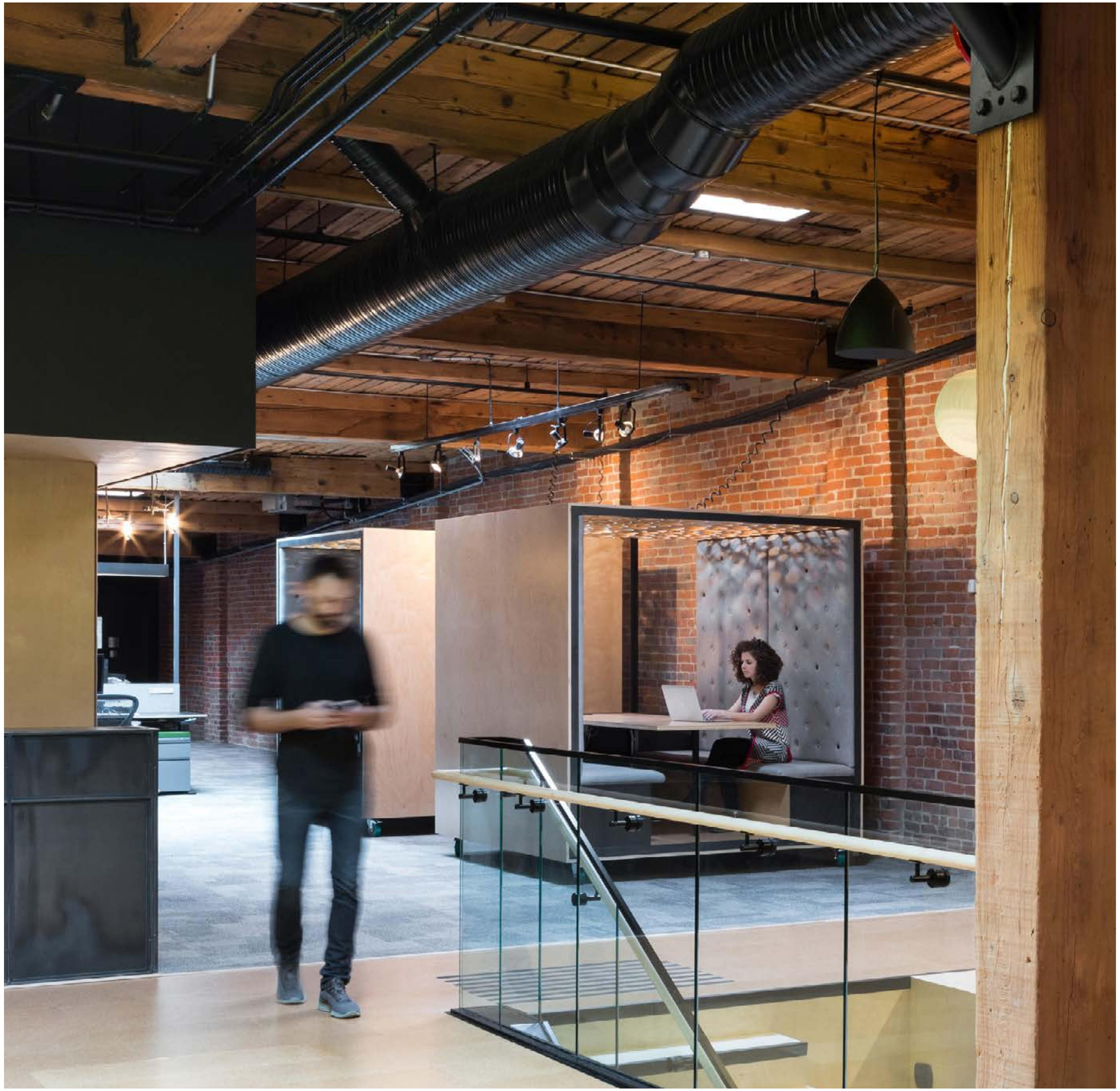
Nail-laminated timber (NLT) allows for the creation of a monolithic "slab" of wood from off-the-shelf dimension lumber, supporting a broad range of architectural opportunities. Historically, NLT was used primarily for the construction of warehouses and other large buildings (refer to **Figure 2.1**). While flat floors and roofs remain the most common NLT building elements, more expressive and dynamic forms are possible.

Although NLT floors and roofs can be covered by finishes, they are often left exposed as a key design element. NLT is typically exposed at the ceiling, where it is protected from wear and the elements.

Right Historic NLT, Slack HQ, Vancouver, BC
Architecture by Leckie Studio Architecture + Design Inc.
Photo courtesy of NaturallyWood

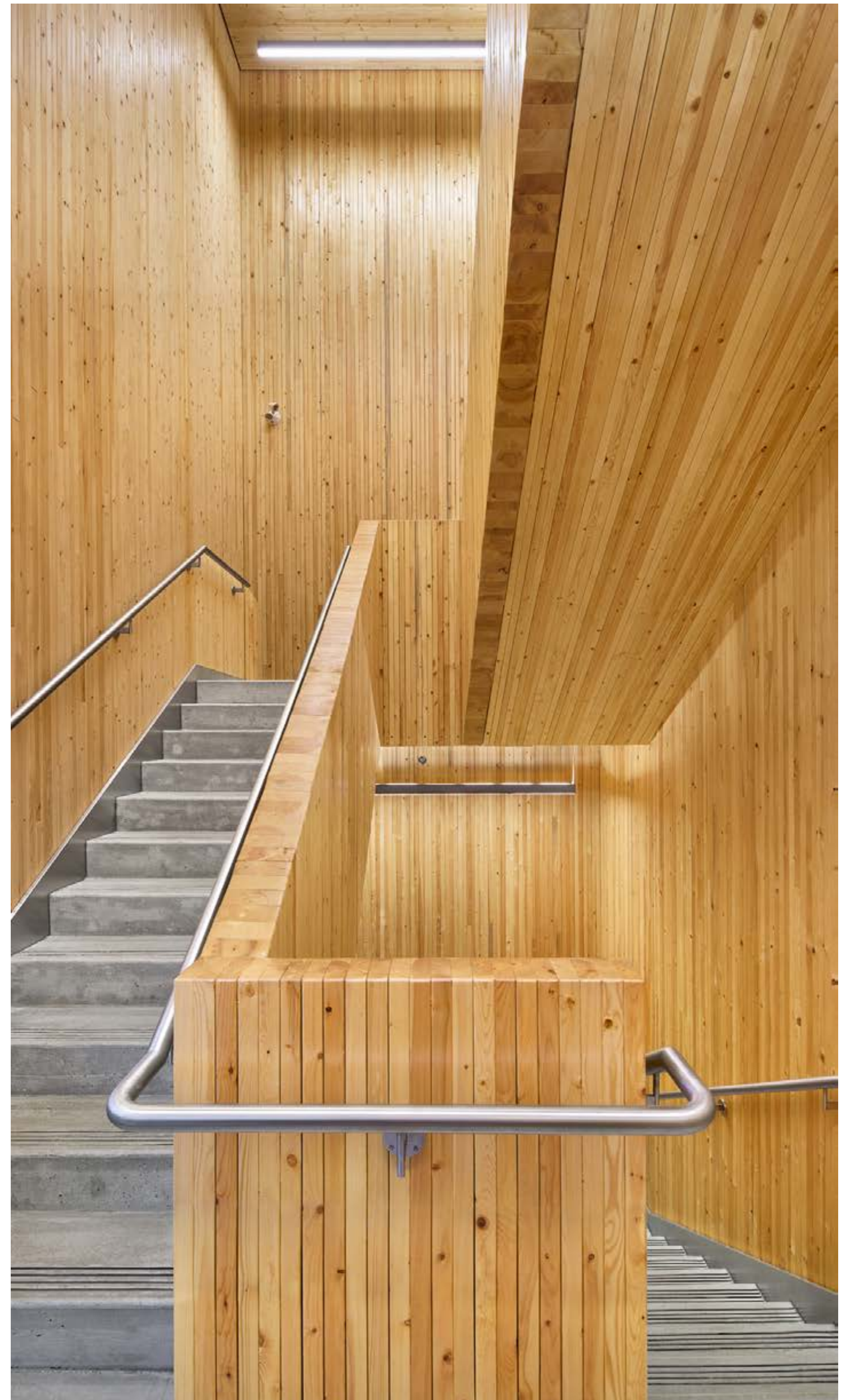
Figure 2.1 Historic NLT, Vancouver Urban Winery, part of the Settlement Building Brand Collective which also houses Postmark Brewing and Belgard Kitchen. Dating from the 1920s, the building was originally used as a steel manufacturing foundry.
Photo courtesy of Vancouver Urban Winery





NLT may also be used as walls where exposing it for aesthetics is desirable, or for elevator and stair cores to meet higher loading or solid wall requirements (refer to **Figure 2.2**). However, NLT does not have enough mass to mitigate airborne sound on its own to meet typical sound isolation requirements. Materials must be added to the top and/or underside of the NLT floor/ceiling structure, or on either side of an NLT wall, to compensate for the lack of mass. Refer to **Section 2.5** for further discussion on acoustics.

Figure 2.2 NLT Stair at Prince George Fire Hall No 1, Prince George, BC
Architecture by hcma *Photo credit* Ed White Photographics
Photo courtesy of NaturallyWood



Below NLT walls under construction at 51 Kingston, Goderich, ON
Photo courtesy of Silvaspan

Creating simple curves from NLT is relatively easy compared to other mass timber panel products because it can be constructed of individual wood laminations connected with relatively flexible fasteners that can form to the curved substructure below. For example, the roof of Aberdeen Station shown in **Figures 2.3** is composed of gently curving steel channels which support the lumber.

Figures 2.3 NLT on curved steel channels, Aberdeen station, Richmond, BC
Architecture by Perkins&Will *Photo courtesy of* Perkins&Will

The atrium at Samuel Brighouse Elementary School, shown in **Figure 2.4**, advances the same concept with integrated steel struts and tension cables, turning the NLT into a truss system to create a whimsically undulating roof.

Figure 2.4
Curved NLT truss system, Samuel Brighouse Elementary School, Richmond, BC
Architecture by Perkins&Will *Photo credit* Nic Lehoux

Compound curves are also possible, provided they are created from straight laminations. The NLT at Brentwood station is curved perpendicular to the laminations, and used a combination of curved NLT, curved-in-plan. **Figure 2.5a** shows the NLT curved to follow the shape of the glued-laminated beams, and **Figure 2.5b** shows the form of the NLT curved-in-plan to accommodate the overall form of the station. The NLT spans between the curved glued-laminated beams set at varying angles results in a building form with compound curvature. The curve-in-plan requires edge support on all four sides of the panel to manage the varying panel width between supports. Offsite manufacturing of these panels with compound curvature is also complex.

Figure 2.5a Building form with compound curvature, interior of Brentwood Station, Burnaby, BC
Architecture by Perkins&Will *Photo credit* Nic Lehoux

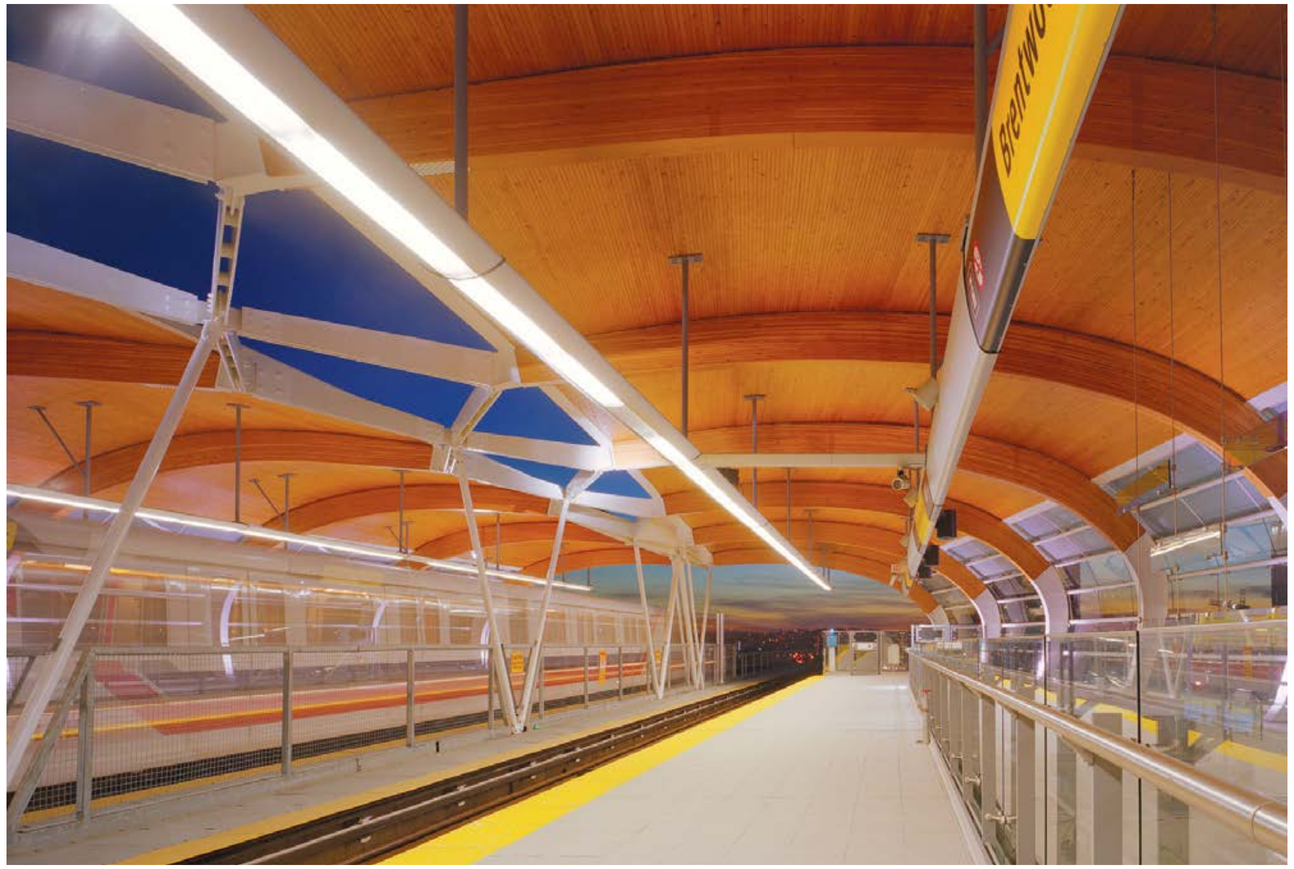
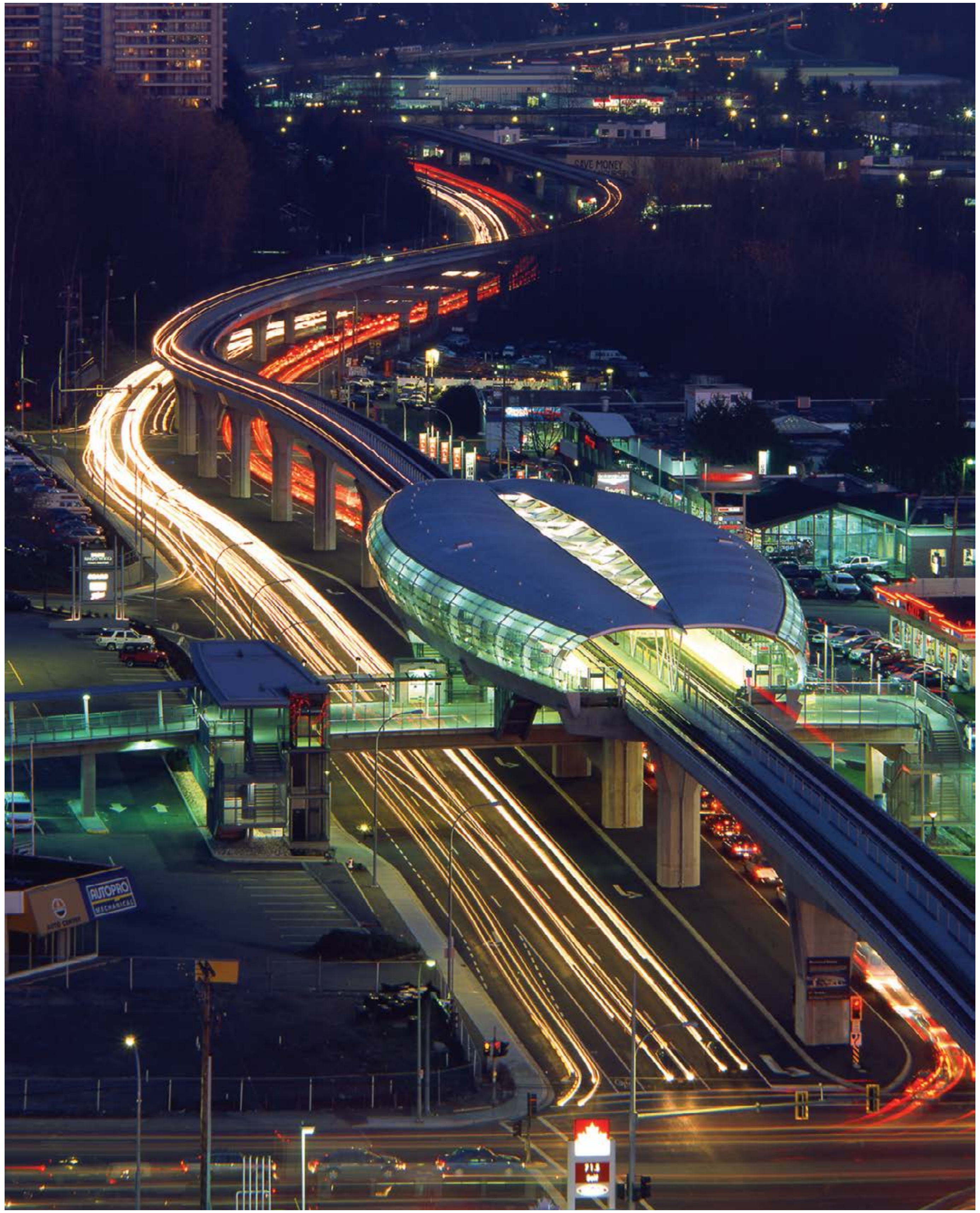


Figure 2.5b Building form with compound curvature, aerial of Brentwood Station, Burnaby, BC
Architecture by Perkins&Will
Photo credit Nic Lehoux



More dramatic, freeform curvatures are also possible. Gradual curves achieved with large radii help to mitigate the visual impact of faceting and stepping between adjacent laminations, as demonstrated by the Tsingtao Pearl Visitor Center and Ādisōke Public Library, shown in **Figure 2.6a and b**.

NLT does allow for some tighter curvatures, however, the degree of curvature along with the max curvature of the sheathing, should be verified in consultation with the NLT fabricator and structural engineer. Curved NLT is not compliant with the CSA O125 certification standard for MLT when fabricated with stepped lamella, or where curvature results in larger gaps, so it should be verified that specific applications, such as EMTC, do not require a certified product.

Curves along laminations are generally not possible with sawn lumber used in typical NLT. In special cases it is possible to achieve curvature along the length of the panel (ie. along the length of the laminations) by curving the laminations. The Ādisōke Public Library in Ottawa demonstrates this by using curved narrow glulams as lamella to create curved panels (**Figure 2.6b**).

Figure 2.6a
Freeform curvature with NLT, Tsingtao Pearl Visitor Centre, Qingdao, China
Architecture by Bohlin Cywinski Jackson *Photo credit* Nic Lehoux

Figure 2.6b
NLT with curved laminations, Ādisōke Public Library, Ottawa, ON
Architecture by Diamond Schmitt *Photo courtesy of* Fast + Epp

2.1.2 Surface characteristics

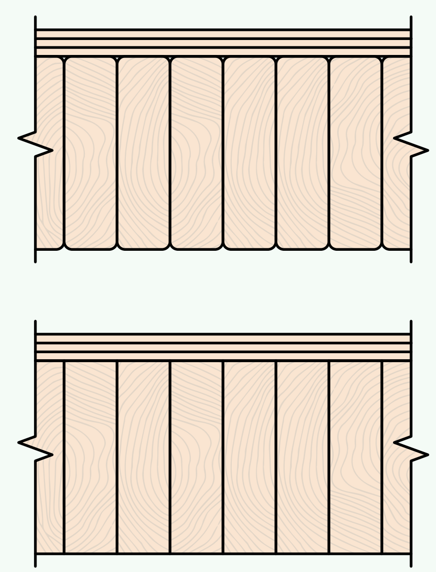
Whether in flat or curved building elements, the components that form NLT remain distinguishable within the final product, allowing for considerable flexibility and freedom for designers to define the appearance of the surface. Visible surface characteristics that must be considered include:

Species: Any species of wood can be used to fabricate NLT; this Guide assumes the use of species listed in the CSA O86. Availability of species will vary by region and offer different colouration and variation in appearance. For example, Douglas Fir appears to be more red or orange, compared to Pine, which appears more yellow or white. Refer to Appendix A for an NLT Appearance Chart comparing common species and lumber grades.

Lumber grade: It is best to specify lumber grade and any other desired characteristics of the timber if the product will be visible in the finished building. For example, one project may require a ceiling that is free from knots, while another may demand a rougher look. Specifications should use regional appearance grading nomenclature to ensure lumber will achieve the desired surface aesthetic. Refer to Appendix A for an NLT Appearance Chart, and Appendix B for sample specifiction.

Eased or sharp edges: Typical North American dimension lumber is milled with slightly rounded corners in cross-section, giving NLT a distinctive grooved or ribbed texture. To achieve a smooth face, the entire surface may be planed after layup, or specifications may call for individual laminations to be planed on one side prior to layup, as shown in **Figure 2.7**. If the NLT is assembled first, and then planed or sanded smooth, the gaps between the boards will become more obvious; the grooves tend to hide these imperfections. Both approaches will impact cost and structural capacity. Not all fabricators will have the ability to plane NLT smooth, and the reduced lamination depth needs to be accounted for in the design of the panels. Refer to Chapter 7 for more on fabrication, and Chapter 4 for more on structural design considerations.

Figure 2.7



Ribbed surface on NLT from un-planed laminations

Smooth surface on NLT from planed laminations

Cross-section size: Another way to modify the surface of NLT is by incorporating different sizes of dimension lumber. This technique achieves a unique aesthetic and can modify the acoustic properties of NLT (refer to Section 2.5). While the number of unique cross-sections is theoretically infinite, most NLT is fabricated as illustrated in **Figures 2.8**, **2.9**, and **2.10**. Where NLT depth is staggered, lumber depths that vary by two inches are the most common combination: for example, alternating 38 mm x 89 mm (2x4) with 38 mm x 140 mm (2x6). Larger variations in depth are less efficient structurally, owing to a large stiffness discrepancy. Structural considerations are addressed in depth in Chapter 4. The visibility of grade stamps on the sides of boards in staggered cross-section NLT should be addressed in the design and fabrication processes.

Figure 2.8
Uniform depth cross-section

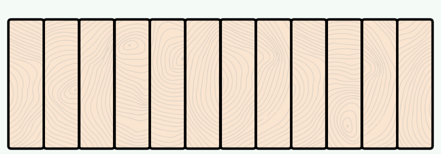


Figure 2.9
1:1 alternating staggered depth cross-section

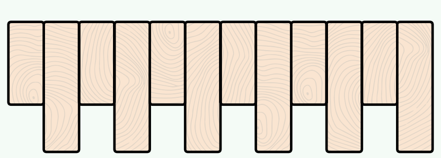
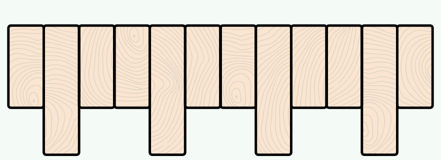


Figure 2.10
2:1 alternating staggered depth cross-section



Set expectations for NLT appearance using physical samples, reference images, and clear specifications with regionally appropriate nomenclature. These should be provided to the fabricator and discussed in detail to ensure that the design intent is delivered. Refer to Chapter 7 for more on fabrication and to Appendix A for an NLT Appearance Chart.

All construction materials and systems are susceptible to damage during transportation, installation, or by other construction activities after installation. For wood, this includes staining from water, rust, and paint; mechanical damage; and burning. Restoring damaged NLT may be accomplished by sanding, refinishing, and patching. NLT can tolerate heavy sanding and refinishing due to its thickness; however, heavy sanding tends to degrade the even appearance of the ribs and grooves of NLT. Patching poses an even greater aesthetic challenge to the ribs and grooves. When reviewing construction deficiencies and repairs, all NLT should be compared with a sample as shown in **Figure 2.11** or a mockup. Detailed considerations on fabrication and installation are provided in Chapter 7 and Chapter 8. Refer to Appendix B for a sample specification including requirements for finish and mock-up requirements.

Below | **Figure 2.11** NLT visual reference
Photo courtesy of StructureCraft

Right | Douglas Fir end grain
Photo credit Wade Comer Photography
Photo courtesy of NaturallyWood

2.2 Planning considerations

NLT is a combustible material and a code-compliant structural system for buildings with varying heights, areas, and occupancies, that allows for combustible construction or heavy timber roof structure where permitted. Currently the NBC permits up to six storeys of combustible construction for residential and business and personal services occupancies only, with limited combinations of other occupancy types on lower levels. The provinces have adopted the NBC's allowance with varying degrees of restrictions on occupancy type, storeys, and height. It is also acceptable to apply EMTC up to 12 storeys per NBCC 2020 [02], or up to 18 storeys in some provinces [03], [04]. Note that to comply with the requirements of EMTC, M-NLT may or may not be required, refer to Chapter 3 and your local code authority for more information. Acoustic requirements may increase floor thickness which may impact overall building height and weight (floor toppings, suspended gypsum wall board (GWB) ceilings). Early engagement with an acoustic consultant is imperative. Refer to Section 2.5 for more on acoustic considerations.

Unlike other mass timber products, NLT can be built on site, which can make procuring material easier and may offer more options. For example, site-built NLT could be made with local wood supply and constructed using local trades, which could reduce cost and environmental impact of shipping fully fabricated panels. This approach may also avoid long lead times often required to procure other manufactured mass-timber products. If site-built NLT requires a fire rating be sure to verify the manufacturing standards required in the fire rating listing are met.

Structurally, NLT is a system that spans only in one direction, which has implications for the layout of the structural grid. NLT requires linear support and cannot be supported on columns alone. Typical spans for NLT of various depths are given in **Table 2.1**; linear supports such as load-bearing walls or beams should be spaced accordingly. These maximum spans may be governed by vibrations rather than strength. Where changes in the column grid or load-bearing wall locations from floor to floor are necessary, load transfers should be accomplished through supplementary framing rather than placing large, concentrated loads on the NLT itself. Refer to Section 4.5.1 for more on point loads.

To reduce floor/ceiling assembly thickness, NLT can be mounted flush with the top of beams. NLT can also be suspended below the bottom of beams, with a raised floor system concealing the beams. Hanging NLT panels (i.e. the top of the NLT panel is below the underside of the support beam) is particularly difficult to achieve.

Cantilevers in the direction of the NLT span are feasible. A useful rule of thumb for concept design is that NLT can cantilever one quarter of its backspan length, although larger cantilevers may be possible depending on loading conditions. Cantilevers projecting through the building enclosure create additional design and detailing considerations; refer to Sections 4.5.3 and 5.2.1.

Planning should also carefully consider tolerance for swelling and shrinkage with NLT. To achieve a consistent aesthetic, consider NLT expansion joint widths in parallel with structural detailing requirements, fabrication tolerances, and installation tolerances. Finish applications and MEP anchorage requirements should be designed to accommodate swelling and shrinkage of NLT.

Table 2.1 Typical NLT floor spans

NLT depth		Typical span range	
millimeters (inches)	nominal lam size	meters	feet
89 mm (3.5 in.)	2x4	≤ 3.7 m	12 ft.
140 mm (5.5 in.)	2x6	3 - 5.2 m	10 - 17 ft.
184 mm (7.25 in.)	2x8	4.3 - 6.4 m	14 - 21 ft.
235 mm (9.25 in.)	2x10	5.2 - 7.3 m	17 - 24 ft.
286 mm (11.25 in.)	1x12	6.1 - 7.9 m	20 - 26 ft.

Spans will vary and may fall outside these ranges depending on use, loading, and vibration criteria.

2.3 Detail considerations

The architectural details for NLT carry the same considerations as for other building materials and systems. Wood construction detailing practices should be followed, but details may resemble those used for other materials. For example, when NLT is used as a non-bearing exterior wall it will bypass the floor slab, like a steel curtain wall system. Detailing in these situations are typically very similar despite the material. Firestopping at these transitions will require an alternative solution or engineering judgment to demonstrate code compliance as there are no ULC listed fire stop systems for this condition.

In addition to affecting the appearance of the surface of NLT, the grooves at eased edges of laminations and gaps between laminations can affect the appearance and the performance of construction details. When a wall, door frame, or other linear element butts up against the underside of NLT, the gaps created by the grooves and the space between laminations must be considered for fire, acoustics, and aesthetics. Situations requiring airtight construction must be carefully detailed. For example, **Figure 2.12** shows enclosed offices with interior partition walls that extend to the underside of an NLT floor structure above. Carefully consider the interface between the walls and the ceilings to mitigate sound travel between spaces.

Due to the difficulty in sealing linear elements to the underside of the NLT, it is good practice to keel NLT within the building enclosure. If a continuous soffit, balcony, or canopy condition is desired from interior to exterior, like the example shown in **Figure 2.13**, devise a detail that accommodates continuity of water, air, and vapour control. Chapters 4 and 5 discuss this condition in more detail, providing strategies to achieve necessary air and vapour control. Refer to Figures 4.34 and 5.5 for example section details. Penetration of the building enclosure with NLT might also affect M-NLT certification if air sealing between the laminations is required. Refer to Section 5.2.1.

When using NLT in a wall application, pay special attention to the connection details at the top and bottom of the walls, particularly if the wall is intended to be exposed. NLT used in a shear wall application is especially challenging; hold-downs must be attached to a vertical surface and cannot be concealed within the wall panel. In general, the strategy of furring and concealing one side of the NLT wall allows these surface mounted connections to be hidden, leaving the exposed side clean. Furring walls can also help mitigate sound transmission and provide a place to run services. Typically, an NLT wall sits on a sill plate made of either glued-laminated timber or steel. Consideration for the expression of this member at the base should be accounted for either by recessing it relative to the face of the NLT or concealing it with a baseboard trim. Connections of exposed NLT walls, even on one face, can be complex and require close coordination with structural and other disciplines.

Figure 2.12
Office partition walls in Head Office, Vancouver, BC
Photo courtesy of Fast + Epp

Figure 2.13 Example of continuous soffit from interior to exterior.
Samuel Brighouse Elementary School, Richmond, BC
Architecture by Fast + Epp *Photo credit* Nic Lehoux

Where roof anchors are required on an NLT roof, coordinate with structural engineers and supplier to ensure the load transfer is met and achieving architectural intent. Also confirm that details that protect the NLT from construction phase moisture and maintain air and water control at the final building enclosure are designed and installed. In some cases, suppliers will propose large visible steel connections on the soffit.

The use of a prefabricated NLT as a stair system was achieved at the Prince George Firehall to give the feature stairwell a stunning monolithic wood expression and texture for the stairs, landing, and walls – refer to the applied example for more information on the complexity involved to achieve this simple and clean architectural expression.

Applied example

NLT stair and guard

Prince George Fire Hall No. 1
Prince George, BC

Design intent

Create a stair core with NLT where all surfaces (walls, guards, stairs, and landings) combine to create a monolithic and uniform expression. Use mass timber to benefit from the qualities of exposed wood, reflect the region's vernacular and access local trades and lumber supply.

The issue

Creating a monolithic look with NLT is challenging. NLT panels do not behave like monolithically poured cast-in-place concrete or large glued mass timber panels like CLT. The very low weak axis strength within a panel, and lack of connection between laminations at panel joints must be carefully considered in the design of the elements and connections. Aesthetically, using the modular look of NLT being composed of multiple smaller vertical members helps the vertical panel joints to disappear making the overall expression look more monolithic.

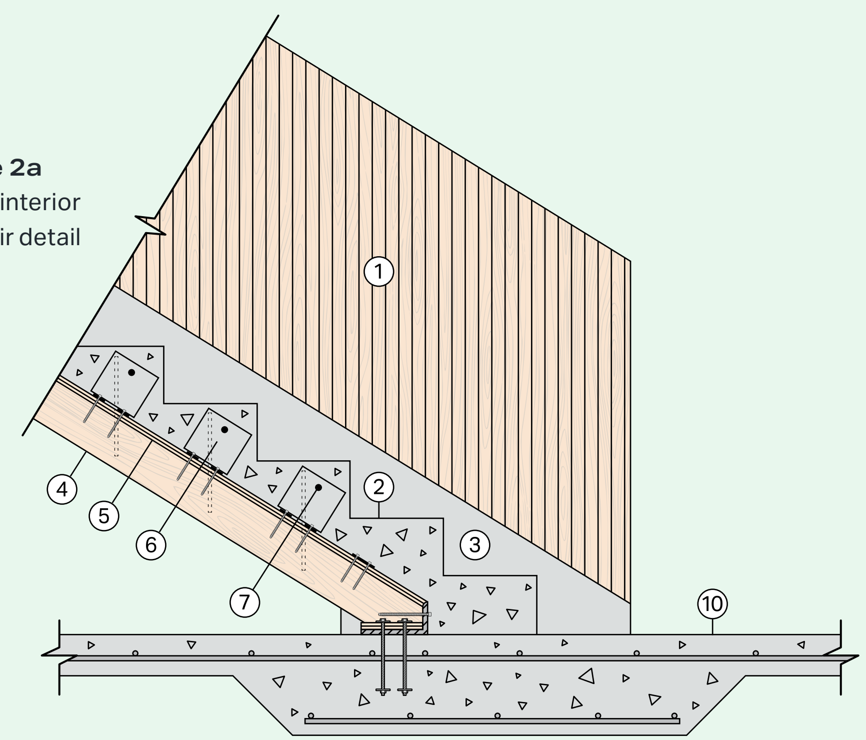


Figure 2a
Typical interior NLT stair detail

Resolution

To support the laminations within the discrete NLT stair panels, additional hidden steel framing was used throughout. Steel members were implemented at the ends of the landing to support the sloped NLT stair slabs. The steel beams were located above the NLT Slab on the landings and concealed with a void form and concrete topping. This approach retained the monolithic wood expression and aligned with using formed concrete stair treads for a durable walking surface. Supporting the NLT at the landing and the stair from the underside of the steel member is complex and required careful placement of fasteners, additional angles, and long threaded rods. **Refer to Figure 2a**.

NLT was also used in the guard application at the stairs and landings. Frequently placed, localized connections are provided between the guard and slab, because NLT does not form a two-way structural diaphragm and therefore has a limited span in the weak direction. Each structural steel connection was carefully concealed and plugged to retain the monolithic expression. **Refer to Figure 2a**.

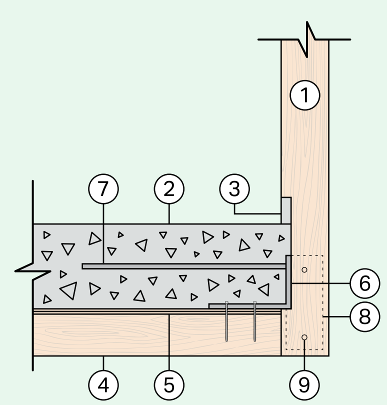


Figure 2b
Typical NLT guardrail connection detail along interior strair treads

1. NLT guardrail
2. Cast-in-place concrete treads
3. Drypack notch into NLT railing
4. NLT stair soffit spanning between landings and ground floor
5. Plywood over NLT soffit
6. Steel angle embed screwed to the NLT stair soffit
7. Dowel for angle embed into stairs
8. Knife plates between NLT guardrail panels
9. Glued-in rods through knife plates joining panels together sloped to follow slope of stair
10. Ground floor slab

Above Prince George Fire Hall No. 1, Prince George, BC
Photo courtesy of hcma *Photo credit* Ed White Photographics

Outcome

Although the final expression of the stair appears simple, to achieve this degree of exposure for NLT walls and soffits required significant effort. Additional time for coordination and detailed review during design and construction was spent to realize the complex approach. It is important to understand the structural limitations of NLT to ensure additional framing and connections provide sufficient support, and the laminations can be integrated in a way that meets the design intent. Solid element mass timber panels could simplify some aspects of connections for these highly exposed complex connections but would result in a very different look.

2.4 Mechanical, electrical, and plumbing considerations

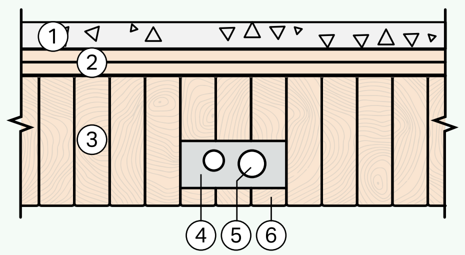
Services such as pipes, conduits, and cables in an NLT building are usually either suspended from the ceiling or contained within a raised floor system. Where services are suspended and the NLT is supported on beams rather than load-bearing walls, the direction of service runs should be carefully considered. Service runs that are parallel to the beams allow for the most efficient use of space, because the services can be contained between the NLT soffit and the beam soffit. Where services must run perpendicular to the beams, they must either penetrate the beams or be routed beneath them. If penetration is required, coordinate carefully with the structural engineer. Where routing services beneath, floor-to-floor heights may be affected if a minimum overhead clearance is required.

Another strategy for suspended services is to create a service chase in the face of the NLT and then insert a cap once the conduit, piping, and/or cabling has been installed. Refer to **Figure 2.14** and **2.15**. This approach creates a concealed space. Refer to **Section 3.4.3** for details on protecting concealed spaces. Refer to **Section 2.5** for acoustic considerations; there are several critical noise control items that need to be coordinated during the early design stages to avoid unresolvable conflicts later.

For an NLT roof application, it is possible to run services such as sprinkler pipes and electrical conduit, above the NLT however, electrical conduit must be protected from above to ensure there is no risk to roofers fastening through the roof and into the conduit. Local provincial roofing contractor associations will have specific guidelines for running services above the deck.

At Rosemary Brown Arena, service pockets above the roof were created to conceal services, but did require extensive coordination between consultants. Refer to the **Applied Example** on the following pages for more information.

Figure 2.14 Service chase in NLT



1. Concrete topping
2. Plywood/OSB
3. NLT
4. Gap for mechanical fire stopped as required
5. Mechanical services
6. Wood cover to hide services as required

Figure 2.15a NLT panel before capping the service chase
Photo courtesy of StructureCraft

Figure 2.15b NLT panel after capping the service chase
Photo courtesy of StructureCraft

Applied example

Concealed services in roof slab

Rosemary Brown Arena, Burnaby, BC

Design intent

Use NLT for the roof with exposed ceiling soffit throughout the main lobby of the ice arena and maximize wood expression without visually interrupting the look with mechanical and electrical elements.

The issue

Exposing wood structure on the roof is always met with the challenge of coordinating mechanical and electrical services for a clean look. Keeping services like sprinklers, electrical conduit and lights hidden and arranged in a coherent manner to minimize visual noise without the ability to hide services in ceiling finishes, requires integrated solutions. In this case, the lobby ceiling required both sprinklers and linear light fixtures.

Solution

The first strategy employed was to use side wall sprinklers as much as possible, to minimize the number of sprinklers on the ceiling. The second strategy was to provide continuous gaps between the NLT slabs that match the width of the linear light fixtures. A pocket was created above these gaps using dimension lumber blocking and plywood/OSB to form a space for services. **Refer to Figure 2c**. Coordination with the structural team was key to ensure that the structural diaphragm of the roof system was maintained over the pocket locations, while also ensuring that the support of the panels was not compromised. In cases where these pockets needed to be larger than the light fixture, thin NLT infill panels where installed below the services to maintain a consistent expression of the panel gaps.

Below Rosemary Brown Arena, Burnaby, BC *Photo courtesy of* hcma *Photo credit* Ema Peter

Below Close-up of adjacent photo

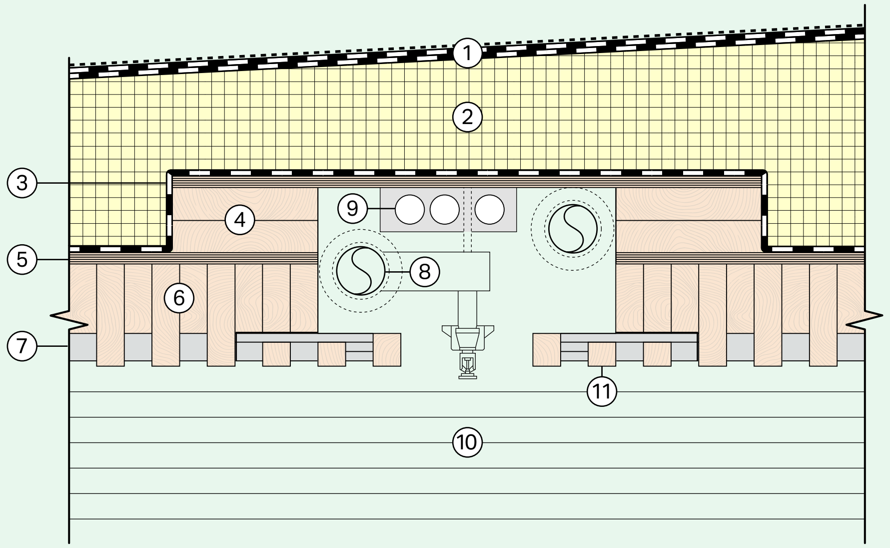


Figure 2c NLT roof service pocket

1. Roof membrane
2. Roof insulation
3. Air/vapour barrier membrane
4. Wood blocking with plywood/ OSB (designed by structural)
5. Plywood/OSB sheathing
6. NLT staggered
7. Sound absorbing acoustic mat
8. Sprinkler pipe
9. Electrical conduit
10. Glulam beam beyond
11. Non-structural NLT infill

Outcome

This approach was successful because of early and detailed coordination between the architect, mechanical, and structural engineers. The mechanical team completed a detailed sprinkler design at a much earlier stage of the project than typical, to avoid the challenge and cost of doing so with a sprinkler contractor at the shop drawing stage. Coordination with the structural team was also a key to ensure that the discontinuity in an NLT roof slab was verified for the structural impacts on both the support conditions and the diaphragm behaviour.

Vertical distribution of services through NLT must be coordinated with the structural engineer and acoustic consultant to ensure any openings with a diameter greater than the width of two laminations are appropriately framed or reinforced. Larger openings must have additional reinforcing or framing for support. Refer to Section 4.5.2 for potential framing requirements at openings. For both vertical and horizontal distribution of services, typical care must be exercised to isolate piping and ducts from the structure to avoid the transfer of noise generated by the flow of water, waste, or air.

When using NLT as walls, keep in mind that there is no wall cavity within which to route services. All pipes, conduit, cables, and so forth must be accounted for and accurately located during fabrication. Providing stud furring to one side of an NLT wall alleviates much of the complexity and coordination required to run services either vertically or horizontally across the NLT wall, while still allowing for wood expression on one side of the wall.

If it is desired to have both sides of an NLT wall exposed, consider strategies such as providing a double NLT wall with a cavity, but be sure to account for the complexity of the lateral restraint of two NLT walls at the head. In addition, service installation and access could be challenging for construction sequencing and access panels could be difficult to integrate seamlessly into the finished wood expression.

Where MEP is not provided in designated larger wall cavities and is expected to be embedded within a wall or ceiling soffit, a 3D integrated virtual model coordinated with or provided by the fabricator is likely required to accommodate coordinated shop drawings. This approach allows issues to be resolved virtually, maximizing the efficiency of prefabrication.

Left Whistler Library, Whistler, BC
Architecture by hcma *Photo credit* Martin Tessler

2.5 Acoustic considerations

Acoustics is a complex field, and an expert should be consulted in the design of floor/ceiling and wall assemblies and the applicable interfaces. While it is common to make use of such expertise for specialized spaces with low noise tolerances, such as a performance or recording space, it is equally important for any building type where there is an expectation of acoustic privacy or general noise and vibration control. These include education facilities, childcare facilities, hospitals, office buildings, multi-family dwellings, and community and recreation centers. Acoustics and noise control is one of the most common complaints in finished and occupied buildings.

In general, the acoustic considerations for an NLT structure are the same as for any other structural system. That is, one must consider how sound passes through it when it is part of a wall or floor/ceiling system and how sound reflects from an NLT surface when it is exposed. Early collaboration between acoustic, architectural, structural, and MEP teams is imperative to identify and address acoustic concerns early in the design. Of critical early design importance is the consideration of additional cost, mass, and thickness of walls and floors/ceilings from the addition of concrete toppings, isolation layers, furring walls, and suspended ceilings as these all will have an affect on building dimensions, including height and usable area, and structural requirements. These, and other issues, are best mitigated through careful and deliberate early design considerations to allow for more practical cost-effective solutions over applying corrective measures further on in the design process with greater design constraints.

Initial testing done by FPInnovations indicates that NLT performs in ways similar to CLT with respect to acoustics. Assemblies and values published in the CLT Handbook [01] can therefore be used as a starting point of reference for designers. Although their acoustic performance may be similar, unlike CLT, NLT typically has small gaps between laminations, which can create 'leakage' paths through which sound can travel. Plywood/GWB/OSB encapsulation and/or a concrete topping over NLT is required to address sound leakage by limiting the passage of airborne sound.

Right UniverCity Childcare Centre, Burnaby, BC
Architecture by hcma *Photo credit* Martin Tessler

2.5.1 Interior space acoustics

An NLT surface is acoustically hard and relatively flat and smooth, making it inherently sound-reflecting, with sound absorption properties like any solid wood construction and not dissimilar to a concrete slab system. In many instances, upgraded room acoustics are an important part of the overall building design. Good room acoustics prevent the build-up of overall noise levels in a space, aid in speech intelligibility for both the spoken word and for sound systems and provide a more comfortable and user-friendly environment.

To create an effective sound absorbing surface using an NLT design, consider using an alternating staggered cross-section layup (refer to **Figure 2.16**) with acoustic material added in the cavities between the deeper laminations. The ceiling surface of such an assembly is composed of 50% lumber and 50% sound-absorbing material having a Noise Reduction Coefficient (NRC) of at least 0.65. The depth of the acoustic medium should be at least 25 mm (1 in.) and the width at least 38 mm (1-1/2 in.) for 'basic' acoustical performance. To achieve 'good' acoustic performance, the total exposed acoustic medium should be at least 70% of the surface area. This can be achieved by greater spacing of the 38 mm x 140 mm (2x6) lumber.

Where a shallow depth of the acoustic material is used it may not absorb low frequencies sufficiently, leading to a space that sounds 'boomy'. Using thicker acoustic materials (e.g., 50 mm (2 in.) thick) will help in this respect.

Where a larger area of exposed wood is desired, and consequently a reduced area of the exposed acoustic medium, consider supplementary acoustic absorption measures. Options include the use of linear or vertical baffles, acoustic clouds, acoustically-backed perforated wood or wood-slat finishes, or additional acoustic treatment on the walls (including low-frequency tuner panels).

Ultimately, an acoustic specialist should be engaged during the design to ensure the desired acoustic environment can be achieved, while considering the desired aesthetic and architectural constraints. This is important for all occupied spaces, with more detailed coordination required for space types with multiple occupants or those with more stringent/specific acoustic requirements. Always consult an acoustics expert for project and product-specific advice. The overall fire rating of the final assembly must also be considered as part of the basic acoustic design; refer to Chapter 3 for more on fire considerations.

2.5.2 Inter-space sound control

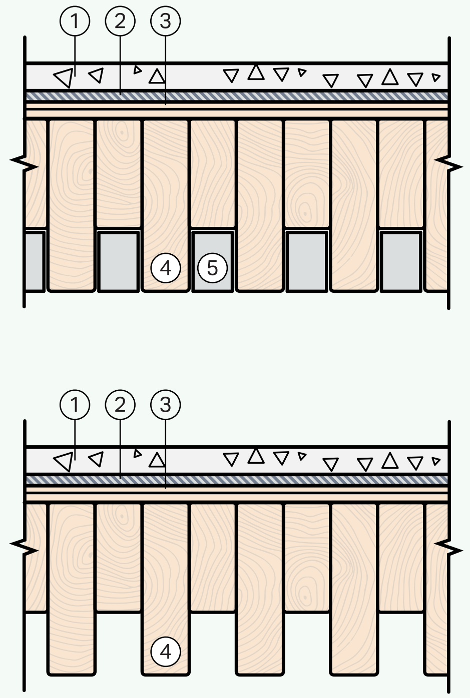
Transfer of sound between adjacent spaces takes two forms, airborne sound, and impact sound. The ability for a building element such as a wall or a floor/ceiling assembly to reduce the transfer of airborne sound is typically designated by a single number rating called the Sound Transmission Class (STC). STC is determined in a laboratory by testing a partition according to specific ASTM requirements. Impact sound is typically generated by footfalls and movement of furniture or dropping objects. The ability of a floor/ceiling assembly to prevent the transfer of impact sound is described by a single number rating system called the Impact Insulation Class (IIC), also determined in laboratory by testing a complete floor/ceiling assembly. Designers should determine the most appropriate rating and design details to satisfy codes, regulations, and owner requirements. Indicative STC and IIC ratings are included in Tables 2.2 and 2.3 for reference.

The 2020 National Building Code sets design targets for separations between dwelling units in Multi-Unit Residential Buildings using the Apparent Sound Transmission Class (ASTC) rather than the previously referenced STC ratings[1] but provides only guidance for best practice for IIC[2]. For all other building types, consultation with an acoustic consultant is recommended to set appropriate STC and IIC design targets.

1 Minimum ASTC rating is 47 between occupied spaces in dwelling units, and minimum STC 55 adjacent to elevator shafts.

2 Best practice IIC minimum is 55 for bare-floor construction.

Figure 2.16 Alternating 38 mm x 89 mm (2x4) and 140 mm (2x6) lumber with and without sound absorbing material



1. Concrete topping
2. Acoustic mat
3. Plywood/OSB
4. NLT
5. Sound absorbing material

Airborne noise control across NLT assemblies

Reducing airborne sound transmission through NLT assemblies is accomplished by addressing both the lack of mass of the NLT and the potential for air gaps. Exposing both sides of NLT construction is not recommended as it is prone to air gaps and does not have enough mass to mitigate airborne noise on its own. To improve the airborne sound isolation performance, additional layers such as furred out GWB walls, resiliently supported ceilings with insulated airspaces, and/or concrete toppings on isolation materials would typically be required.

Sample NLT STC ratings are provided for wall assemblies in **Table 2.2** and floor/ceiling assemblies in Table 2.3. The National Research Council of Canada has only tested base NLT walls and NLT walls with a single sided furring wall. Double sided furring walls could be explored but will need an acoustical consultant to review and provide specific guidance.

Acoustic sealant is required for all construction types to seal the interface between a wall and floor or ceiling to reduce sound leaks and flanking[3], but in the case of a wall running perpendicular to the laminations of an NLT assembly there is potential for longer gaps that could allow sound to bypass the wall and the surface applied sealant. Accordingly, designers should carefully consider interface details when using NLT.

3 Use of an acoustic caulk at the header and base plate of a demising wall in all construction is a requirement to optimize the acoustic performance of the demising wall system.

Table 2.2 STC test data for NLT walls

	Wall assembly	STC
1	19 mm plywood/OSB + 38 mm x 89 mm (2x4) NLT panel (baseline measurement)	29
2	13 mm plywood/OSB + 38 mm x 140 mm (2x6) NLT panel (baseline measurement)	31
3	19 mm plywood/OSB + 38 mm x 184 mm (2x8) NLT panel (baseline measurement)	31
4	19 mm plywood/OSB + 38 mm x 235 mm (2x10) NLT panel (baseline measurement)	36
5	19 mm plywood/OSB + 38 mm x 286 mm (2x12) NLT panel (baseline measurement)	41
6	38 mm x 89 mm (2x4) NLT panel + 38 mm wood studs w/batt insulation + 2 layers of 13 mm GWB	40
7	38 mm x 140 mm (2x6) NLT panel + 19 mm plywood/OSB + 38 mm wood studs (400 mm OC) w/batt insulation + 2 layers of 13 mm GWB	44
8	38 mm x 184 mm (2x8) NLT panel + 19 mm plywood/OSB + 38 mm wood studs (400 mm OC) w/batt insulation + 2 layers of 13 mm GWB	43
9	38 mm x 235 mm (2x10) NLT panel + 19 mm plywood/OSB + 38 mm wood studs (400 mm OC) w/batt insulation + 2 layers of 13 mm GWB	47
10	38 mm x 286 mm (2x12) NLT panel + 19 mm plywood/OSB + 38 mm wood studs (400 mm OC) w/batt insulation + 2 layers of 13 mm GWB	48
11	38 mm x 89 mm (2x4) NLT panel + 13 mm airspace + 64 mm wood studs w/batt insulation + 2 layers of 13 mm GWB	52
12	38 mm x 140 mm (2x6) NLT panel + 19 mm plywood/OSB + 13 mm airspace + 64 mm wood studs w/batt insulation + 2 layers of 13 mm GWB	60
13	38 mm x 184 mm (2x8) NLT panel + 19 mm plywood/OSB + 13 mm airspace + 64 mm wood studs w/batt insulation + 2 layers of 13 mm GWB	59
14	38 mm x 235 mm (2x10) NLT panel + 19 mm plywood/OSB + 13 mm airspace + 64 mm wood studs w/batt insulation + 2 layers of 13 mm GWB	64
15	38 mm x 286 mm (2x12) NLT panel + 19 mm plywood/OSB + 13 mm airspace + 64 mm wood studs w/batt insulation + 2 layers of 13 mm GWB	68

Flanking noise considerations

Flanking occurs when sound bypasses the main demising partition via adjoining constructions. The Building Code requires residential dwelling units to meet ASTC 47 which is a field rating that represents all sound transmission paths (including flanking).

Based on NRC published data, significant flanking is expected across continuous exposed NLT that can result in acoustical non-compliance. To address this flanking path, the NLT should either be discontinuous across the junction or have a massing layer provided on both sides of the junction. The massing layer would typically be a furring wall, mass topping (e.g., isolated concrete topping) or dropped GWB ceiling for floor assemblies.

Table 2.3 STC and IIC testing data completed for NLT floors

	Floor assembly (top to bottom)	STC	IIC
1	19 mm (3/4 in.) plywood/OSB + 38 mm x 89 mm (2x4) NLT panel (baseline measurement)	**29**	**N/A**
2	13 mm (1/2 in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT panel (baseline measurement)	**34**	**32**
3	19 mm (3/4 in.) plywood/OSB + 38 mm x 184 mm (2x8) NLT panel (baseline measurement)	**31**	**N/A**
4	19 mm (3/4 in.) plywood/OSB + 38 mm x 286 mm (2x12) NLT panel (baseline measurement)	**41**	**N/A**
5	Bare CLT panel (5-ply, 175 mm [6-7/8 in.] thick)	**39**	**25**
6	38 mm (1 ½ in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 38 mm x 184 mm (2x8) NLT panel	**56**	**45**
7	38 mm (1 ½ in.) normal weight concrete topping + Pliteq GenieMat FF10 acoustical mat + 38 mm x 184 mm (2x8) NLT panel	**57**	**47**
8	102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT	**51**	**44**
9	Carpet + 102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT	**51**	**58**
10	102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF25 acoustical mat + 13 mm (1/2 in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT	**54**	**50**
11	102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF50 acoustical mat + 13 mm (1/2 in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT	**56**	**52**
12	50 mm (2 in.) Gypcrete, Maxxon Acousti-Mat 19 mm (¾ in.) Premium + 38 mm x 140 mm (2x6) NLT + 13 mm (½ in) plywood/OSB	**47***	**N/A**
13	38 mm (1-1/2 in.) Gypcrete 2000 + Maxxon Acousti-Mat II acoustical mat + 13 mm (½ in.) plywood/OSB + 2x6 NLT	**-**	**-**
14	38 mm (1-1/2 in.) Gypcrete 2000 + Maxxon Acousti-Mat 3 acoustical mat + 13 mm (1/2in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT	**-**	**-**
15	102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT + RC + 16 mm (5/8 in.) Type C Gypsum	**55**	**49**
16	102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood/OSB + 38 mm x 140 mm (2x6) NLT + Pliteq GenieClip RST Clip + R8 Fibreglass batts + 16 mm (5/8 in.) Type C Gypsum	**60**	**59**
	*ASTC rating		

Impact sound for floor assemblies

Impact sound is often perceived to be more disruptive than airborne sound; especially in situations where the level of airborne sound is well controlled. For example, a residential building constructed of concrete, or a modified NLT construction designed to meet building code requirements for airborne sound will effectively block the sound of voices from the suite above, but the sound of someone walking in hard-soled shoes or of chair movement may be clearly audible in the occupied space below. Complaints of impact noise are the most common noise complaint in multi-family residential buildings.

As previously noted, the NBC currently recommends a minimum rating of IIC 55 for residential buildings, while the minimum requirement in the International Building Code (IBC) is IIC 50. Floors in residential buildings with IIC ratings of less than 50 often result in significant complaints related to impact noise. For this reason, it is recommended to design for a minimum of IIC 50, although a target of IIC 55 is preferred for greater resident satisfaction, and IIC 60 or higher should be considered for premium multi-family units.

For non-residential construction, floor/ceiling assembly impact noise control targets can range significantly from below IIC 50 for non-critical environments to IIC 60+ where more critical impact isolation needs prevail (such as theaters, studios, or similar).

To improve impact insulation performance, materials are typically applied on top of the NLT floor structure, below it, or for best performance both below and above. When NLT ceilings are left exposed, an upper performance limit of approximately IIC 53 can be achieved through the addition of a mass topping layer on an isolation layer. Improving the IIC rating further typically requires thicker acoustic underlayment and toppings, the addition of a suspended ceiling (ACT or resiliently suspended GWB with an insulated air space), and/or the use of carpet. With these additional controls, ratings of IIC 55+ are possible. Table 2.3 lists examples of various floor/ceiling configurations and their STC and IIC ratings.

In all cases, the acoustic specialist should be engaged with the architectural and structural teams early in the design to ensure a reasonable solution can be achieved that meets the project intent.

Field performance

Careful control of flanking paths is important for all construction and material types. With good design and construction, the Apparent Sound Transmission Class/Impact Isolation Class (ASTC/AIIC) ratings are typically up to five points lower than those achieved in laboratories (STC/IIC). Table 2.3 provides STC and IIC test results for NLT floors. Included in the table for comparison is the acoustic performance of bare NLT with plywood/OSB topping and bare CLT. It is always important, however, to contextualize the results and the applications in which systems are typically used. For example, STC and IIC ratings are derived from 1/3 band octave data that occur over a range of frequencies. To better understand the comparison of one assembly's acoustic performance to another, the differences over that entire frequency range should be evaluated.

While the industry builds a more complete database of tested assemblies for NLT, designers may opt to use other mass timber assembly tests as a guide to predict the performance of NLT. For example, there are several CLT acoustic assemblies listed in the CLT Handbook [01] as well as others available from acoustical mat manufacturers; some provide STC/IIC values, and some provide ASTC/AIIC values. If an NLT deck of a similar thickness was used in place of the CLT, a rule of thumb suggests that the assembly performance could be estimated by subtracting three from the STC/IIC or ASTC/AIIC values. In addition, there are proprietary software programs that can estimate the STC and IIC of non-standard assemblies. Such programs generally predict results with an error of +/- 3 points for STC and +/- 5 points for IIC.

When building with NLT, it is recommended that project budgets include allowance for post-construction testing to verify field performance against requisite or recommended targets. To the extent possible, measures for retroactive adjustments should be developed with the acoustic consultant during the design in case deficiencies in performance noted during testing need to be addressed. Alternatively, a time and budgetary allowance for pre-construction mock-up testing should be carried. This may provide a more cost-effective approach to determining the STC and IIC performance of demising assemblies and mitigation measures needed to be implemented, prior to construction. This is of particular importance for new and novel NLT assemblies and configurations, where existing or published test data may not exist.

2.5.3 Durability considerations

Durability considerations for any wood product also apply to NLT; ultraviolet (UV) light and moisture are primary concerns. NLT must be protected in service from direct exposure to the exterior environment with proper preservative treatment. Where NLT is exposed to UV light, its colour will fade unless the wood is protected with a suitable coating. Coatings with higher pigment amounts typically resist UV longer than clear coatings (refer to Section 7.3).

Consult manufacturers to assist with selecting coatings, and weather test options to help select the appropriate product. A continuous film coating applied to NLT after fabrication will likely develop cracks between laminations, causing the film to fail. A penetrating finish may not crack, but concealed faces of laminations will not be exposed to receive the coating.

Where untreated wood is exposed to moisture, there is significant risk of staining and dimensional change during construction in any case where the wood is the final architecturally exposed surface. Additional risk of mold and decay in cases where the wood is unable to dry as moisture is present for an extended period of time. Further discussion is provided in Chapters 5 and 8. Exposed end grains at the edges of NLT are most susceptible to moisture, leading to swelling and distortion of the laminations. However, moisture exposure on any part of the panel, including moisture trapped between adjacent laminations or between laminations and sheathing can have a significant impact on the durability and lifespan of the panels. Exposure to moisture can occur during construction or in service and should be avoided to the greatest degree.

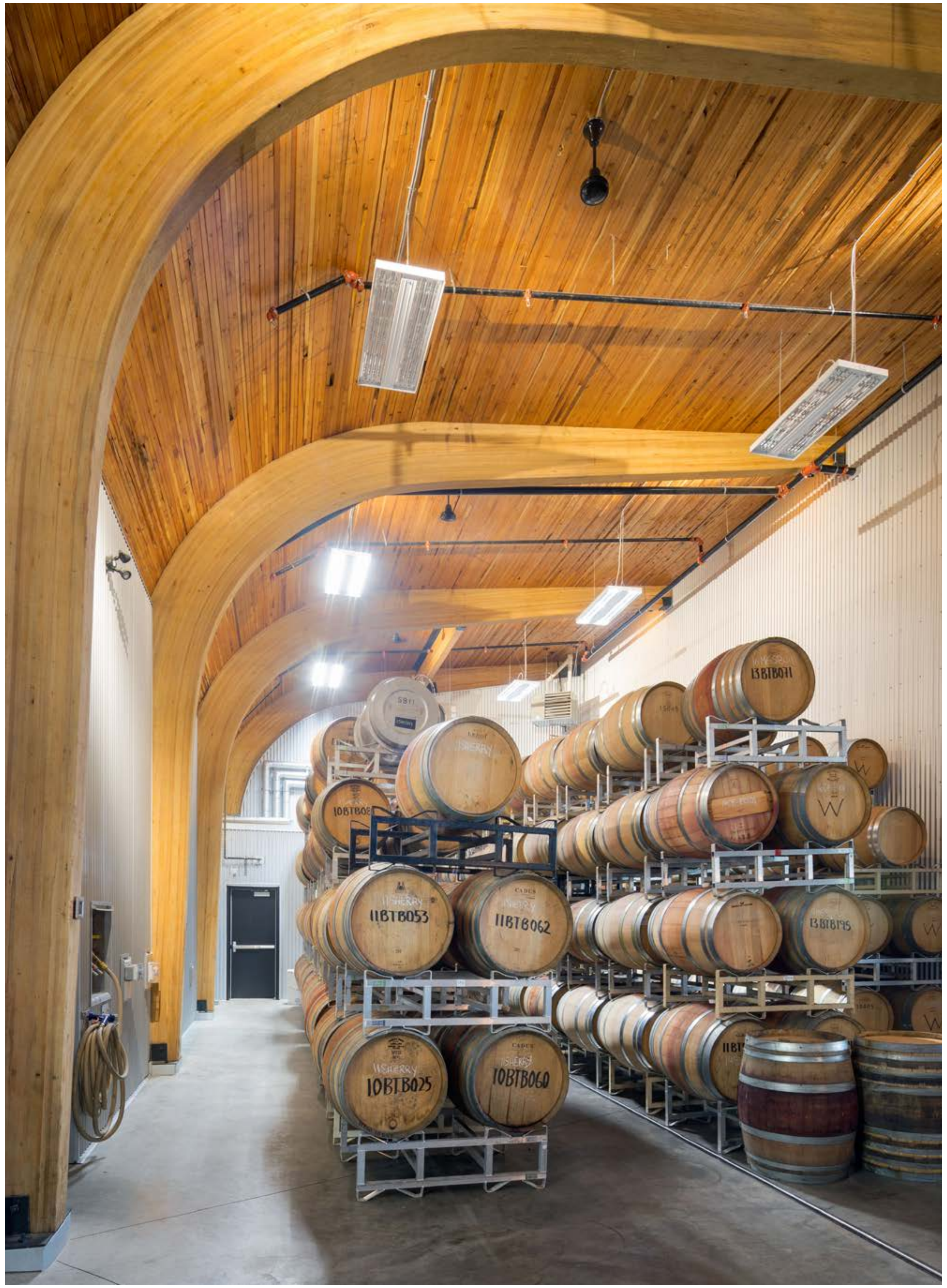
Ensure exterior wood is protected from direct water exposure and is set back far enough from the edge of an overhang to shelter it from wind driven rain. Enclosure elements must also be designed to appropriately dry construction phase moisture and manage rainwater and condensation in service. Refer to Chapter 5 for more discussion on designing the NLT enclosure to manage heat, air, and moisture and to Chapter 8 for managing construction phase moisture during fabrication, transportation, storage, and installation. Consider that unplanned moisture exposure during the construction phase can delay project schedules, increase material and labour cost, and negatively impact the quality of the work. Appropriately managing moisture and striving for a durable NLT building begins in design with the moisture management planning process as discussed in Section 8.6.

2.6 Embodied carbon and life cycle assessment

Wood used for structure and other applications can reduce the overall embodied carbon impact of a building. Life cycle assessment (LCA) tools should be used to evaluate the embodied impact a project using wood products by conducting a Whole Building (WBLCA). Environmental Product Declarations (EPDs) for a range of mass timber products are currently available for several North American manufacturers, although none exist for NLT. If conducting WBLCA, using EPDs for a similar product such as CLT or DLT will provide a practical approximation for the purposes of estimating embodied carbon impact. However, if an EPD of a different product is used to model NLT, limitations in the data and potential consequences in the results should be clearly reported.

Right Time Winery, Kelowna, BC
Architecture by HDR *Photo credit* Dan Schwalm *Photo courtesy of* RDH Building Science

Below NLT Panel
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood



Chapter 2.0 references

[01] Karacabeyli, Erol, and Brad Douglas. 2013. CLT handbook: Cross- laminated timber. Pointe-Claire, Québec: FPInnovations.

[02] The National Building Code of Canada 2020 (NBC).

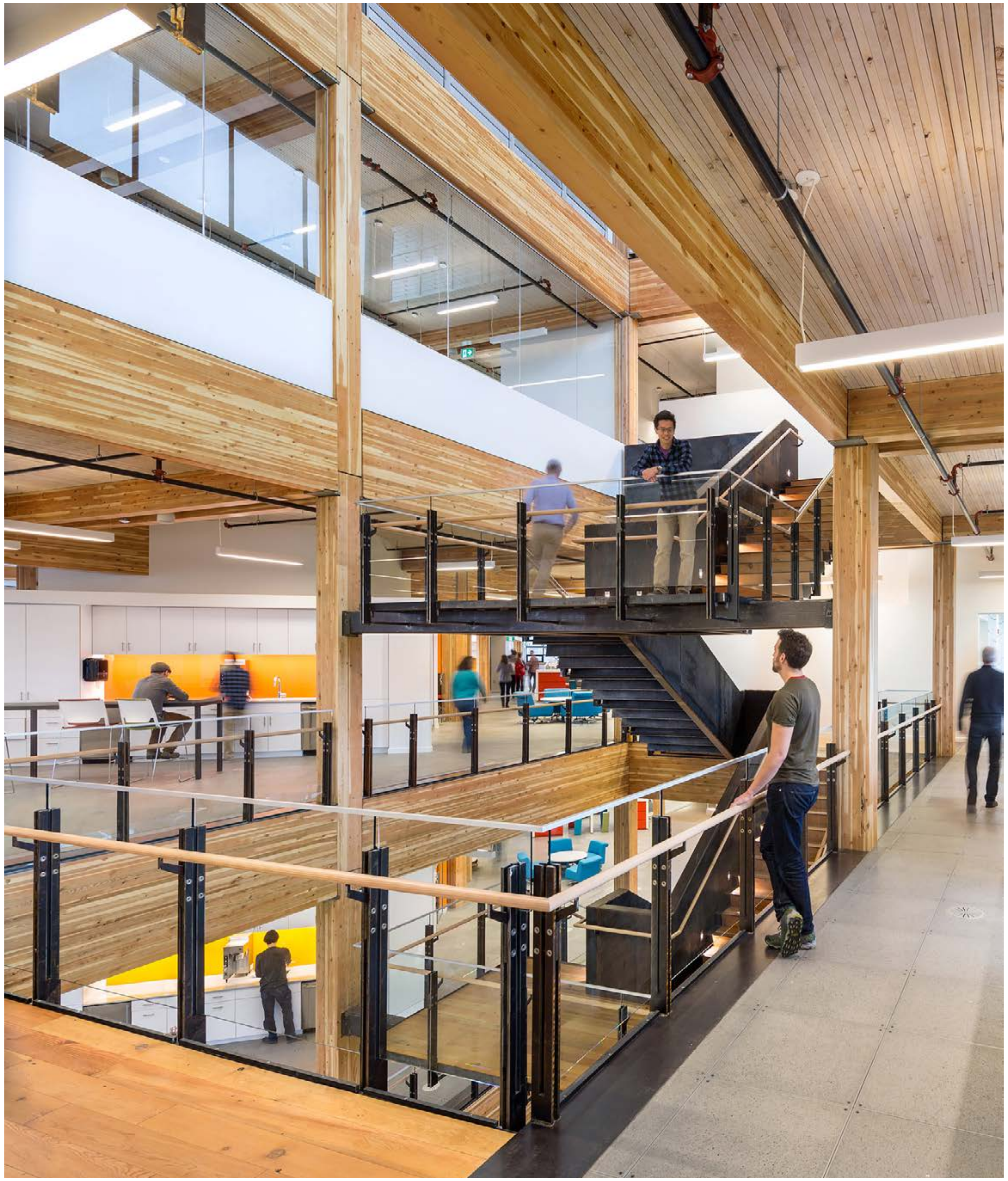
[03] BC Ministry of Housing. B.C. builders can now use mass timber in taller buildings, April 10, 2024. https://news.gov.bc.ca/releases/2024HOUS0055-000522.

[04] Ontario Ministry of Municipal Affairs and Housing. Ontario Expanding Mass Timber Construction Up to 18 Storeys. Accessed April 10, 2024. https://news.ontario.ca/en/release/1004272/ontario-expanding-mass-timber-construction-up-to-18-storeys.

Below Askew's Uptown Market, Salmon Arm, BC
Architecture by Allen + Maurer Architects *Photo credit* Derek Lepper Photography *Photo courtesy of* NaturallyWood

3.0 Fire

3.0 Fire



This chapter provides guidance on the use of nail-laminated timber (NLT) in accordance with fire safety provisions of the National Building Code of Canada (NBC), with special reference to the 2020 edition.

The NBC is the model building code for Canada, adopted with relevant amendments by all provinces as the applicable building code. The prescriptive solutions in Part 3 of Division B of the NBC include provisions for the use of NLT structural elements in buildings permitted to be of combustible construction, heavy timber construction, or encapsulated mass timber construction (EMTC), and in sprinklered buildings not more than two storeys in height, regardless of construction type.

Construction using NLT has been prescribed in the NBC since the first edition in 1941, described as "solid sawn lumber planks set on edge and well spiked together" per Division B Part 3, or "solid wood" per Appendix D. The NBC 2020 includes minimum allowable sizes when combustible construction with a fire-resistance rating of up to 45 minutes is prescribed in Division B Part 3 and provides historic generic acceptable solutions for fire-resistance ratings up to 1.5 hours in Appendix D-2.4. EMTC, which is a new addition to the NBC 2020, allows the use of mass timber-elements, including NLT. A total fire-resistance rating of at least 2 hours is required for all EMTC building types, achieved through either char, encapsulation and char, or encapsulation only.

The intent of this guide is to provide direction on both the prescriptive use of NLT and offer a performance-based framework to extend beyond the prescriptive provisions.

Right Head Office, Vancouver, BC
Architecture by Proscenium Architecture+Interiors *Photo credit* Ed White Photographics

3.1 Fire safety in timber buildings

The primary objectives for the construction requirements under Division B Articles 3.2.2.20 to 3.2.2.92 of the NBC 2020, as noted in Article 3.2.2.1, are to limit the probability of fire spread, and to limit the risk of collapse caused by the effects of fire.

The intent of these construction requirements is to provide safety to building occupants, safety to fire fighters and emergency responders, and property protection. Similar objectives are noted in Article 3.2.2.2 to provide guidance on the construction of buildings that may not fit directly under the prescriptive construction provisions in Articles 3.2.2.20 to 3.2.2.92.

Methods to satisfy the foregoing performance requirements include the following, as illustrated in **Figure 3.1**:

- Compliance with prescriptive requirements of Division B ("acceptable solution");
- Compliance through alternative solutions. These include:
  - Simple building code alternative solutions per Division A.
  - More complex alternative solutions: in particular, performance-based design, which may require third-party review or approval at the provincial level.

The prescriptive requirements of the NBC for construction type are based on occupancy, building area, building height, and the presence of a sprinkler system. Combustible construction, where permitted by the acceptable solutions of the NBC, is typically considered to be lightwood frame construction, which is regarded as the type of combustible construction with the lowest level of performance in fire. Heavy timber construction is considered a special subset of combustible construction and is allowed to be used where combustible construction is permitted and not required to provide more than 45 minutes of fire-resistance rating. It can also be used for selected uses in buildings otherwise required to be of noncombustible construction. The minimum heavy timber dimensions outlined in Division B Part 3, Article 3.1.4.7. are deemed acceptable in buildings where combustible construction is permitted and a fire-resistance rating no greater than 45 minutes is required. In areas where a greater fire-resistance rating is required, Division B Appendix D-2.4 may be used to determine the required dimensions of NLT. Based on this fire-resistance rating limitation and limits to combustible construction in the NBC, NLT has mainly been used in buildings of relatively low height, until the introduction of EMTC.

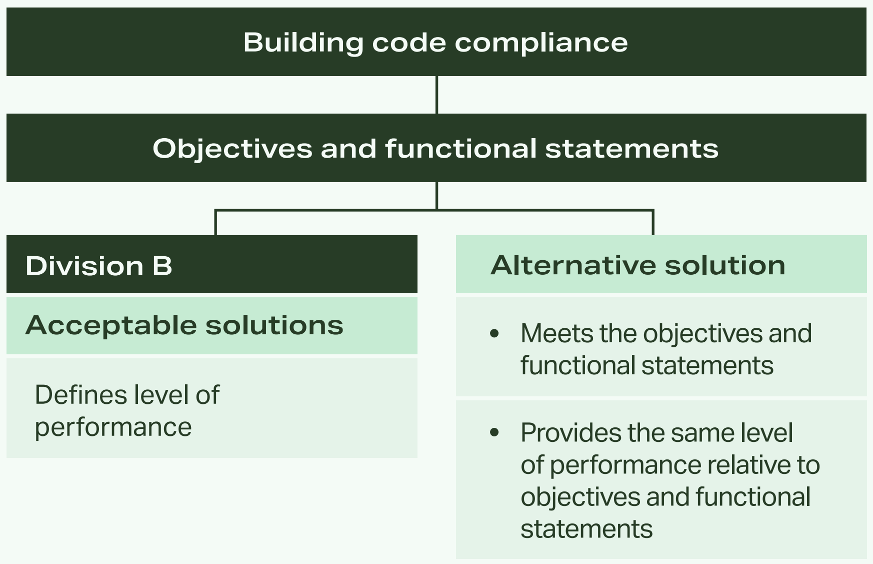
EMTC is a new construction type, which is separate from combustible and noncombustible construction, and which is included in the NBC 2020. This construction type requires that structural mass timber elements have a fire-resistance rating up to 2 hours. Refer to Section 3.2 for more on EMTC.

The NBC acceptable solutions in Division B prescribe maximum allowable building heights for combustible construction ranging from two storeys for care occupancies to six storeys for residential and business and personal services occupancies, and maximum allowable building heights of up to 12 storeys for EMTC buildings of residential and business and personal services occupancies. Refer to Section 3.3.1 for more.

The NBC's Division A Sentence 1.2.1.1 (1) allows design flexibility beyond prescriptive requirements through alternative solutions described under Section 2.3 of Division C. The alternative solutions must demonstrate to the authority having jurisdiction (AHJ), typically at the municipal level, that the objectives and functional statements of the NBC will be achieved. Alternative methods used to comply with the NBC could range in scope from addressing specific details, such as minor combustible elements beyond that permitted by the acceptable solutions of Division B of the NBC, to whole building design. Refer to Section 3.3.2 for more on building code alternative solutions. Refer to Section 3.3.3 for discussion on performance-based design.

There are minimal provincial variations relative to the use of NLT. Combustible construction is permitted for buildings up to six storeys in most provinces. Further, several provinces have adopted the EMTC provisions, which directly permit the use of NLT based on prescriptive requirements of the NBC 2020. For example, BC currently permits EMTC as an acceptable solution. Prior to the recent province wide adoption and ahead of the NBC 2020 publication, BC implemented a Jurisdiction Specific Regulation (JSR) which permitted EMTC up to 12 storeys for residential and business and personal services buildings as an acceptable solution. The JSR applied in specific municipalities which had agreed to the early implementation of the EMTC provisions. Ontario and Alberta have also amended their respective provincial building codes to allow EMTC. As of May 1, 2024, the Alberta Building Code will have 12 storey EMTC. Quebec has specific provisions for an "expedited" alternative solution for encapsulated mass timber construction up to 12 storeys, which would directly permit the use of NLT. Newly released updates to the EMTC provisions in BC allow for increased levels of exposure for some building types between seven and 12 storeys, as well as an increase to 18 storeys for fully encapsulated buildings. Refer to updated British Columbia Building Code 2024. Similar code updates are being considered in other provinces and in the NBCC 2025.

Figure 3.1 Building code performance requirements compliance path



3.2 Fire performance of combustible and encapsulated mass timber construction

Combustible construction

There are historically two types of combustible construction in the NBC: wood-framing (also known as platform framing) using dimension lumber and small-dimensioned structural engineered wood products, and heavy timber construction. In wood-frame construction, walls and floors are framed using dimension lumber. The wood studs in wood-frame construction are generally covered by gypsum board to conceal insulation and services within the cavities of the assemblies and to meet fire safety requirements such as flame-spread ratings, integrity of fire separations, and fire-resistance ratings. In heavy timber construction, wood elements such as NLT that meet the minimum sizes per Article 3.1.4.7 of Division B and that are permitted to be used where a fire-resistance rating of up to 45 minutes is required, are used to form structural frames. The structural members are permitted to be exposed as their large mass provides an inherent degree of resistance to ignition and flame-spread.

Mass timber construction is like heavy timber construction except that member sizes are typically larger than the minimum sizes prescribed for heavy timber construction in the NBC. The fire-resistance rating of mass timber is driven by the sizes of members of a proposed design in relation to the load-resistant capacity of the design and may provide fire-resistance ratings exceeding the maximum ratings contemplated by the NBC 2020 acceptable solutions for combustible construction. Division B, Appendix D-2.4 of the NBC 2020 provides a table of minimum sizes for NLT solid wood walls, floors, and roofs for fire-resistance ratings up to 1.5 hours. Where higher ratings are required, other calculation methods are available as discussed later in this guide.

Right Algonquin College DARE District, Ottawa, ON
Architecture by Diamond Schmitt *Photo credit* Doublespace Photography

Encapsulated mass timber construction (EMTC)

EMTC is considered a unique construction type separate from combustible and noncombustible construction. It is currently permitted for buildings of residential or business and personal services occupancy up to 12 storeys in building height, with other occupancy types such as assembly and retail permitted on the lower storeys. EMTC is defined as "… that type of construction in which a degree of fire safety is attained by the use of encapsulated mass timber elements with an encapsulation rating and minimum dimensions for structural members and other building assemblies." Based on the prescribed encapsulation materials and by virtue of the solid wood elements, EMTC behaves like noncombustible construction to a large extent, especially during the initial stages of a fire.

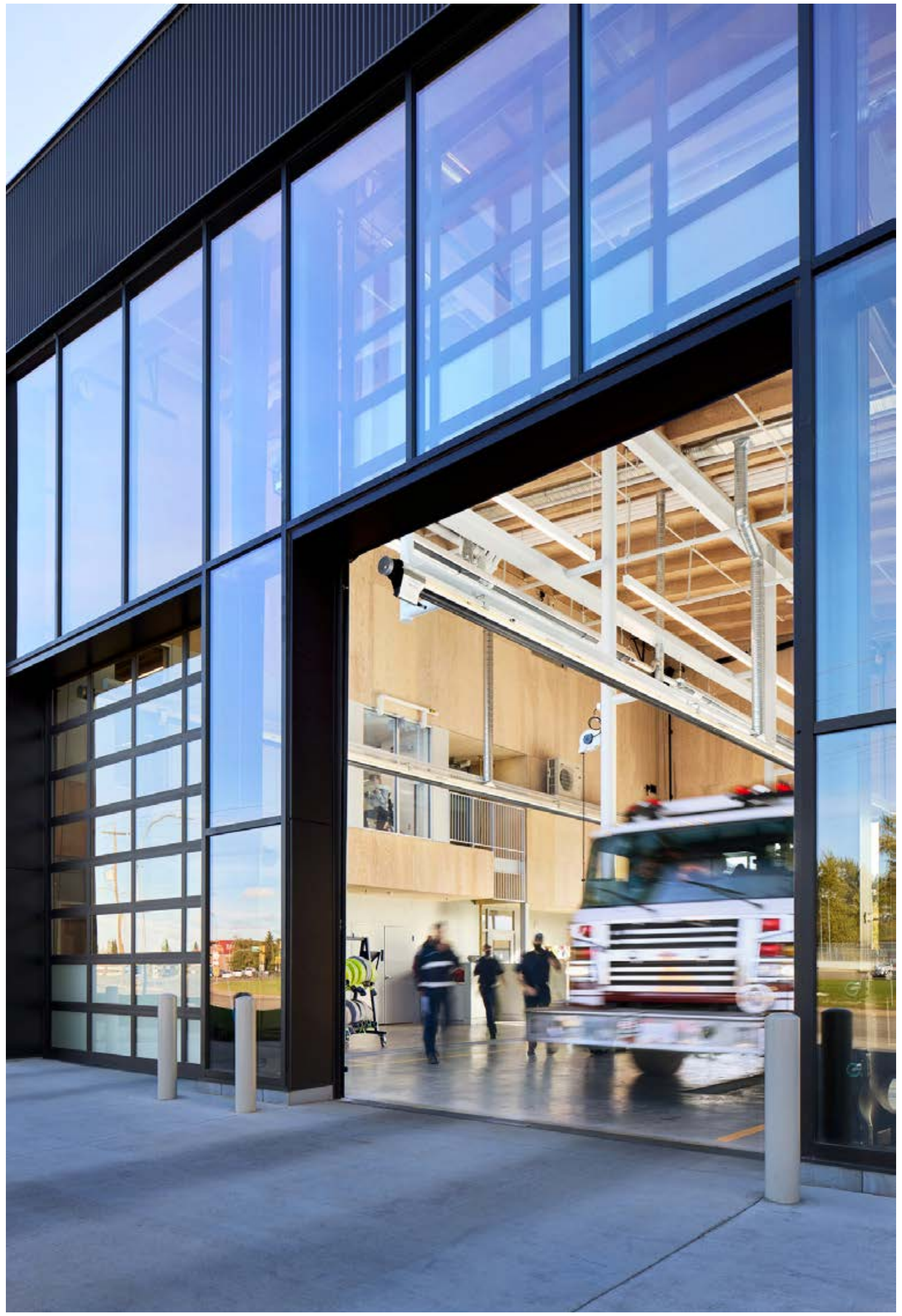
Under the EMTC category, the mass timber elements such as NLT, are encapsulated between materials with noncombustible properties such that the timber element would have limited contribution to a fire at least during its initial stages when the encapsulation is still in place. Typical encapsulation materials are fire-resistance rated gypsum board for both wall and ceiling assemblies and concrete as a topping for floor assemblies. The mass timber elements are required to meet minimum sizes per Article 3.1.6.3 of the NBC 2020. In addition, the fire-resistance rating is determined based on the thickness of the mass timber element and the encapsulation materials through fire testing or through analytical methods in Annex B of CSA O86, "Engineering Design in Wood" [02].

A limited percentage of exposed mass timber surfaces is permitted under the EMTC provisions as detailed in Article 3.1.6.4 of the NBC 2020. The remainder of the mass timber elements or assemblies are required to be provided with sufficient encapsulation materials to achieve a minimum encapsulation rating of 50 minutes. Note that this is separate from the fire-resistance rating; the NBC 2020 assigns an encapsulation rating of 50 minutes for two layers of 12.7 mm Type X gypsum board whereas CSA O86 CL B.8 assigns a fire-resistance rating contribution of 60 min for the same two layers of 12.7mm Type X gypsum. It is noted that the top side of floor assemblies is required to be fully protected with encapsulation materials such as a minimum of 38 mm thick concrete topping, with no exposed surfaces permitted.

The NBC 2020 prescribes that the encapsulation materials be applied directly to the mass timber element, with any concealed space created because of the attachment of the encapsulation material required to not exceed 25 mm. The Notes to Division B Part 3 of the NBC 2020 clarify that the intent is to encapsulate all exposed mass timber surfaces (except as specifically permitted in Article 3.1.6.4), including both sides of floor and interior wall assemblies, the underside of roof assemblies, and the interior side of exterior wall assemblies. Encapsulation is not required for the upper surface of a mass timber roof assembly when there is no concealed space above it, or for the exterior side of a mass timber exterior wall assembly. Spatial separation and cladding requirements of the NBC still need to be fulfilled for exterior wall assemblies.

Encapsulation rating is defined in the NBC 2020 as the time in minutes that a material or assembly of materials will delay the ignition and combustion of encapsulated mass timber elements when it is exposed to fire under specified conditions of test and performance criteria. This is different from the fire-resistance rating contribution of encapsulation materials, which is the fire-resistance rating that the encapsulation material contributes to the total fire-resistance rating of the assembly.

It is anticipated that NBC 2025 will allow an increase in the percentage of exposed surfaces permitted based on additional fire testing which has become available since the NBC 2020 provisions were implemented. The testing demonstrated that an acceptable level of performance can be achieved with fully exposed ceilings where walls are strategically encapsulated. This provision has gone through the public review process and is likely to be adopted by various provinces prior to release of NBC 2025. Prior to updates to the NBC 2020, alternative solutions may be developed based on the results of these tests. Be aware that the level of exposed mass timber elements permitted and/or desired often needs to be balanced with the need to conceal building services, as well as fire separation and acoustic design requirements. Refer to Chapter 2 for discussion on acoustic design.



Above Prince George Fire Hall No 1, Prince George, BC
Architecture by hcma *Photo credit* Ed White Photographics

3.2.1 Fire-resistance ratings

Fire-resistance ratings are based on the following criteria:

Structural stability

Resistance of the assembly or member to structural collapse or exceedance of deformation limits.

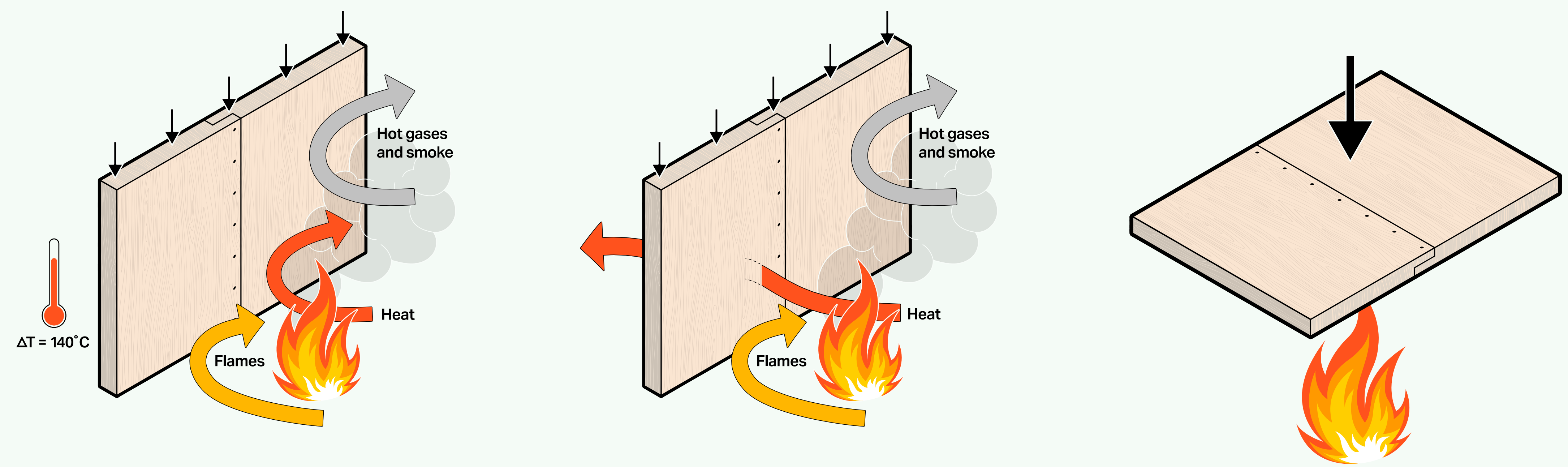
Integrity

Ability of the assembly to limit the passage of hot gases or fire to the unexposed side.

Insulation

Ability of the assembly to limit a specified rise in temperature on the unexposed side.

Figure 3.2 Functions of fire-resistance
Adapted from the CLT Handbook [19]



The applicable criteria to determine the fire-resistance rating for a specific element or assembly depends on its intended purpose.

For example, a structural column is expected to meet the stability criterion, but not integrity or insulation. A structural floor, acting as both a structural component and a fire separation, is required to meet all three criteria. NLT floor assemblies used in fire-resistive applications are typically required to meet all three criteria.

There are three primary methods for determining fire-resistance rating above 45 minutes for NLT:

1

NBC assemblies

Division B, Appendix D-2.4 of the NBC 2020 provides a table of minimum sizes for solid wood walls, floors, and roofs for fire-resistance ratings up to 1.5 hours; this table is included in this guide for reference as Table 3.1. NLT panels, by virtue of their fabrication as solid wood members spiked together, meet the definition of solid panels. These designs have been in the NBC for many decades, and it is not known whether the designs are based on actual fire tests or historic practice that has been grandfathered into the NBC. The generic solutions provided in Appendix D-2.4 are acceptable solutions under the NBC provided the NLT is fastened as indicated in Appendix D-2.4.

Minimum structural member sizes for EMTC are also prescribed under Table 3.1.6.3. It is noted that unlike heavy timber construction where in the minimum sizes specified in Table 3.1.4.7 are deemed acceptable in combustible construction not required to provide fire-resistance rating exceeding 45 minutes, the minimum sizes noted Table 3.1.6.3, with encapsulation, would not necessarily provide a 2 hour fire-resistance rating in an EMTC building; structural calculations are required to determine the fire-resistance rating provided, and the thickness of the mass timber elements may need to be increased as a result.

2

Calculated fire-resistance

NLT systems can be designed to meet the minimum fire-resistance ratings based on char analysis and structural calculations. CSA O86 is the structural design standard referenced in the NBC 2020. Annex B of this standard provides a methodology for establishing structural fire-resistance ratings. The calculation methodology provided by Annex B of CSA O86 is an acceptable solution for mass timber members and elements under Appendix D-2.11.4 of the NBC 2020. Currently, the calculations methods in Annex B of CSA O86 are noted as applicable to wood elements meeting the requirements of CSA O141 "Canadian Standard Lumber" per CSA O86 CL 6.1, including NLT. Reference 6.5.10.3 of CSA O86 describes the size and fastening requirements for NLT addressed by this section of CSA O86 and notes that these provisions are applicable to site-built NLT.

For smaller buildings applying conventional combustible construction design practices, adherence to the NBC provisions in Article 3.1.4.7 and Appendix D-2.4. is acceptable for fire design but limited to 90 minute fire-resistance ratings. The NBC does not specify loading requirements; refer to Chapter 4 for information on structural requirements.

The calculated fire-resistance rating for EMTC is typically based on the thickness of the mass timber panel and the encapsulation materials. CSA O86 assigns a fire-resistance rating contributed by Type X gypsum board when it is used as an encapsulation material, with the remainder of the fire-resistance rating contributed by the mass timber element. At a minimum, EMTC is required to be encapsulated with materials which provide an encapsulation rating of 50 minutes.

Annex B of CSA 086 notes that the fire separating function (with respect to integrity or insulation failure) is outside the scope of the standard and will have to be established separately. Addressing this fire separating function would typically involve the use of protection membranes at one or both faces of an assembly used as a fire separation as described in Appendix D-2.11.4 of the NBC 2020. Testing has demonstrated that an NLT wall may continue to retain its structural integrity even after it has failed the insulation or integrity criteria. Accordingly, NLT walls which are not required to function as fire separations may not need membrane protection; however, appropriate analysis is required to establish this.

3

Tested assemblies

Reports demonstrating an assembly or structural member has been tested in accordance with CAN/ULC-S101 is an acceptable solution under the NBC. Recent fire tests have been carried out to investigate various characteristics of NLT assemblies including char rate and fire-resistance [03] [04], flame-spread [05], and the effect of construction variations such the influence of gaps within the assembly [06]. These tests provide a limited list of tested fire rated assemblies. It is anticipated that as the use of mass timber becomes more widespread, additional testing will become available.

Table 3.1 Minimum thickness of solid wood walls, roofs, and floors (mm) (1)(2)
Adapted from Table 2.4 of the NBC 2020

	Fire-resistance rating			
Type of construction	**30 minutes**	**45 minutes**	**1 hour**	**1.5 hours**
Solid wood floor with building paper and finish flooring on top (3)	89 mm	114 mm	165 mm	234 mm
Solid wood, splined or tongued and grooved with building paper and finish flooring on top (4)	64 mm	76 mm	-	-
Solid wood walls of load bearing vertical plank (3)	89 mm	114 mm	140 mm	184 mm
Solid wood walls of non-load bearing horizontal plank (3)	89 mm	89 mm	89 mm	140 mm

(1) Refer to CSA O141, “Softwood Lumber,” for sizes.
(2) The fire-resistance ratings and minimum dimensions for floors also apply to solid wood roof decks of comparable thickness with finish roofing material.
(3) The assembly shall consist of 38 mm thick members on edge fastened together with 101 mm common wire nails spaced not more than 400 mm o.c. and staggered in the direction of the grain.
(4) The floor shall consist of 64 mm by 184 mm wide planks either tongued and grooved or with 19 mm by 38 mm splines set in grooves and fastened together with 88 mm common nails spaced not more than 400 mm o.c.

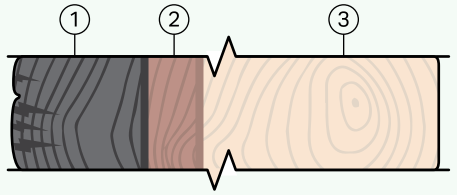
Below Centennial Beach park Pavilion, Delta, BC
Architecture by PUBLIC Architecture *Photo credit* Nic Lehoux

3.2.2 Char

Charring of wood occurs when it is exposed to temperatures ranging from approximately 280°C to 300°C [07]. Extensive testing has allowed char rates of wood to be reliably predicted when exposed to the CAN/ULC S101 standard fire time-temperature curve for various types of mass timber elements. The cross-sectional dimensions of a wood element have a considerable impact on fire performance due to the development of char on the surface of a burning member. The char significantly reduces the rate of burning; the char at the exposed side of the wood member acts as thermal insulation and delays heating of unexposed wood. **Figures 3.3** and **3.4** show a typical cross-section of a wood member exposed to fire on one side. In **Figure 3.3**, the profile illustrates a pyrolysis zone or heated layer in the portion of the wood member beginning to undergo charring. Behind the pyrolysis zone is wood at ambient temperature, which retains all its structural strength.

Figure 3.4 Wood charring *Photo courtesy of* Holmes Fire

Figure 3.3
One-dimensional char profile



1. Char layer
2. Pyrolysis zone
3. Normal wood

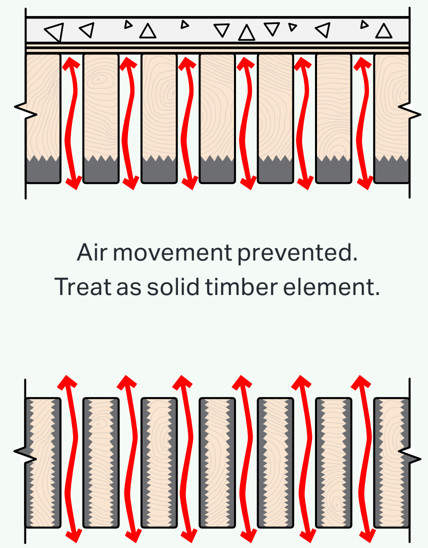
NLT elements that meet the minimum sizes prescribed in Division B, Article 3.1.4.7 of the NBC 2020 have inherent fire-resistance due to their thickness and are recognized as elements of "heavy timber construction." Such members are permitted by the NBC to be used where a fire-resistance rating up to 45 minutes is required and combustible construction is permitted, and thus do not require char calculations. Should greater fire-resistance be required, the NBC establishes minimum member sizes for fire-resistance rating of NLT elements up to 1.5h in Appendix D-2.4 which also do not require char calculations. Char calculations are however required for assemblies exceeding a fire-resistance rating of 1.5h, including for EMTC assemblies, despite the minimum size requirements noted in Article 3.1.6.3.

Generally, char calculations may be used to determine the structural stability of elements exposed to the CAN/ULC-S101 standard fire to achieve any desired rating. This process involves assigning the appropriate char rate, determining the depth of char on all exposed sides and thickness of the heated layer, and evaluating the structural capacity of the remaining structural element.

Topping continuity and char behavior

Where fire-resistance-rated construction is required, the topping used over NLT may have a considerable impact on char behavior and resulting fire-resistance, as illustrated in **Figure 3.5**. Existing documentation and fire testing suggests where hot gases pass between the NLT laminations, bi-directional char may occur [08] [06]; i.e. char may occur on the sides of the individual laminations as well as the bottom. Where NLT includes a monolithic topping such as concrete, gypsum, plywood/OSB or similar materials, and gaps between laminations are relatively tight, char behavior has been shown to be primarily one- dimensional. This is due to the flow of hot air through the assembly being negligible, keeping char limited to one direction on the exposed bottom surface. In EMTC, this concern is inherently addressed by the encapsulation materials prescribed. However, this phenomenon would still require special consideration for areas in EMTC where exposed mass timber is permitted. The use of mass timber manufactured under careful quality control standards with tight gaps between laminations helps to address this concern.

Figure 3.5
Air movement through NLT



Air movement prevented.
Treat as solid timber element.

Air movement possible.
Account for side charring.

Below | Figure 3.6
NLT Influence of gaps testing. Char depth based on spacing between laminations.
Photo courtesy of GHL and FPInnovations

To treat NLT as a solid timber element, in addition to the top membrane, NLT should be manufactured using dry, quality lumber such that the laminations are tight and gaps between the laminations are minimal; drying of wood with a high moisture content tends to lead to the expansion of the gaps between the laminations. Some testing has shown that where the gaps are excessive, 4 mm (0.16 in.) or more, treatment of NLT as a solid member may not be appropriate, even with a top membrane. Other testing has shown that where construction is tight, consideration of NLT as a solid, monolithic member may be appropriate [06].

A new CSA standard, CSA O125, "Mechanically laminated timber –Production and qualification specifications" [01] has recently been developed to address mechanically laminated timber (MLT) products such as NLT. MLT and the CSA O125 standard are referenced under CL 8.2 of CSA O86. As the name suggests, the objective of the standard is to provide production specifications and quality control for MLT, to address structural integrity per CSA O86 and meet satisfactory serviceability standards. The width of gaps is inherently addressed by fabrication of NLT to this standard. Refer to **Figure 3.6** for an illustration of the impact of gaps on char of NLT; as shown, the char rate is higher for panels with larger gaps. Further testing is required in this area to provide additional data on the degree of tightness required to consider an NLT panel as monolithic.

Where NLT is being used as a fire separation, air and therefore smoke may move through the assembly. Quality control during construction to limit the width of gaps in the assembly and including a top membrane, resolves this for floor assemblies. However, for walls, shafts or stair fire separations, possible smoke movement must be considered, which typically requires that at least once side of the assembly be protected with a continuous membrane. Appendix D-2.11.4 provides further requirements for the protection of mass timber assemblies to address integrity and thermal insulation properties of the rated assembly. EMTC walls used as fire separations may require encapsulation on both sides, and encapsulation is always required above EMTC floor assemblies, thus, the insulation and integrity criteria are inherently met.

Calculated char rate

The char rate is the speed at which solid wood burns and creates char through the depth of a wood member. It is expressed in units of length divided by time [01]; mm/min:

Char rate = char depth [mm] / time [min]

For similar fire exposure, char rates are generally consistent between types and species of wood and are typically reported as a one-dimensional char rate or a notional (effective) char rate. The one-dimensional char rate is applicable where the effect of corner rounding is taken into account separately, or for slab elements exposed to fire from one side (e.g., walls and floors). The notional char rate inherently accounts for the effect of corner rounding and this need not be calculated separately. Accordingly, the notional char rate is typically greater than the one- dimensional char rate. **Figure 3.7** shows a wood beam exposed to fire where the effect of corner rounding is evident.

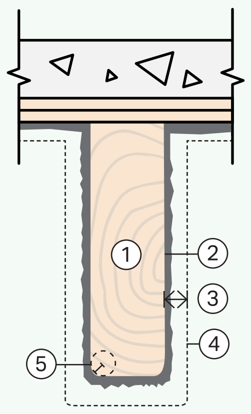
The residual cross-section on which the structural fire-resistance rating of an NLT member is determined by subtracting both the char depth and a “zero-strength” layer. This layer accounts for the pyrolysis zone and additional heated portion of wood below charring temperature on all fire-exposed surfaces. The reduced strength of the pyrolysis zone is represented in calculations by a smaller zero-strength layer. The resulting residual cross-section or ambient wood below is assumed to maintain full strength and is used to evaluate structural stability and fire-resistance rating.

Annex B of CSA O86 provides design char rates for various wood products exposed directly to the CAN/ULC-S101 standard fire temperature conditions. Specific details for NLT have not yet been incorporated in CSA O86 as test data on the char rates of NLT are limited. Therefore, determining fire-resistance ratings of NLT may require close review by a fire safety engineer and structural engineer on a case-by-case basis. The limited testing that is available has shown char rates of 0.55 to 0.8 mm/min, with char rate being higher at joints [03] [04] [09]. The char rate may also be higher in assemblies with gaps between laminations exceeding 2 mm as previously noted, and depending on the type and thickness of protection provided on one or both sides of the assembly.

A calculation method was recently developed by FPInnovations for MLT and validated against full-scale fire-resistance floor test results [10]. The method showed that using a one-dimensional char rate of 0.80 mm/min provides calculated failure times and mid-span deflections that closely track those of test data. A char rate of 0.80 mm/min is consistent with the rates obtained from full-scale fire-resistance floor tests. When following this approach, no other modifications are needed in Annex B to implement MLT assemblies. The structural design in fire conditions was made following the proposed provisions intended to be published in the 2024 edition of CSA O86 for MLT floor elements subjected to out-of-plane bending. Therefore, for structural fire-resistance rating calculations, 0.80 mm/min established based on fire tests by FPInnovations is recommended for MLT [10]. The provisions for ‘Nail-laminated decking’ per CL 6.5.10.3 of CSA O86 may also be used but will result in larger cross-sections in comparison to the recommended char rate of 0.80 mm/min or the values provided in Appendix D-2.4 of the NBC 2020.

Product manufacturers with specific quality control procedures may achieve significantly better char rates and performance. These products can be used based on the specific manufacturers testing reports.

Figure 3.7
Representative example of effective depth



1. Residual section
2. Calculated charring line
3. Calculated depth of charring
4. Profile of original section
5. Radius of arris rounding

3.2.3 Fire spread and smoke development

To control the risk of fire spread and smoke development at early stages in a fire, the NBC regulates the materials and interior finish surfaces that can be used in different buildings based on occupancy classification, type of construction permitted, location of finishes, and the presence or absence of sprinkler protection. Limitations on interior finishes are intended to delay ignition, slow fire and smoke development, and limit fuel contribution to a fire; these in turn delay the onset of untenable conditions and flashover. For exposed NLT (both as structure and interior finish), the interior finish classification requirements may apply in addition to fire protection requirements.

Interior wall and ceiling finish materials are typically evaluated based on testing in accordance with CAN/ULC-S102 to determine flame-spread ratings and smoke developed classifications. Evaluated finishes are assigned a numerical, dimensionless flame-spread rating or smoke developed classification based on formulas noted in the test standard. The species of wood used for NLT should be evaluated to confirm the appropriate flame- spread rating for the NLT. Most softwood finishes achieve a flame-spread rating of no greater than 150, which is generally permitted to be used as interior wall finish in sprinklered buildings with the exception of exits and lobbies used for exits.

Refer to NBC 2020 Subsections 3.1.5, 3.1.6, and 3.1.13 of Division B for interior finish requirements. The interior finish requirements noted in the NBC 2020 Subsection 3.1.13 of Division B apply to combustible construction, noncombustible construction, and EMTC.

Appendix D-3 of the NBC 2020 provides generic flame-spread ratings and smoke developed classifications for several building materials, including for lumber of a minimum thickness of 16 mm. For NLT, the flame-spread rating in Appendix D-3 is a conservative value. Recent surface flammability testing [05] has demonstrated that NLT is able to provide lower flame-spread ratings than prescribed generally for softwood. For standard NLT assemblies with a relatively smooth continous surface and lumber boards running along the direction of flame-spread, the flame-spread rating was shown to be up to 50, with a smoke developed classification of up to 55. For fluted sections, with a high degree of surface variability, the flame-spread rating and smoke developed classification was shown to be in the order of 90. It is anticipated that lower flame-spread ratings could be achieved by implementing good quality control measures during fabrication. The requirement for flame-spread rating of 25 in some locations will restrict how much of the NLT can be exposed.

Specific information on flame-spread ratings for several Canadian wood species are made available by the Canadian Wood Council (www.cwc.ca).

3.3 Fire design

3.3.1 Acceptable solutions

The NBC includes acceptable solutions for fire design of buildings in Division B Parts 3 and 9. Currently, depending on occupancy type, combustible construction is permitted for buildings up to six storeys in building height and EMTC is permitted for buildings up to 12 storeys. **Table 3.2** provides a summary of maximum building height (by storey) permitted for each occupancy category. Combustible construction in the form of wood-frame construction is permitted for all building categories except in Group A Division 1 occupancies, where heavy timber construction is specifically prescribed, and in Group B Division 1 occupancies, where noncombustible construction is required. EMTC is currently only permitted in Group C and Group D. Updates to the NBC in the future are expected to include other occupancy types.

Below Tsleil-Waututh Administration and Health Centre, North Vancouver, BC
Architecture by Lubor Trubka Associates Architects *Photo courtesy of* NaturallyWood

Table 3.2 Maximum building height permitted for combustible construction and EMTC by occupancy type

Occupancy type	Group & division	Maximum building height permitted
Assembly	A1	**1 storey (heavy timber)**
	A2	**2 storeys**
	A3	**1 storey**
	A4	**1 storey**
Detention	B1	-
Treatment	B2	**2 storeys**
Care	B3	**3 storeys**
Residential	C	**6 storeys**
		includes A2, E, and storage garages on lower storeys
	C	**12 storey (EMTC)**
		includes A2, E, and storage garages on lower storeys
Business and personal services	D	**6 storeys**
		includes A2, E, F-2, F-3, and storage garages on lower storeys
	D	**12 storey (EMTC)**
		includes A2, E, F-2, F-3 and storage garages on lower storeys
Mercantile	E	**3 storeys**
High hazard industrial	F1	**3 storeys**
Medium hazard industrial	F2	**4 storeys**
Low hazard industrial	F3	**4 storeys**

Per the acceptable solutions in Division B of the NBC 2020, NLT is permitted in the following cases:

- Any building permitted to be of combustible construction with structural members required to have a 45-minute fire-resistance rating or no rating. The NBC 2020 does not require the protection of connections in this case, provided the connections conform to the provisions found in Sentences 3.1.4.7.(7) to (11) of Division B.
- Any building permitted to be of combustible construction with structural elements required to have a 1-hour fire-resistance rating. The fire-resistance rating of the structural elements may be determined as described in this guide in Section 3.2.1, using Appendix D-2.4 of the NBC 2020, standard fire-resistance tests, char calculations, or other design methods. Fire protection of the connections is required.
- Roof assemblies of sprinklered buildings up to two storeys in building height and structural members in the storey immediately below the roof, regardless of the type of construction prescribed by the NBC, if the roof assemblies conform to Sentence 3.1.4.7.(6) of Division B.
- Buildings of residential or business and personal services occupancy of EMTC up to 12 storeys in building height. The structural elements are required to provide a 2-hour fire-resistance rating as described in this guide in Section 3.2.1, using standard fire-resistance tests, char calculations, or other design methods.
- Solid lumber partitions (i.e. non-loadbearing walls) in buildings required to be of noncombustible construction.

Consult a qualified fire protection engineer for calculation of fire-resistance ratings above 45 minutes and for complex NLT design and/or NLT geometry (e.g., staggered lumber boards resulting in uneven surfaces). Until NLT is incorporated into Annex B of CSA O86, the use of a calculation method should be approved by the AHJs.

Below Centennial Beach Park Pavilion, Delta, BC
Architecture by PUBLIC Architecture *Photo credit* Nic Lehoux

3.3.2 Building code alternative solutions

Where a design differs from the acceptable solution specified in Division B of the NBC, it should be treated as an "alternative solution" that is required to achieve at least the minimum level of performance required by Division B. Alternative solutions may vary in complexity and generally fall into two categories: simple and more complex performance-based designs.

Where NLT conforms to the prescriptive requirements of the NBC, the approval process is usually more straightforward. Generally, most AHJs are familiar with wood design and heavy timber construction as prescribed by the acceptable solutions of the NBC. More recently, designers and AHJs are also becoming familiar with mass timber with the introduction of EMTC into the NBC.

Designers are increasingly using NLT in modern buildings beyond prescriptive limits. Division C Section 2.3 of the NBC describes the elements of a Code analysis necessary when documenting an alternative solution. This provision reflects the NBC's intent not to limit appropriate materials, design approaches, or construction methods not covered by prescriptive requirements.

In general, an alternative solution is a compliance method intended to demonstrate that a material, design, or method of construction that is not specifically noted as an acceptable solution in Division B still achieves at least the minimum level of performance required by Division B of the NBC. This minimum level of performance is defined in the areas described by the objectives and functional statements attributed to the applicable acceptable solution. Intent statements, typically available with the online version of the NBC, provide further clarification as to what a prescribed NBC provision aims to achieve or avoid.

The alternative solution approach involves indentifying a non-compliant condition, developing an alternative solution, demonstrating that the minimum level of performance required by the NBC is achieved, and ultimately gaining approval from the AHJ. Depending on the level of complexity of the alternative solution, the AHJ may request a third-party review. It is important to note that an alternative solution is typically developed based on a specific project need and cannot be extended to another site or building without further investigation.

Simple alternative solutions

For simple alternative solutions, where a condition not directly prescribed by Division B is proposed, it is sometimes easier to consider enhancing or adding fire safety measures to balance the risks. An alternative solution does not necessarily need to propose mitigating features or "trade-offs"; it is simply required to demonstrate that the intents, objectives, and functional statements of the applicable acceptable solution are met by the proposed alternative solution.

Examples of possible enhanced fire safety measures include:

- Installation of a sprinkler system where not already prescribed.
- Enhanced sprinkler systems with additional features that may not be otherwise required.
- Enhanced fire-resistance for structural elements.
- Enhanced compartmentalization within the building.
- Installation of noncombustible vertical exit enclosures.
- Advanced analysis to demonstrate safety and/or robustness.

An example of a typical alternative solution is one where NLT construction is proposed for an exterior wall located at property line with a limiting distance of less than 1.2 m (4 ft.). The acceptable solution under Division B Subsection 3.2.3 would prescribe that the wall be of noncombustible construction even where the building is permitted to be of combustible construction; however approaches involving inherent fire-resistance rating, encapsulation of the combustible elements, and noncombustible cladding may be considered equivalent and acceptable as an alternative solution. In such a case, it may be advantageous to engage in early discussion with the AHJ to convey the advantage of using similar materials throughout the building to avoid differential shrinkage while still providing the minimum level of performance required by the NBC.

The NBC currently includes a list of exterior wall assemblies deemed to satisfy the requirements of CAN/ULC-S134 "Standard Method of Fire Test of Exterior Wall Assemblies" which is precribed for specific exterior walls due to construction requirements or spatial separation requirements. This list of assemblies include wall assemblies incorporating CLT. Another simple alternative solution would be to demonstrate that the use of NLT in lieu of CLT will achieve an equivalent level of performance. This list can be found in Division B, Appendix D-6 of the NBC.

Other examples of common alternative solutions related to the use of NLT include the following:

- Exterior canopies using NLT in buildings required to be of noncombustible construction;
- NLT roofs of two-storey portions of higher buildings required to be of noncombustible construction; and
- NLT construction in small areas of buildings required to be of noncombustible construction.

Successful implementation of non-standard NLT panels may be achieved without major conservatism through the use of alternative solutions. Refer to Applied Example: Alternative solution for fire-resistance rating of NLT floors for an example of where this was successfully achieved.

Applied example

Alternative solution for fire-resistance rating of NLT floors

The Exchange, Kelowna, BC

Project context and code approach

The Exchange is a four storey sprinklered building of combustible construction, designed to include assembly, office, retail, and medium hazard industrial occupancies. The building was constructed under the 2018 British Columbia Building Code with prefabricated NLT floor assemblies supported by glulam beams and columns. Based on the applicable construction Article for the building, Article 3.2.2.58, a 1-hour fire-resistance rating was prescribed for floor assemblies and loadbearing elements.

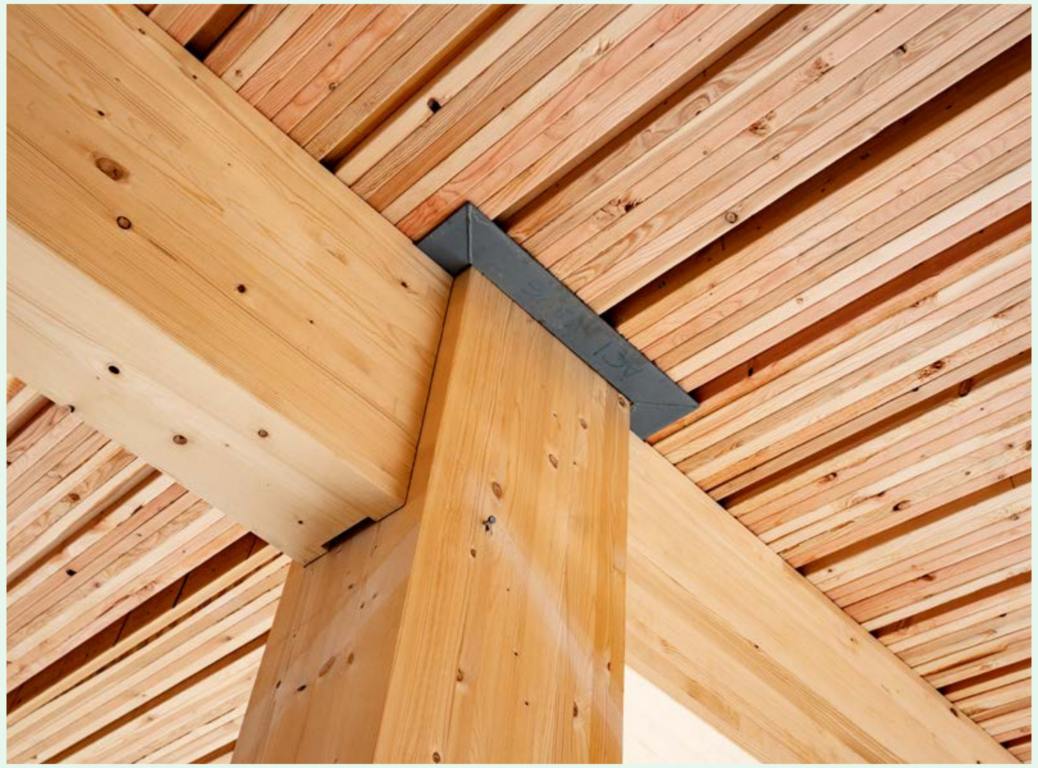
The NLT proposed has a unique fluted profile designed such that for every seven pieces of 2×8 dimension lumber, there is one 2×6 member. This creates a flute depth of about 38 mm raised above the bulk of the underside plane of the NLT floor system. The proposed assembly consists of the following components:

- 38 mm concrete topping
- 19 mm plywood/OSB sheathing
- Acoustic mat
- Fluted NLT assemblies with a maximum thickness of 185 mm (2x8) and a minimum thickness of 140 mm (2x6)

The issue

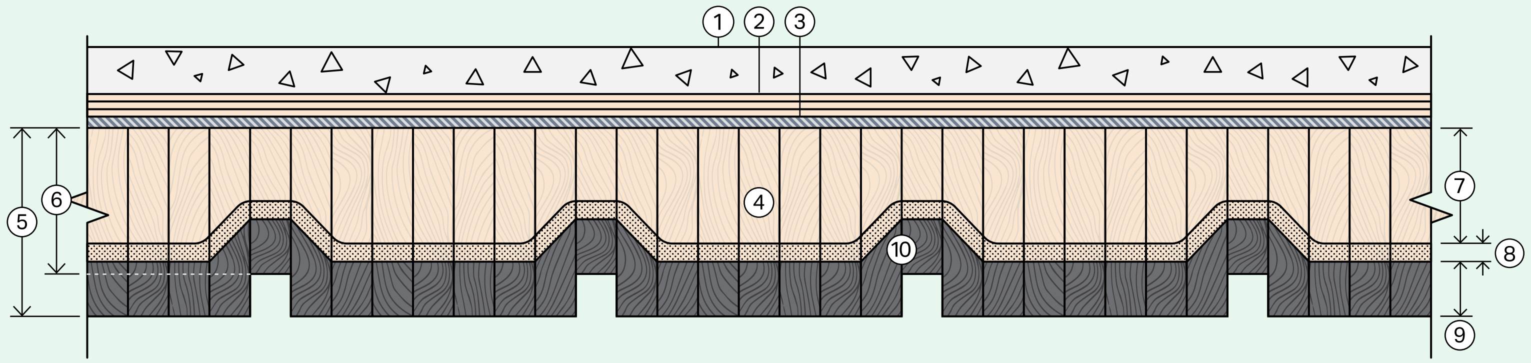
The prescribed code solutions for determining fire-resistance ratings do not address unique configurations such as the fluted section proposed for this project. The BC Building Code provides two acceptable solutions for determining the fire-resistance rating for the NLT floor assemblies: rely on assemblies tested to CAN/ULC S101 or use methods outlined in Appendix D.

Appendix D permits the use of the minimum sizes for solid wood floors noted in Appendix D-2.4 of the Building Code or calculations based on Annex B of CSA O86. Appendix D, Table D-2.4.1 (refer to NBC excerpt in **Table 3.1** of this guide) prescribes a minimum 165 mm of solid wood with building paper and finish flooring to achieve the prescribed 1-hour fire-resistance rating. This provision does not specifically address the fluted condition of this project's floor assemblies. Therefore, the fire-resistance rating of the fluted floor assembly would have to be conservatively determined based on the minimum thickness of 140 mm, while ignoring the extra depth provided by the 2x8 dimension lumber which form the bulk of the assembly. An engineering approach was therefore proposed by alternative solution based on published fire test reports on NLT [03] [06] and calculation methods established in CSA O86.



Above The Exchange, Kelowna, BC
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

Figure 3a Charred NLT cross-section for grouped, deep laminations



1. Continuous air barrier such as concrete topping (38 mm)
2. Plywood/OSB diaphragm sheathing (19 mm)
3. Acoustic mat
4. Fluted NLT panel
5. Initial flat NLT depth (2x8)
6. Initial staggered NLT depth of shallow lams (2x6)
7. Remaining NLT depth
8. Zero-strength layer
9. Design char depth per alternative solution
10. Char depth with effect of corner rounding at fluted section

Solution

The alternative solution approach was based on a char rate of 0.8 mm/min per data from the previously noted fire tests. The char depth was assumed to be largely one-dimensional, while accounting for corner rounding at the fluted grooves as shown in **Figure 3a**. The structural engineer then calculated the structural capacity of the residual floor assembly to demonstrate that the fire loads could be sustained following exposure of the floor assembly to a 1-hour standard fire.

Moisture control during manufacturing and the site installation process was also a significant consideration for this alternative solution because the char rate of 0.8 mm/min is dependent on keeping gaps between laminations to no more than 2 mm [06].

Right Tsleil-Waututh Administration and Health Centre, North Vancouver, BC
Architecture by Lubor Trubka Associates Architects *Photo courtesy of* NaturallyWood
Photo credit Dr. Roman Trubka

Complex alternative solutions

Complex alternative soltuions would typically involve relatively more significant deviation from the solutions prescribed in Division B and may involve several building systems. There is no established boundary between simple and complex alternative solutions. However, complex alternative solutions would typically require more detailed risk analysis and may require fire testing or the use of fire modelling tools to demonstrate that a minimum level of performance is achieved. An example of a complex alternative solution would be the use of NLT firewalls due to the prescribed definition requiring a firewall to be of noncombustible construction. CLT firewalls have been successfully tested and shown to provide adequate fire performance. NLT may similarly be used for the construction of firewalls. Attention will need to be paid to gaps between laminations and between panels to limit smoke and flame transport horizontally through the NLT lumber boards and upward along the boards. Membrane protection at both sides of the wall may be required.

Examples of other alternative solutions that may be considered as complex include the following:

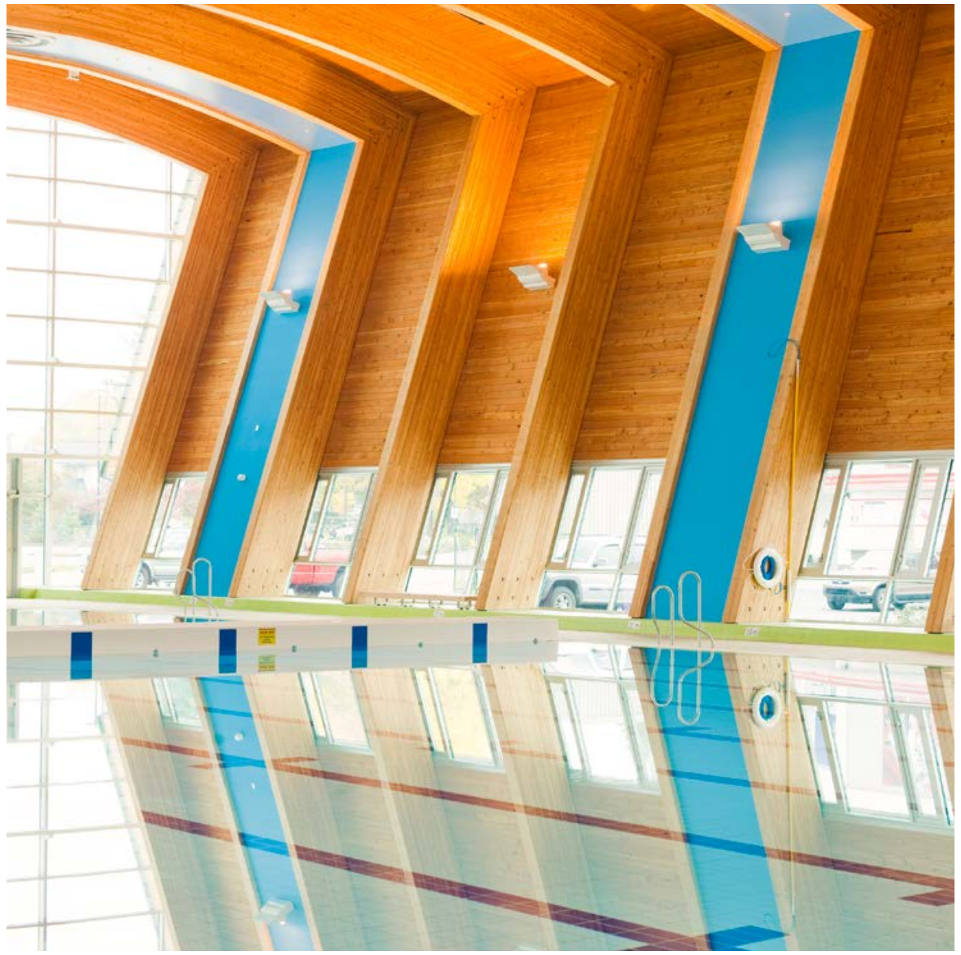
- Use of NLT for the construction of a building of assembly occupancy with three or more storeys.
- Exposed NLT assemblies beyond that permitted under EMTC provisions.

The process for such more complex alternative soluions is similar to that required for simple alternative soltuions. Early engagement with the AHJ would be more critical in this case and peer review is more likely to be required. Guidance on peer review can be found in the EGBC "Guide To The Standard For Documented Independent Review Of High-Risk Professional Activities Or Work" [11].

3.3.3 Performance-based alternative solutions

The NBC is an objective-based code, and AHJs expect that alternative solutions will demonstrate that the minimum level of performance required by the NBC in the areas described by the objective and functional statements are met. This process typically requires the level of performance provided by the alternative solution to be compared to that provided by the provisions of the acceptable solution. In certain cases, however, the proposed alternative is so significantly outside the acceptable solutions of the building code that a separate approval process other than described at Division C Section 2.3 may be required. This process typically occurs at the provincial level. In such cases, the whole building may be analyzed to demonstrate that an acceptable level of performance is provided. This may include analysis of design objectives not necessarily addressed in the NBC. The approval process for such an alternative solution may vary between provinces; for example, in BC, there is an option for approval through Site-Specific Regulation approved by Ministerial Order. The Tallwood House at Brock Commons, an 18-storey student residence of fully encapsulated mass timber construction located on the University of British Columbia campus in Vancouver, BC, was approved through a Site-Specific Regulation developed by the provincial government's Building and Safety Standards Branch. The Site-Specific Regulation was authorized by the provincial Building Standards and Safety Act and approved by the minister responsible for housing in BC.

The performance-based approach should be based on agreed-upon performance goals and objectives, engineering analysis, and assessment of alternatives against design goals and objectives using accepted engineering tools, methodologies, and performance criteria. This process may involve analysis from first principles of fire dynamics, risk analysis, computer modelling, and fire testing, and often involves a third-party peer review. In such cases, the AHJ should be engaged early in the design process to minimize impact on a project timeline.



Above Hilcrest Aquatics Centre, Vancouver, BC
Architecture by hcma *Photo courtesy of* hcma

The performance-based approach may be especially useful in the design of tall buildings using NLT. Due to the inherent openings that may exist between NLT laminations, special considerations may be required to address smoke movement, interior finish and flame-spread requirements, scissor stair design, and elevator design among other considerations.

While the use of NLT is not uncommon in Canada, performance-based design is. A performance-based design guide can be helpful to inform both designers and reviewers of the principles of such an approach.

Examples of performance-based design guides and resources include the following:

- Technical Guide for Design and Construction of Tall Wood Buildings in Canada [07]
- Appendix D of the NBC
- SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings [12]
- ICC Performance-Based Code for Buildings and Facilities [13]
- International Fire Engineering Guidelines [14]
- National Performance Based Design Guide [15]
- Series of ISO standards and technical reports, such as ISO 23932-1, ISO 16733-1, ISO 16733-2, ISO/TR 16576, ISO/TR 24679-1 and ISO/TR 24679-5 [16]
- Joint Professional Practice Guidelines - Encapsulated Mass Timber Construction Up To 12 Storeys [09]
- Guide To The Standard For Documented Independent Review Of High-Risk Professional Activities Or Work [11]

3.4 Additional considerations

3.4.1 Connections

Where the NBC requires a fire-resistance rating for elements of the building structure, vertical-load-resisting (i.e. gravity) connections are required to be protected to provide a fire-resistance rating which is at least the same as the rating for the structural elements they connect. Examples include burying of connections within the structural wood member, providing sacrificial wood to cover connections, or installing gypsum board protection or other approved materials. Connections may also be designed by direct connection of the wood members with no fasteners. Such connections must be evaluated for performance in fire. Refer to **Figures 3.8, 3.9,** and **3.10** for examples of some of these connection types. Historically, heavy timber connections for massive wood members were composed of exposed steel or cast iron that also served as column caps for load distribution [07]; refer to **Figures 3.11** and **3.12**. Additional information and design guidelines can be found in Chapter 8 of the Fire Safe Use of Wood - Global Design Guide [17].

Where NLT is used to conform to combustible construction providing a fire-resistance rating of 45 minutes and conforms to the definitions of heavy timber construction, the NBC recognizes that protection of steel connections is not warranted.

Where NLT is used for fire-resistance ratings exceeding 45 minutes, connections must be protected or tested to demonstrate the required fire-resistance is achieved. In some cases, failure of the connection will not cause collapse, and protection of the connection may not be required; for example, no fire-resistance is required for connections of elements that provide only lateral load resistance. Careful review is required for connections between steel columns and mass timber members, especially where exposed lateral members are in contact with protected gravity connections. Thermal analysis may be required in such situations.

Figure 3.8 Internal steel plate connection buried within wood member
Photo courtesy of FPInnovations

Figure 3.9 Internal plate and concealed fasteners
Photo courtesy of FPInnovations

Figure 3.10 Timber floor steel column
Photo courtesy of Fast + Epp

Figure 3.11 Structural connection with column cap at the Landing Building
Photo courtesy of GHL Consultants Ltd.

Figure 3.12 Structural connection with column cap at the Leckie Building
Photo courtesy of FPInnovations

3.4.2 Penetrations

Modern buildings typically contain an array of services that penetrate fire- resistance-rated elements of the structure such as walls, floors, and shafts. Where penetrations exist in fire-resistance-rated construction, the NBC 2020 requires them to be cast-in-place or protected with firestop systems which have been tested to CAN/ULC S115. Some provincial codes, such as those in BC and Ontario, also permit penetrations to be "tightly-fitted." Where tested/listed firestop systems are not available, the use of custom firestop systems may require review by a Professional Engineer. Some provinces may require that the engineering judgement by sealed by a Professional Engineer. Further guidance is found in the Engineers and Geoscientists BC Practice Advisory titled, *Engineering Modifications to Fire-Tested and Listed Assemblies* [23].

For exposed wood in general, fire testing has shown the importance of insulating the wood from metal penetrations, as the hot metal can cause increased charring at the penetration and allow passage of hot gasses and smoke [18]. There are limited tested or listed firestop systems for NLT; however, designs tested for CLT can reasonably be expected to perform similarly in NLT. The movement of NLT due to expansion and shrinkage will need to be considered when firestops tested for CLT are used for NLT; sealants typically used as part of such firestop systems should have the expansion capacity for the movement anticipated

Experience with testing of penetrations in CLT has shown in order to limit the probability of increased charring due to metal pipes or fittings in contact with timber, the metal penetrants must be separated from the wood by a minimum of 12 mm (0.5 in.) of mineral wool. Refer to the latest edition of the CLT Handbook [19] and the EGBC- AIBC Joint Practice Guide for EMTC [09] for additional details on penetration protection.

Similar experience with CLT testing has shown that plastic pipe penetrations must account for the effect of charring and receding of the slab depth; firestopping materials typically cannot be located on the underside of a timber floor as gaps may open above the firestop material as the timber chars and provide an avenue for fire spread.

Joints built into NLT to accommodate swelling during construction must also be firestopped (refer to Chapter 4 for more).

3.4.3 Concealed spaces

The NBC definition of heavy timber construction assumes the avoidance of concealed spaces under floor and roof assemblies. While NLT may not inherently include voids or concealed spaces, concealed spaces may be created when NLT is used as part of EMTC assemblies where nailing elements for the attachement of the encapsulation materials may create void spaces, or when used with dropped ceilings, furred walls, or raised floors . Subsection 3.1.11 of Division B of the NBC 2020 addresses the protection of concealed spaces through the use of fire blocks to limit the size of any concealed space and Articles 3.1.6.3 and 3.1.6.16 address the protection of concealed space for EMTC assemblies. Notwithstanding the NBC provisions, additional protection may be required to limit the probability of fire spread in concealed spaces, depending on the sprinkler standard applied. In general, buildings sprinklered to NFPA 13 require sprinkler protection in concealed spaces unless other conditions outlined in NFPA 13 are met, or an acceptable engineered alternative solution is developed.

In general, voids and concealed spaces require sprinkler protection under the following conditions, as outlined by NFPA 13:

- When sprinkler protection is required per code (based on the height, area, number of stories, fire-resistance requirement, etc.);
- In cavities up to 4.5 m3 (160 ft3) that do not contain fire blocking or fire stopping; and /or,
- When the cavity is not filled with noncombustible insulation.

Notable exceptions include:

- Certain residential buildings where NFPA 13R is the permitted sprinkler standard; or,
- Where the fire blocking is equal to material used in NLT.

3.4.4 Construction fire safety

Fire safety during construction is not an objective of the NBC. It is regulated by the National Fire Code (NFC) and is typically the responsibility of the general contractor. However, for buildings more than four storeys in building height, including EMTC buildings, and for buildings with complex alternative solutions and performance- based designs that include an extensive use of wood beyond typical applications, it is worth integrating fire safety during construction as part initial design considerations.

The NFC currently has special protection requirements for EMTC buildings over four storeys outlined in its Division B, Subsection 5.6.4. These provisions include the requirement to encapsulate a significant portion of the mass timber walls and floors for all but the four uppermost storeys as construction progresses. Additionally, a minimum of two protected exit stairs need to be extended as each storey is constructed, and charged standpipes and refuse control is required. The intent of these measures is to limit the potential for fire spread within and between storeys which could lead to a large fire which threatens adjacent buildings. It is anticipated that the NBC 2025 will include modifications to these requirements. In the meantime, alternate approaches for protection during construction other than the encapsulation criteria currently prescribed by the NBC 2020 have been successfully proposed for several mass timber projects through the alternative solutions process.

Examples of resources that guidance on fire safety during construction and which may inform initial design considerations are:

- Division B Part 8 of the NBC, "Safety Measures at Construction and Demolition Sites."
- Division B Section 5.6 of the National Fire Code.
- NFPA 241, "Standard for Safeguarding Construction, Alteration, and Demolition Operations" [20].
- Technical Guide for Design and Construction of Tall Wood Buildings in Canada [07].
- Fire Safety During Construction for Five and Six Storey Wood Buildings in Ontario: A Best Practice Guideline [21].
- Construction Site Fire Safety: A Guide for Construction of Large Buildings [22].
- Municipal bulletins on construction fire safety.

Right The Exchange, Kelowna BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

Chapter 3.0 references

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4.0 Structure

4.0 Structure

Nail-laminated timber (NLT) is a system that typically spans in one direction to resist out-if-plane loading, or in some cases are implemented as walls. Although its monolithic nature makes it a mass timber system rather than a joist system, it can be conceptualized structurally as dimension lumber joists spaced at the joist width (e.g., for 2x material, joists spaced at 38 mm (1-1/2 in.). NLT can consist of any species, grade, and sizes of dimension lumber. Floors and roofs are typically sheathed on the top side with plywood/OSB to carry in-plane shear caused by lateral loads.

The strength and serviceability of NLT systems for both gravity and lateral loads must meet the minimum requirements of applicable codes and standards. Given timber's high strength-to-weight ratio, serviceability requirements such as deflection and vibration often govern the design of NLT floors. Designing for fire-resistance may also be a governing factor.

The guidance in this chapter is specific to NLT. The reader is assumed to have a general working knowledge of wood properties, and design procedures according to CSA O86, the Canadian standard for Engineering design in wood. CSA O86 clause references in this chapter refer to the 2024 edition. CSA O86:24 has introduced a new clause for Mechanically Laminated Timber (MLT) in CL 8.2, which provides guidance specific to the design of certified M-NLT as described in the introduction to this guide. Not all NLT is or can be classified as M-NLT, and in many cases M-NLT is not required, and simple NLT would be acceptable or even preferred. Both NLT and M-NLT can be designed to meet the requirements of CSA O86 depending on form and application. The choice of requiring either M-NLT or NLT, or allowing either option, has both architectural and fire considerations (refer to Chapters 2 and 3 for more detail) and should be evaluated and coordinated with other consultants on any project. The approach to specifying the NLT and/or M-NLT requirements for a specific project is discussed in greater detail in Section 4.6.

Right East Village Presentation Centre, Calgary, AB
Architecture by James KM Cheng *Photo courtesy of* StructureCraft

4.1 Gravity load design procedures

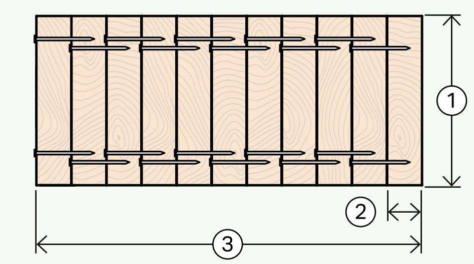
For gravity load resistance, treat NLT or M-NLT as a built-up beam or built-up column as shown in **Figure 4.1**. For floors/roofs and walls follow the respective provisions in CSA O86. Strength design is outlined in CL 8.2 for M-NLT, and in clause 6.5.10.3 for NLT. The calculated resistance of the panels must meet or exceed the applied design loads.

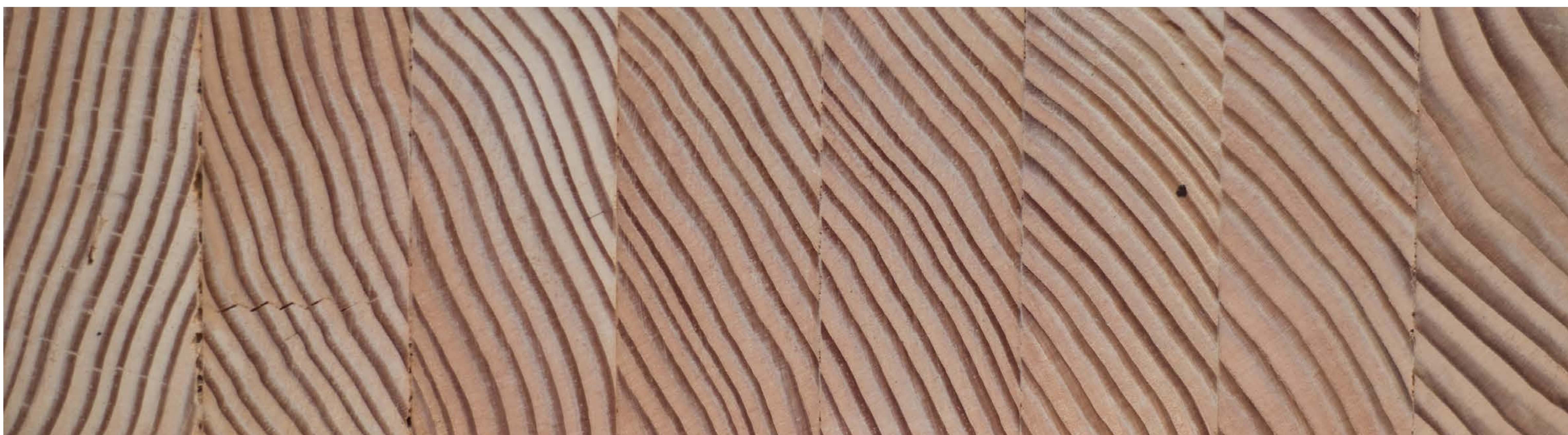
As discussed in Section 2.5.3, moisture exposure conditions, either in service or in construction, can significantly impact both the strength and the long-term deflections of NLT/M-NLT, and affect durability. Vibrations can govern the design and should be checked when NLT/M-NLT is used for floors or occupied roofs. Where it is exposed and required to meet certain fire-resistance ratings, determine post-fire capacities in accordance with the procedures outlined in Chapter 3 and Section 4.2.

Panels layups can be set to support each lamination at all supports or can use staggered butt joints throughout the panel to meet the requirements of CSA O86. Similarly, wall panels can be designed to terminate all laminations at each level, or where multi-level continuous walls exist, laminations can either be supported at all levels, or can use staggered butt joints to meet the requirements of CSA O86. Strength and stiffness reduction factors for staggered butt jointed panels are discussed in greater detail in Section 4.1.1.

Figure 4.1
NLT cross-section

1. NLT depth (d)
2. Lamination thickness (b_{lam})
3. NLT panel width (b)





4.1.1 Design modification factors

Use modification factors for the design of NLT and M-NLT from CSA O86. Factors applicable for M-NLT are described in CSA O125 and CSA O86 CL 8.2, and factors for NLT are described in CSA O86 CL 6. Guidance provided here describes the similarities and differences in factors for NLT and M-NLT, and how to apply them. Where factors are not included here, such as load-duration factor and treatment factor, application does not differ from CSA O86 guidance for sawn-lumber construction.

Service factor K_S

NLT and M-NLT should be used in dry-service conditions. Wet-service conditions are not advisable in any situation, and explicitly not permissible for M-NLT. Where systems are appropriately protected from rain but exposed to humidity changes, such as roof overhangs or canopies, they are considered sufficiently protected to be designed as a dry-service condition, provided they are also protected from wind driven rain.

System factor K_H

For both M-NLT and NLT, the use of system factor, K_H, will vary for continuous (i.e. laminations supported on all supports) or butt jointed laminations , refer to **Table 4.1**.

Table 4.1 NLT and M-NLT system factors

Layup type	System factor (K_H) for bending moment and shear resistance	System factor (K_H) for other properties
Continuous laminations	1.1	1.0
Butt jointed laminations (any pattern)	1.0	1.0

Size factor K_Z

Use lumber size factors per CSA O86 to determine the size factor, K_Z, for M-NLT or NLT. For panels composed of laminations with more than one size, the size factor, K_Z, is based on the deepest lamination. For bending and shear, refer to CSA O86 CL 6.4.5 to determine the size factor.

The size factor for compression resistance parallel to grain is not directly addressed in CSA O86 for NLT or M-NLT. The size factor calculation is based on the guidance for sawn lumber members per CSA O86 CL 6.5.5.

$$K_{Zc} = 6.3\,(dL)^{-0.13} \leq 1.3$$

where

d = cross-section dimension of the NLT in the direction of buckling, mm

L = length of lamination, mm

The cross-sectional dimension considered depends on the governing buckling consideration. for more discussion on the buckling orientation refer to the Slenderness Factor, K_c section of this guide.

Layup factor (K_{layup})

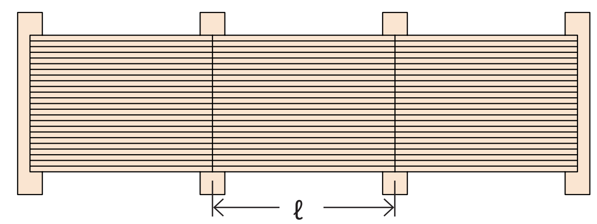
M-NLT and NLT have two additional modification factors: a layup factor, K_{layup}, to account for different lamination lengths and layups; and a section factor, $K_{section}$, to account for panels with laminations of varying depth. The layup factor accounts for panels with staggered layups using butt joints between supports. This type of panel is often used to allow for longer panel fabrication without a requirement for finger jointing and is a common approach to reduce the cost of NLT or to accommodate site-built NLT, because it permits use of a variety of lumber lengths (refer to Chapters 6 and 7 for more details). However, these modified layups result in reduced strength and stiffness that must be accounted for in design.

Refer to Table 4.2 for layup types and the associated modification factors for bending (b), shear (v), stiffness (E) for both M-NLT and NLT defined in CSA O86. The design of NLT or M-NLT panels under axial loading is not specifically addressed in O86. In the absence of better information, layup factors for axial loads (c) are provided assuming only those laminations continuous between supports (i.e. each floor) are engaged; this same approach was used in the standard to develop the shear layup factor.

Table 4.2 NLT layup types with adjustment factors

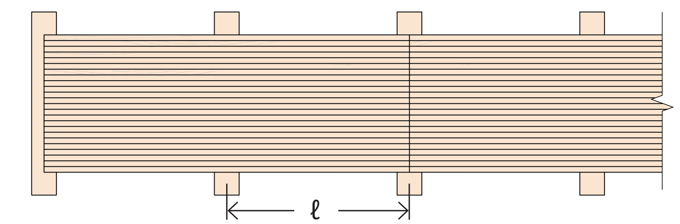
NLT - 1	$K_{layup, E}$	$K_{layup, b}$	$K_{layup, v}$	$K_{layup, c}$
NLT and M-NLT	1.0	1.0	1.0	1.0

- All Laminations are continuous and single span.
- No butt joints within panels.
- Panels abut at supports.



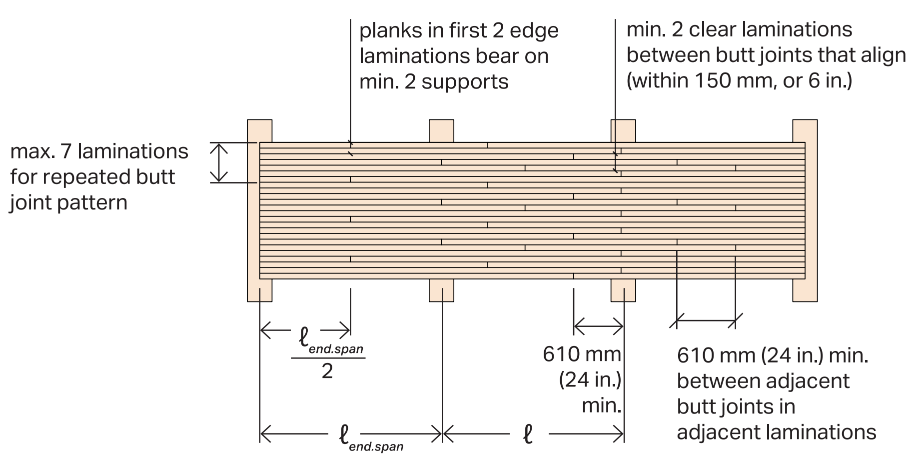
NLT - 2	$K_{layup, E}$	$K_{layup, b}$	$K_{layup, v}$	$K_{layup, c}$
NLT and M-NLT	1.0	1.0	1.0	1.0

- All laminations are continuous over multiple supports.
- No butt joints within panels.
- Panels abut at supports only.



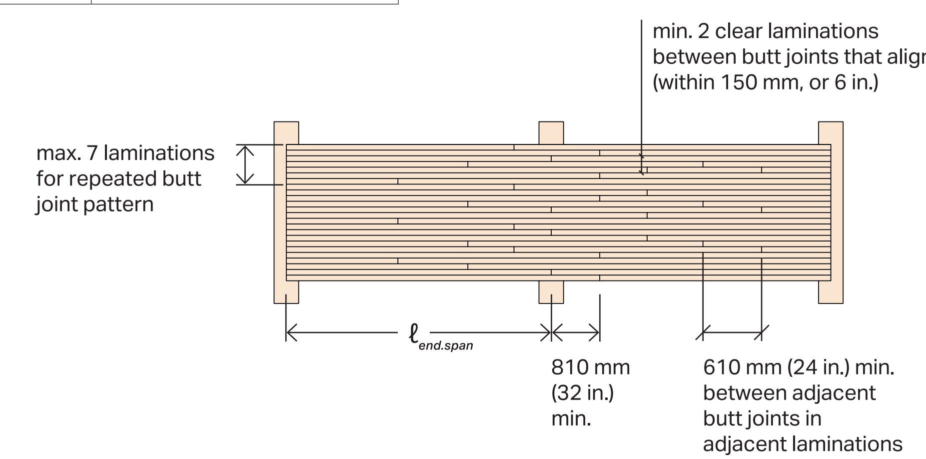
NLT - 3	$K_{layup, E}$	$K_{layup, b}$	$K_{layup, v}$	$K_{layup, c}$
M-NLT	0.7	0.8	0.67	0.57
NLT	0.69	0.8	0.5	0.57

- Laminations have controlled random pattern with but joints at and between supports.
- Panels are continuous over four or more supports.



NLT - 4	$K_{layup, E}$	$K_{layup, b}$	$K_{layup, v}$	$K_{layup, c}$
M-NLT	0.65	0.8	0.75	0.57
NLT	$0.044 \frac{1}{s^{0.2}} \left(\frac{L}{d}\right)^{0.9}$ = 0.38	$0.29 \frac{1}{s^{1/9}} \left(\frac{L}{d}\right)^{0.25}$ = 0.38	0.65	0.57

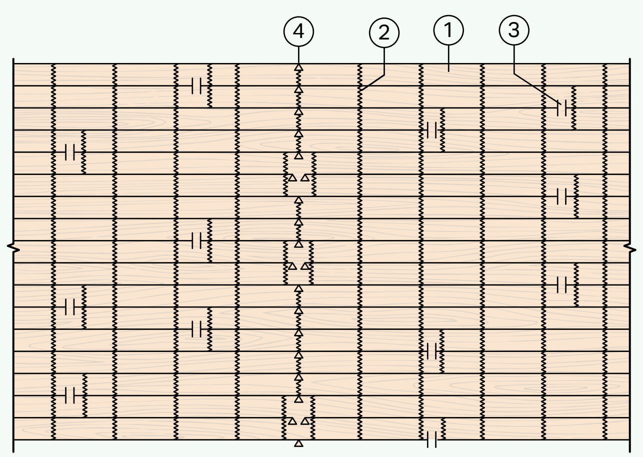
- Laminations have controlled random pattern with butt joints at and between supports.
- Panels are continuous over three supports.



- For NLT of type NLT-4, conservative values for bending and deflection factors are applied compared to M-NLT; the NLT factors are developed from research without tight fabrication controls, [01], [02]. The calculated factors provided represent L/d = 25, and s for a 2x4 NLT-4 system. Note that these factors are beyond the scope of CSA O86.
- The factors for NLT of type NLT-3 meet the requirements of CSA O86 for nailed laminated decking, generally in alignment with the M-NLT factors.

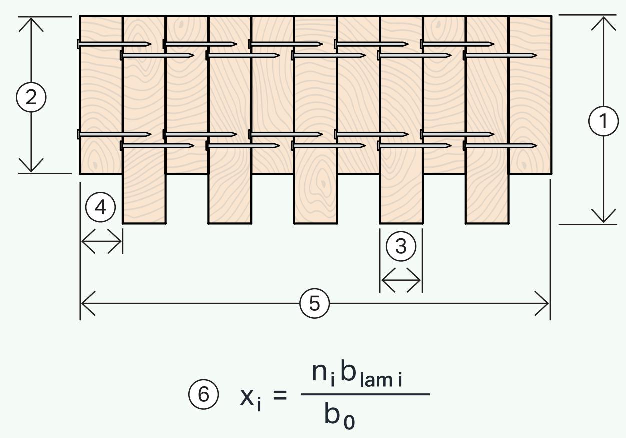
Additional layup types are also possible but complex for both NLT and M-NLT. For M-NLT where alternate layups are proposed, CSA O125 provides guidance for testing as well as effective bending, stiffness, and strength approaches for the development of alternate layups. For NLT, alternate butt-spliced NLT layups are theoretically possible but should be approached with care; they could be developed through a finite element analysis using a grillage model. Refer to **Figure 4.2** for a grillage model illustration where the laminations are modelled as beam members and connected with shear springs representing the nails. For more detail on the development of this kind of model, including appropriate nail spring stiffness values, refer to Kramer and Haller research [01], [02], [03].

Figure 4.2
Grillage model



1. NLT lamination (modeled as beam element)
2. Spring between lams representing nails (model stiffness to match nail shear behaviour)
3. Break in lamination at butt joint (modeled without connection to lam within the course)
4. Support location (modeled as pin supports at each lam)

Figure 4.3
Staggered NLT cross-section



1. NLT deep lamination depth (d_1)
2. NLT shallow lamination depth (d_2)
3. NLT deep lamination thickness ($b_{lam}1$)
4. NLT shallow lamination thickness ($b_{lam}2$)
5. NLT panel width (b_0)
6. Ratio of lamination depths (x_i), where n_i = the number of laminations of depth d_i

Table 4.3
Staggered NLT adjustment factors

Stiffness	Bending moment	Shear	Bearing	Axial
$K_{section,\,E}$	$K_{section,\,b}$	$K_{section,\,v}$	$K_{section,\,cp}$	$K_{section,\,c}$
$x_1 + x_2\left(\frac{d_2}{d_1}\right)^3$	$x_1 + x_2\left(\frac{d_2}{d_1}\right)^2$	x_1	x_1	$x_1 + x_2\left(\frac{d_2}{d_1}\right)$

d_i = depth of lamination i, mm $\qquad x_i = \frac{n_i b_i}{b_0}$

where
n_i = number of laminations with depth d_i over the width of MLT panel b_0
b_i = thickness of lamination i, mm
b_0 = width of MLT panel measured perpendicular to the panel length direction , mm
i = 1 for the deep lamination, 2 for the shallow lamination

Section factor ($K_{section}$)

The section factor, $K_{section}$, is the second factor specific to NLT. This factor applies to M-NLT and NLT panels with variable cross-sectional depth. This type of panel may be used for architectural or acoustic effect or to accommodate finish requirements, as discussed in Chapter 2. A common example of a staggered NLT cross-section with two alternating lamination depths is shown in **Figure 4.3**, though any number of depths and patterns can be used.

For these cross-sections, the variation in depth of the laminations is more structurally complex than it initially appears. The nails do not provide sufficient stiffness to create a fully composite system with all laminations reaching their maximum bending resistance. Summing the resistance of all the laminations (deep and shallow) is therefore not conservative. Instead, when the deeper laminations reach their full resistance, only a portion of the shallower lams' strength is engaged, based on their relative stiffnesses. CSA O86 provides an approach for the calculation of these factors considering the non-composite action and effective stiffness of the different lamination for bending resistance and stiffness shown in **Table 4.3**. The shear strength factor effectively assumes only the deepest laminations carry the shear load; this approach is conversative but as shear rarely governs this should not impact design overall. The bearing factor also assumes only the deepest laminations are consistently in full contact with the support; if blocking is provided this may also be overly conservative if it can be ensured that the blocking will remain a tight fit in all locations; this is generally not a design concern as the bearing will likely not govern. Finally, the axial layup factor accounts for the gross area of all laminations, effectively assuming an even distribution of load between all laminations.

The modification factor $K_{section}$ is always less than 1.0 for staggered NLT and is intended to modify stress and stiffness calculations based on the deeper laminations (i.e. flat NLT with a constant depth of "d_1"). For M-NLT or NLT using more than two lamination depths, the shallowest laminations, with the smallest contribution, may be ignored effectively creating a narrower panel, or a similar approach based on relative stiffnesses can be developed.

Lateral stability factor (K_L)

For NLT and M-NLT using the lateral stability factor, K_L, for bending is considered differently. M-NLT panels can ignore the lateral stability factor outright, effectively assuming it to always be 1.0. Comparatively for NLT panels, the lateral stability factor should be considered but will be taken as 1.0 in most cases. For NLT in any condition where the sheathing is directly fastened to the compression edge of the laminations, they can be considered laterally braced, and the stability factor can be taken as 1.0.

Similarly, if sheathing is held away from the panel, but sufficient blocking is provided between the sheathing and the laminations, the stability factor can still be taken as 1.0. For unrestrained conditions, NLT fabricated with typical 2x dimension lumber can take the lateral bracing factor, K_L, as 1.0 in the following conditions per **Table 4.4** (as described in CSA O86 CL 6.5.3.2). The cases presented do not include blocked conditions which can accommodate unsheathed NLT to depths up to 286 (2x12). These conditions could be achieved with strapping on top of the NLT or similar conditions, but are not discussed in depth here. In rare cases where the lateral-stability factor, K_L, cannot be taken as 1.0 as described above, the factor should be calculated like any other sawn lumber member, with the width taken as the width of the narrowest individual lamination, regardless of nailing, and the depth taken as the deepest lamination.

Table 4.4 Panels where laminations are considered restrained without sheathing

Lateral restraint condition for 38 mm laminations	**Maximum panel/lamination depth (CL 6.5.3.2.1)**	
Fully unrestrained	90 mm	2 x 4
Restrained at supports only	140 mm	2 x 6

Slenderness factor (K_C)

For the design of M-NLT, axial resistance is beyond the scope of the existing CSA O125 and CSA O86 CL 8.2. Similarly it is not directly addressed for NLT in CSA O86 CL 6.5.10. To design for axial resistance of portions or entire panels of M-NLT or NLT, slenderness factors (K_c) are needed. In general, the design and evaluation of appropriate modification factors references the O86 evaluation for sheathed stud walls and built-up compression members for guidance per CSA O86 CL 6.5.5, with the addition of relevant NLT/M-NLT factors.

Where sheathing is provided fastened to at least one face of the panel, NLT or M-NLT laminations can be considerer braced against weak axis buckling, similar to a sheathed light-wood framed wall. Only buckling about the strong axis of the panel (ie. panel width, b_0) or weak axis of the panel (ie. panel depth, d) need be considered, although buckling about the panel depth will nearly always govern.

For buckling about the weak axis of the panel the slenderness ratio (C_{Cd}) is determined based on the effective lamination length between supports (L_e), and the depth of the deepest lamination (d_1). These values must be modified by both the section and layup factor which inform the geometry of the panel. The slenderness factor (K_{Cd}) is then calculated per CSA O86 CL 6.5.5, with the addition of section and layup factors.

For buckling about the strong axis of the panel (ie. panel width (b_0) specific modifiers for the NLT or M-NLT section and layup need not consider as they relate to the geometry and stiffness about the panel depth (d) only.

$$C_{C.b\_wall} = \frac{L_e}{b_{wall}} < 50$$

$$K_{c,b\_wall} = \left[1.0 + \frac{F_C K_{ZC} \left(C_{Cb\_wall}\right)^3}{35\left(E_{05}\right) K_{SE} K_T}\right]^{-1}$$

$$\frac{C_{Cd}}{K_{section,E}} = \frac{L_e}{d_1 K_{section,E}} < 50$$

$$K_{c,d} = \left[1.0 + \frac{F_C K_{ZC} K_{section,c} K_{layup,c} \left(\frac{C_{Cd}}{K_{section,E}}\right)^3}{35\left(E_{05} K_{section,E} K_{layup,E}\right) K_{SE} K_T}\right]^{-1}$$

Where sheathing is not provided to restrain individual laminations against buckling, alternate approaches are required. Panels can be considered as built-up members similar to the requirements of CSA O86 6.5.5.4. Note that the built-up provisions do limit the overall number of laminations that can be considered as a built-up member to five. To design for unsheathed NLT panels in axial loading as built up elements there are two options:

- groups of 5-lamination "panels" can be considered as individual compression elements, or
- engineering judgement may be used to extrapolate the behaviour of a wider wall.

To consider NLT panels as built-up compression elements in any case, the laminations require sufficient nailing to qualify as a built-up compression member with piece-by-peice nailing per CSA O86 CL 6.5.5.4.3. Strength reduction values called built-up factor, $K_{built-up}$ in this guide, for different lamination sizes and nailing patters are provided in **Table 4.5**.

In these cases, the individual laminations are again considered restrained, and the slenderness factor for the full wall panel width is reduced by a "built-up factor" ($K_{built-up}$) per CSA O86 seperate from the slenderness factor (K_c). The slenderness factor (K_c) would otherwise be calculated for the full wall panel calculations.

Table 4.5 Adjustment factor for built-up member ($K_{built-up}$)

Lamination size	Number of nail rows	Fastner spacing	Adjustment factor for built-up member ($K_{built-up}$)	
mm	3.0 mm nails	in a row (mm)	Visually graded lams	MSR/MEL lams
38 x 89	2	200	0.52	0.48
		300	0.42	0.38
38 x 140	2	150	0.48	0.45
		300	0.32	0.28
38 x 184	3	150	0.51	0.47
		300	0.35	0.31
38 x 235	4	150	0.47	0.45
38 x 286		300	0.32	0.28

Note: Only two of the prescribed nailing patterns (NLT-3 or NLT-4 as described in Section 4.4) for limited depths meet these requirements. The associated cases and built-up factors for 38x140 and 38x89 can be applied without specifying additional nailing. The built-up adjustment factors provided apply only where nails fully penetrate two laminations (76 mm nails) as required for M-NLT or NLT per this guide.

Left The Exchange. Kelowna BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

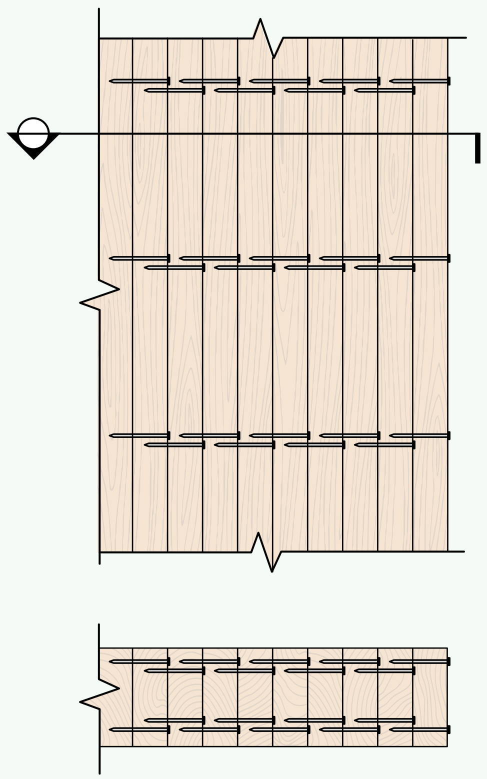


Figure 4.4a
No added buckling strength without end screws

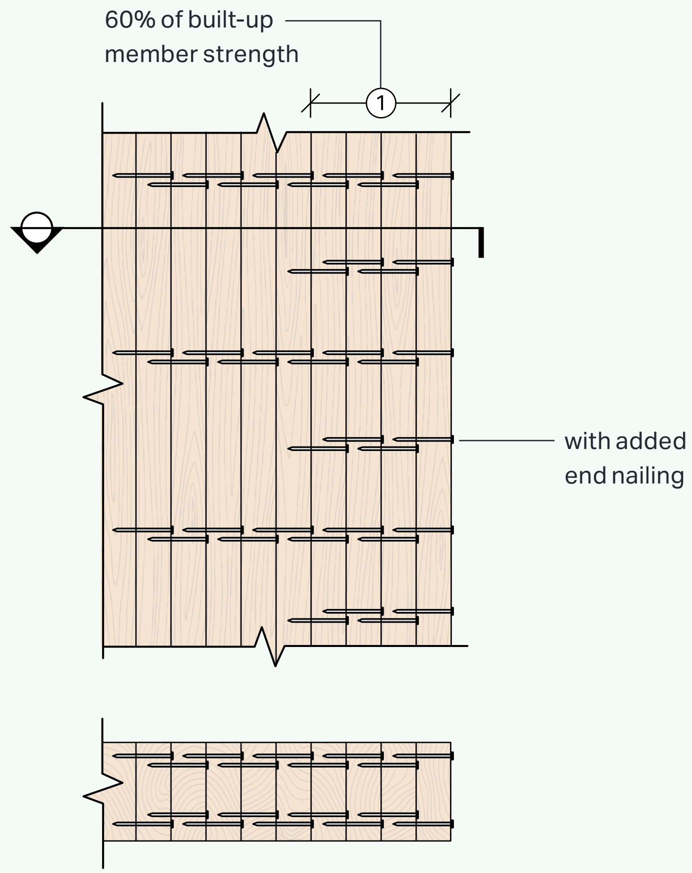


Figure 4.4b
Additional nailing for buckling restraint at edges

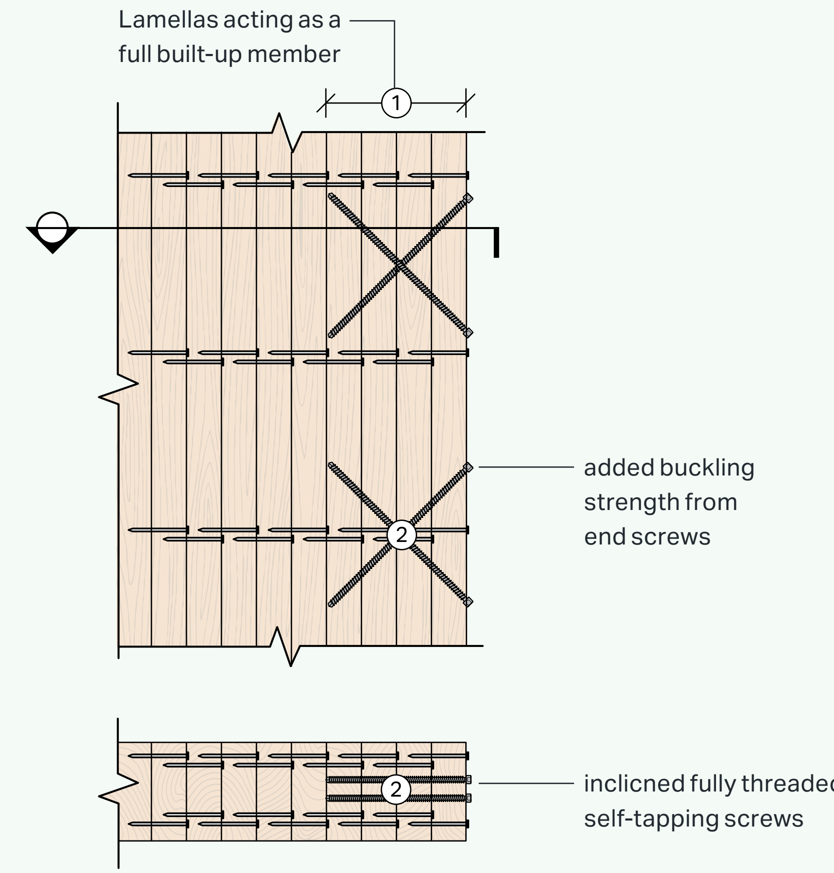


Figure 4.5
Screw connection between lamination for composite panel edge element

For cases where neither sheathing nor sufficient nailing to achieve built-up requirements is provided for example continuous lamination with minimum nailing, the simplest solution is to add additional nailing either throughout the system for uniform axial loads (i.e. walls), as shown in **Figure 4.4a** or add local additional nailing or screws where local peak axial loads are required (i.e. diaphragm chords) to achieve a built-up member, as shown in **Figure 4.4b**.

In rare cases where the above approaches are not feasible, it is possible to restrain the laminations against buckling with members at the ends of the wall/panel that is sufficiently strong and stiff in bending to restrain the cumulative buckling force of each lamination. The buckling force can be applied as a horizontal point load to the end member. The locations where the buckling force need be applied would correspond with the effective length locations required to make the wall laminations work in compression without buckling; for tall walls many buckling restraint locations may be required. The cumulative buckling force at each buckling restraint location can be estimated between 1.25% (CSA O86 CL5.5) to 2% (CSA S16) of the axial force of each lamination multiplied by the number of laminations. The full brace force must be restrained at each buckling restraint location over the height of the wall.

The wall end members could consist of either solid wood or steel members sized to resist the required bending strength and stiffness. Alternatively, consider a composite section of multiple laminations with strong and stiff connections to achieve composite action and provide a sufficiently strong and stiff composite member. The degree of composite action considered could be developed in concept with the gamma approach discussed in CL 13 for timber composite floors. Practically this would likely require inclined self-tapping screws design per CSA O86 CL 12.12 used for the connections between laminations as shown in **Figure 4.5**.

4.1.2 Resistance

Resistance design of M-NLT or NLT floors and roofs is based on CSA O86 provisions for bending moment resistance, shear resistance, and compressive resistance perpendicular to grain (bearing), and compression parallel to grain.

Bending moment

Design of M-NLT and NLT for bending follows CSA O86 provisions and should ensure the factored bending moment (M_f) is less than the factored bending moment resistance (M_{rNLT}). For M-NLT, determine the bending resistance in accordance with CSA O86 CL 8.2; for NLT develop bending based on CSA O86 CL 6 for sawn lumber with appropriate factors presented in previous sections of this guide.

M-NLT: $M_{r\,M\text{-}NLT} = \phi F_b S_x K_{Zb} K_{layup,b} K_{section,b}$

NLT: $M_{r\,NLT} = \phi F_b S_x K_{Zb} K_L K_{layup,b} K_{section,b}$

where

ϕ = Per CSA O86 CL 6.5.3
F_b = $f_b(K_D K_H K_{Sb} K_T)$
f_b = specified strength in bending, MPa (see CSA O86 Tables 6.5 to 6.10)
S_x = section modulus of a rectangular panel with depth equal to the deepest lamination, mm^3

Shear

Shear rarely governs the design of uniformly loaded M-NLT or NLT, but a review of the design approach is included here for completeness. The design of these panels for shear resistance per CSA O86 regardless of whether the panel is classified as M-NLT or NLT, ensuring the factored shear force (V_f) is less than the factored shear resistance (V_{rNLT}).

$$V_{r.NLT} = \phi F_v \frac{2A_n}{3} K_{Zv} K_{layup,v} K_{section,v}$$

where

ϕ = Per CSA O86 CL 6.5.4
F_v = $f_v(K_D K_H K_{Sb} K_T)$
f_v = specified strength in shear, MPa (see CSA O86 Tables 6.5 to 6.10)
A_n = net area of a rectangular panel with depth equal to the deepest lamination. Obtained by excluding any area removed through dapping/notching etc., mm^2

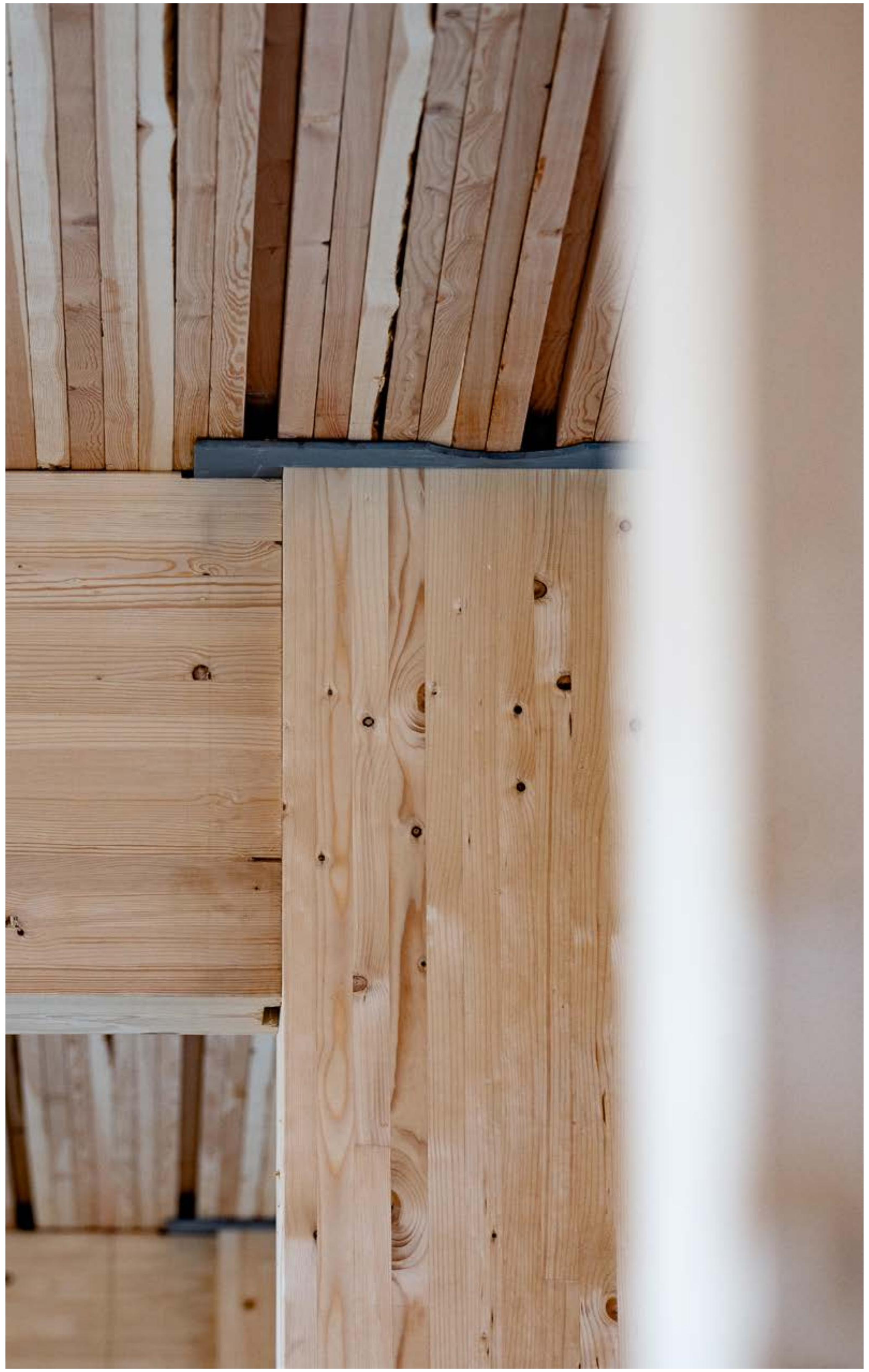
Where design of NLT includes notches, complete an additional check to evaluate the notch facture, K_N, of the panel as per CSA O86. The approach should also be reduced by the panel layup and section factors. The notch depth should never exceed 25% of the panel depth, like any other sawn lumber member.

$$F_{r.NLT} = \phi F_f A_g K_{layup,v} K_{section,v} K_N$$

where

F_f = $f_f (K_D K_H K_{Sf} K_T)$
f_f = specified fracture shear strength at notch, MPa as per CSA CL 6.5.4.4.1
K_N = Notch factor as per CSA CL 6.5.4.4
A_g = gross area of a rectangular panel with depth equal to the deepest lamination. , mm^2

Below The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood



Bearing

Bearing rarely governs the design of uniformly loaded NLT. Design NLT/M-NLT for bearing following CSA O86 provisions; ensure the factored bearing force (Q_f) is less than the factored compressive resistance ($Q_{r\,NLT}$) of the NLT perpendicular to grain. The bearing section factor ensures that bearing is only considered for those laminations in contact with the support. For NLT with a staggered cross-section that requires a fire rating, consider blocking within the gaps where bearing occurs to prevent char on the top side of the support. Refer to Chapter 3 for further discussion of char.

Where vertical elements are supported by NLT near the panel's support such as a platform framed gravity wall system with wall offsets, the effect of only the applied loads acting within the panel depth from the center of the support should be calculated following CSA O86 as shown below. For cases with staggered cross-sections, the section factor, $K_{section,cp}$, is incorporated into the average bearing area equation for the bottom of the panel only as well as the overall bearing calculation as follows:

$$Q_{r.NLT} = \phi F_{cp} A_b K_{section,cp}$$

where

ϕ = Per CSA O86 CL 6.5.6

F_{cp} = $f_{cb}(K_D K_{Scp} K_T)$

f_{cp} = specified strength in compression perpendicular to grain, MPa (see CSA O86 Table 6.5, 6.6., 6.9 and 6.10)

A_b = bearing area of a rectangular panel based with constant depth/even bearing, mm²

$K_{section,cp}$ = cross section reduction factor for variable cross section depth. taken = $K_{section,v}$

$$Q'_r = 2/3\phi F_{cp} A'_b$$

where

$A_{b'}$ = Average of top and bottom bearing areas, mm²

$$A'_b = b\left(\frac{K_{section.cp}L_{bot} + L_{top}}{2}\right) \leq 1.5b \times \min(K_{section.cp}L_{bot}, L_{top})$$

Axial compression

Design the NLT using CSA O86 provisions ensuring the factored axial compression force is less than the compressive resistance of the NLT parallel to grain. The approach is the same for both M-NLT and NLT. The design must consider a panel buckling about the weak axis of the panel (panel depth) and the strong axis of the panel (panel width) for sheathed panels or panels meeting the requirements of a built-up member as discussed in the **Slenderness factor**, K_c section of this guide.

The axial compression resistance is calculated as follows:

Axial resistance
Buckling about panel depth (d)

$$P_{r,d} = \phi F_c A_{wall} K_{zc} K_{c,d} K_{layup,c} K_{section,c}$$

Axial resistance
Buckling about panel width (b_o)

$$P_{r,b_{wall}} = \phi F_c A_{wall} K_{zc} K_{c,b_{wall}} K_{layup,c} K_{section,c} K_{built\text{-}up}$$

where

ϕ = Per CSA O86 CL 6.5.5
F_c = $f_{cb}(K_D K_{Scp} K_H K_T)$
f_c = specified strength in compression parallel to grain, MPa (see CSA O86 Tables 6.5, 6.6, 6.9, and 6.10)
A_{wall} = area of a rectangular panel with depth equal to the deepest lamination and the width of the panel in consideration, mm²

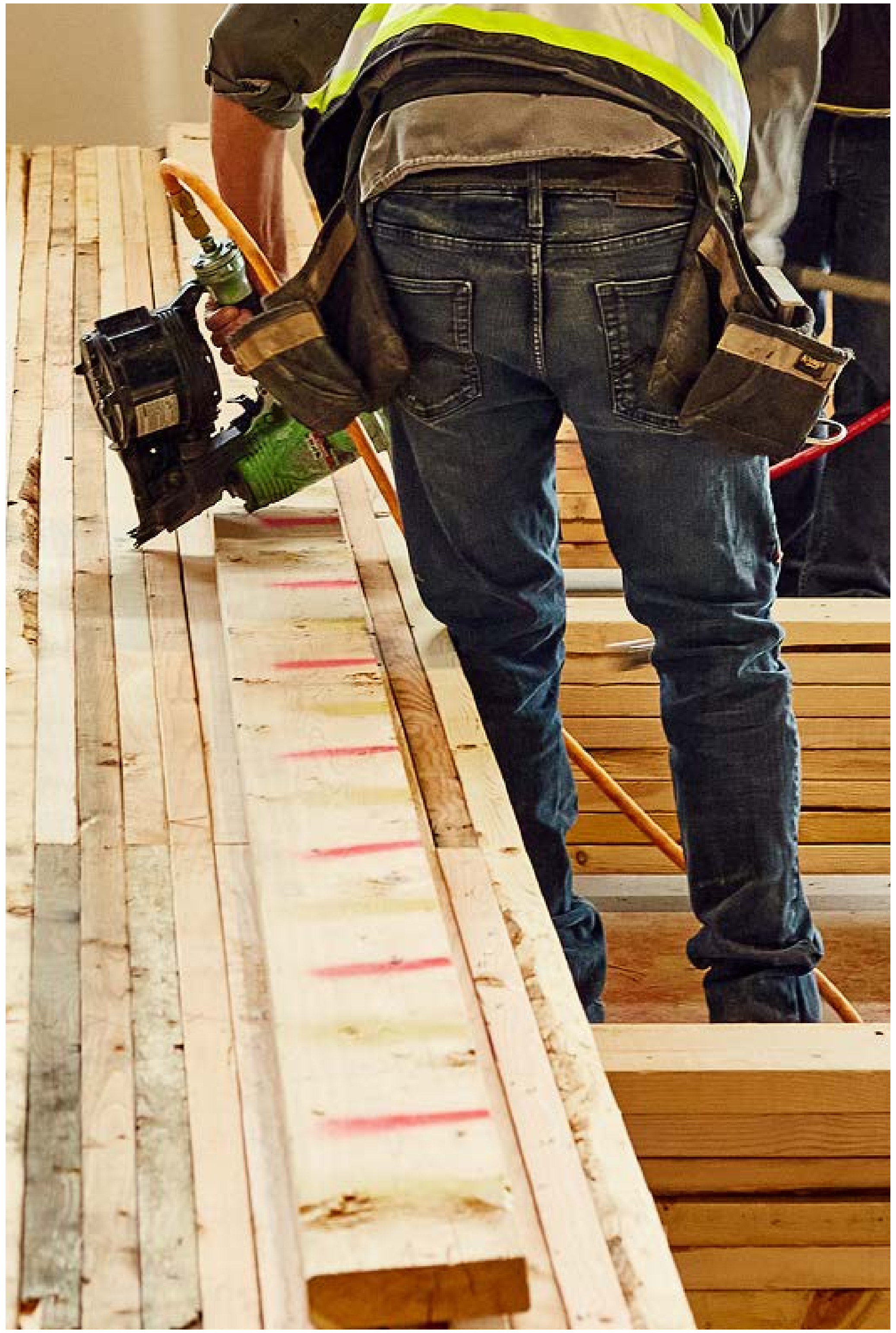
For axial compression design without sheathing or sufficient nailing to be considered a built-up member, the individual laminations cannot be considered restrained against buckling about their weak axis (lamination width). This is rarely the case and would likley only be needed for consideration in cases with strong end members restrain interior laminations against buckling as discussed in the **Slenderness factor**, K_c section of this guide. In this rare case, the axial compression resistance is calculated as follows:

Axial resistance
Buckling about each lamination (b_{lam})

$$P_{r,d} = \phi F_c \left(X_1 A_{lam.1} K_{zc.1} K_{c,b_{lam,1}} + X_2 A_{lam.2} K_{zc.2} K_{c,b_{Lam,2}} \right)$$

where

X_i = As described in the cross-section factor, $K_{section}$ section of this guide
$A_{lam,i}$ = area of a individual laminations, mm²
i = defines which lamination is being reviewed for NLT axial members with varying cross-sectional depth. i=1 for the deepest lamination.
$K_{c,b_{lam},i}$ = slenderness factor for a single lamination "i" within the panel. typically about the weak axis



Above NLT panel mockups at The Exchange, Kelowna, BC, during construction
Photo credit Wade Comer Photography *Photo courtesy of* NaturallyWood

4.1.3 Deflections

Analyze NLT deflections using a simplified beam analogy and compare the results to code-prescribed and/or project-specific limits, regardless of classification as M-NLT or NLT.

Base stiffness properties on specified modulus of elasticity values given in CSA O86 CL 6, adjusted in accordance with CSA O86 modification factors given in CL 5.4.1 and additional factors described in Section 4.1.1.

$$(EI)_{eff} = K_{layup,E} K_{section,E} K_{SE} K_T EI$$

E = specified modulus of elasticity of the laminations, MPa (see Tables 6.5, 6.6, 6.9 and 6.10)

I = moment of inertia of MLT section based on the deepest laminations, mm^4

Where the moment of inertia is calculated based on the deepest lamination, it is typically calculated on a per unit width basis.

Creep and long-term loading

Creep deflections from long-term loading are an important consideration for the design of any wood member, as they can easily exceed short-term or standard-term elastic deflection values. Pay special attention to situations with large dead loads or sustained live loads, high ambient temperatures, highly variable humidity levels, or any service conditions that will tend to increase the moisture content of wood.

Creep factors for deflection are developed and applied in CSA O86 in CL 5.4.2 where long-term loads are amplified by a creep factor. Refer to **Table 4.6**.

$$\Delta_T = \Delta_{el,ST} + \Delta_{LT}$$
$$\Delta_{LT} = K_{cr} \Delta_{el,LT}$$

where

$\Delta_{el,ST}$ = elastic (immediate) deflection due to loads other than dead load and the sustained portion of live load in the load combination. Refer to CSA O86 CL 5.4.2 and commentaries for further discussion

Δ_{LT} = Deflection due to long term loads (dead load and the sustained portion of live load in the load combination)

K_{cr} = creep factor

$\Delta_{el,LT}$ = elastic (immediate) deflection due to dead load and the sustained portion of live load in the load combination.

Refer to CSA O86 CL 5.4.2 and commentaries for further discussion of the definition of short and long term loading.

Table 4.6 Creep factors

Material	Service condition	K_{cr}
NLT or M-NLT	Dry	without butt joints: 1.7
NLT or M-NLT	Dry	with butt joints: 2.0
Note: creep can be excluded or deducted from some calculations as discussed in CSA O86 and commentaries (e.g., cambers, deflection occurring prior the installation of sensitive finishes, etc.)		

Moisture impacts on deflection and creep

Beyond the discussion of wet-service conditions here as well as those discussed in Chapter 5, it is important to understand the impacts that moisture may have during construction. Even if NLT is detailed for dry-service conditions, the wood may still be exposed to moisture during construction, particularly if moisture is not well managed on site and the NLT is not allowed to dry after rain exposure. If the NLT becomes wet, consider measures such as temporary shores to control creep deflections that may occur, particularly in deflection-sensitive areas such as cantilevers.

In cases where creep during construction has already occurred, take particular care with concrete topping slabs for the following reasons:

- **Concrete ponding:** Creep deformations developed prior to casting the topping will result in ponding effects if the topping is poured to a fixed elevation rather than a constant thickness.
- **Desorption:** The topping prevents moisture evapouration from the top surface of the NLT, reducing the drying rate of the NLT.
- **Increased creep loading:** The concrete topping is a long-term load which will increase the creep deflections.

Refer to Chapter 8 Section 8.6 for more on moisture control during construction.

4.1.4 Vibration

Because of NLT's high strength-to-weight ratio, vibrations become more likely to govern floor design as spans increase.

Vibration-controlled floor spans have historically been designed using simple approximations such as upper limits on elastic live load deflection (e.g., L/480 or L/600) or lower limits on the fundamental frequency of the floor system (e.g., 6 Hz or 8 Hz). The typical span ranges given in Table 2.1 also factor vibrations into account for occupancies that are not especially vibration sensitive, such as offices. These rules of thumb and span ranges are useful for preliminary design but should not be relied on exclusively. In some cases, these guidelines may be too stringent, and in others they may be insufficient. Simplified design equations for mass timber supported on walls is provided in CSA Annex A CL A.8.1.5.3. Although designed for CLT, this can be applied to NLT using the calculated effective stiffness of the NLT panel, EI_{eff}.

$$L_{max} \leq 0.11 \frac{\left(\frac{EI_{eff}}{10^6}\right)^{0.29}}{m^{0.12}}$$

where

L_{max} = vibration-controlled span limit, m
EI_{eff} = effective flatwise bending stiffness for a 1 m wide panel, N•mm²
m = linear mass of CLT for a 1 m wide panel, kg/m

The above equation assumes the floor:

- has a single span with both ends simply supported. For multiple-span floors with a non-structural element that is considered to provide enhanced vibration effect, the calculated vibration-controlled span may be increased by up to 20%, provided it is not greater than 8 m.
- is bare with no topping material. For floors with concrete topping, where the concrete is applied directly to the CLT panel, this equation may be used assuming bare floor construction for calculation purposes, i.e., weight of concrete is ignored in calculating the mass, m, provided the area density of the topping is not greater than twice the bare CLT floor area density.

Be aware that slight variations on this equation are provided in different CLT guidance documents, including the CLT Handbook, the NDS, and others, the differences are due, in part, to variability of what is considered an acceptable response.

This approach does not consider the stiffness reduction of the system where panels are supported on beams, which will lead to a decrease in stiffness of the system for considerations. Refer to the US Mass Timber Floor Vibration Design Guide [04] for information on an approximate method for accounting for beams supporting panels and girders supporting beams in the system design. This can be done by modifying the equation by the natural frequency, f_n, of the system as follows:

$$\frac{1}{f_n^2} = \frac{1}{f_{panel}^2} + \frac{1}{f_{beam}^2} \left[+ \frac{1}{f_{girder}^2} \ldots \right]$$

Because frequency is proportional to stiffness and mass, assuming the system weight is not greatly affected by the weight of the beams and purlins, an approximation of the stiffness of the system is possible as follows:

$$EI_{system} = K_{system} EI_{eff}$$

where

$$K_{system} = \left[1 + \frac{(L_{beam})^4 EI_{panel}}{(L_{panel})^4 EI_{beam}} + \frac{(L_{girder})^4 EI_{panel}}{(L_{panel})^4 EI_{girder}} \right]$$

EI_{eff} = EI_{panel} as calculated in Section 4.1.3 of this guide
L_{panel} = span of panels supported on beams
L_{beam} = span of beams supporting panels
L_{girder} = span of girders supporting beams
EI_{beam} = bending stiffness of beams
EI_{girder} = bending stiffness of girders

It may be appropriate to consider the sheathing as composite with the panel for vibration, refer to the US Mass Timber Floor Vibration Design Guide [04] for further discussions of composite behaviour in vibration.

NBC Structural Commentary D provide guidance on dynamic loading, frequencies, acceleration limits, and design strategies to prevent or correct problems with floor vibrations. AISC's design guide on vibrations of steel-framed structures [05] also provides a useful overview, and most of the content can be applied directly to NLT systems by using the appropriate stiffness values in the equations. The US Mass Timber Floor Vibration Design Guide [04] also provides significant guidance on design and analysis for floors for footfall vibration. ISO 10137 [06] and ISO 24323 [07] provides additional recommendations.

For NLT floors with potential vibration concerns, or with more complex vibration requirements, a more in-depth design can be completed with 3D FEM models and by evaluating modal behaviour and response accelerations and velocities. Refer to the US Mass Timber Floor Vibration Design Guide [04] for more information on this more complex design approach.

4.2 Fire design

As described in Chapter 3, NLT or M-NLT with an exposed soffit can meet fire-resistance rating requirements in multiple ways.

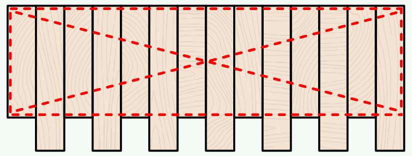
Where ratings are based on code-prescribed minimum dimensions or on test data, structural calculations are not required. Refer to Chapter 3 for more discussion on where NLT is acceptable or where M-NLT is recommended or required. The guidance provided here for fire design applies to either panel classification.

Generally, fire-resistance ratings are achieved through char, encapsulation, or a combination of the two. Char calculations are generally completed with the provisions in Annex B of CSA O86 or with the provisions in the NBCC Appendix D, refer to Chapter 3 for more information. Encapsulation is specified by the architect and provided with Type X drywall or other gypsum-based elements; Annex B provides information for required layers of Type X to achieve a given fire-resistance rating. One common approach uses a combination of the two, called partial encapsulation, where drywall is provided to achieve the first part of the fire rating and char is used to achieve the second. Refer to Chapter 3 for further discussion as well as the Joint Professional Practice Guidelines Encapsulated Mass Timber Construction Up To 12 Storeys from EGBC [08].

NLT is often governed by deflections or vibrations; therefore, the overall depth of the NLT may not need to increase to achieve the required fire-resistance rating for ratings of 1-hour or less, although fire ratings of 2-hours required for encapsulated mass timber will generally require an increase in depth, or partial encapsulation.

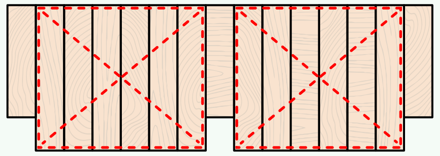
For fire rating calculations completed as per Appendix D, only rectangular sections are addressed. Accordingly, an effective rectangular section equivalent to the rectangular section of only the shallowest laminations should be considered for fire-resistance rating using this method, as shown dashed in red in **Figure 4.6**.

Figure 4.6
Effective rectangular section for shallow laminations



Alternatively, for sections with several deeper laminations in a group, the effective section could be taken as a series of narrower panels, and ignoring the shallower laminations between panels, as shown dashed in red in **Figure 4.7**.

Figure 4.7
Effective rectangular section for deeper laminations in a group

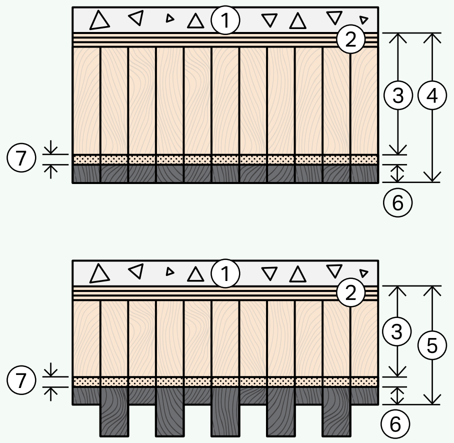


In situations where the design is completed as per CSA O86 Annex B, more detailed char calculations allow for more detailed design, as well as specifically addressing connections and variable char for staggered systems. Annex B provides guidance on both calculation of the char and heat effective zones on a section, as well as the design of that section in the post fire case, including most of the typical design factors discussed in Section 4.1.

Char rates for evaluation of both M-NLT and NLT are not explicitly addressed in CSA 086 Annex B. Refer to Section 3.2.2 for discussion on char and consult with a fire engineer for appropriate fire rating and char rate. Apply the total char and the heat affected zone to the design panel to develop a new section for the fire design case.

Although most design factors are directly discussed in CSA O86 Annex B, Annex B does not specifically address some of the factors required for the design of M-NLT or NLT. The layup modification factors, K_{layup}, described in Section 4.1.1 are still applicable for NLT in the char analysis case, and would remain unchanged. In cases where the deeper portions of the panel are narrow, char will effectively eliminate the deeper laminations, as illustrated in **Figure 4.8**, resulting in a flat panel and a cross-section factor, $K_{section}$, of 1.0.

Figure 4.8
Charred NLT cross-section

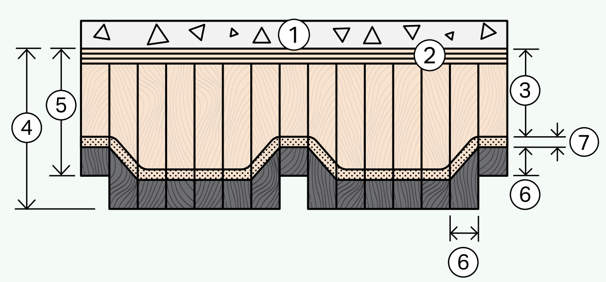


1. Continuous air barrier such as concrete topping
2. Plywood/OSB diaphragm sheathing
3. Remaining NLT depth (d_{fire})
4. Initial flat NLT depth (d)
5. Initial staggered NLT depth of shallow lams (d_2)
6. Char depth (x_c)
7. Zero-strength layer (x_t)

In other cases, where larger groups of deeper laminations are present next to each other, apply char on all exposed faces equally, as shown in **Figure 4.9**, and the new cross-section factor calculated from that charred element. It may be simplest to conservatively consider the depth of char as consistent across an entire lamination for example, the post-fire section in the **Figure 4.9** could be approached as three shallow laminations between groups of four deep laminations.

Refer to Applied Example in Chapter 3 for the design approach and alternative solution used for a similar fluted panel at the Exchange project in Kelowna, BC.

Figure 4.9
Charred NLT cross-section for grouped, deep laminations



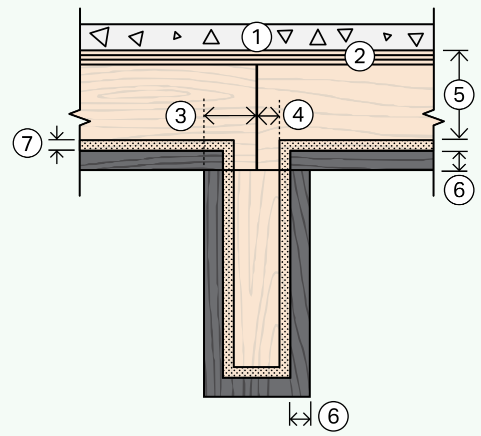
1. Continuous air barrier such as concrete topping
2. Plywood/OSB diaphragm sheathing
3. Remaining NLT depth (d_{fire}) varying remaining
4. Initial flat NLT depth (d)
5. Initial staggered NLT depth of shallow lams (d_2)
6. Char depth (x_c)
7. Zero-strength layer (x_t)

4.2.1 Fire design for floors

Beyond the panel design discussed above, there are some specific considerations for floor design in fire conditions. Floors are generally protected on their top surface by concrete topping or other non-combustible fire rated surface. Minimum concrete topping thicknesses of 38mm are required in the EMTC (or equivalent gypsum-based product) to effectively protect the timber for the full 2-hour event, so no char need be considered on the top side of the floor panel.

If the NLT is supported on an exposed wood member, such as a glued-laminated beam, the required bearing, based on the reduced bearing length of the NLT should be considered, as shown in **Figure 4.10**. As with all fire designs, deflection and serviceability need not be considered.

Figure 4.10
Bearing reduction where supported on exposed charred timber beam



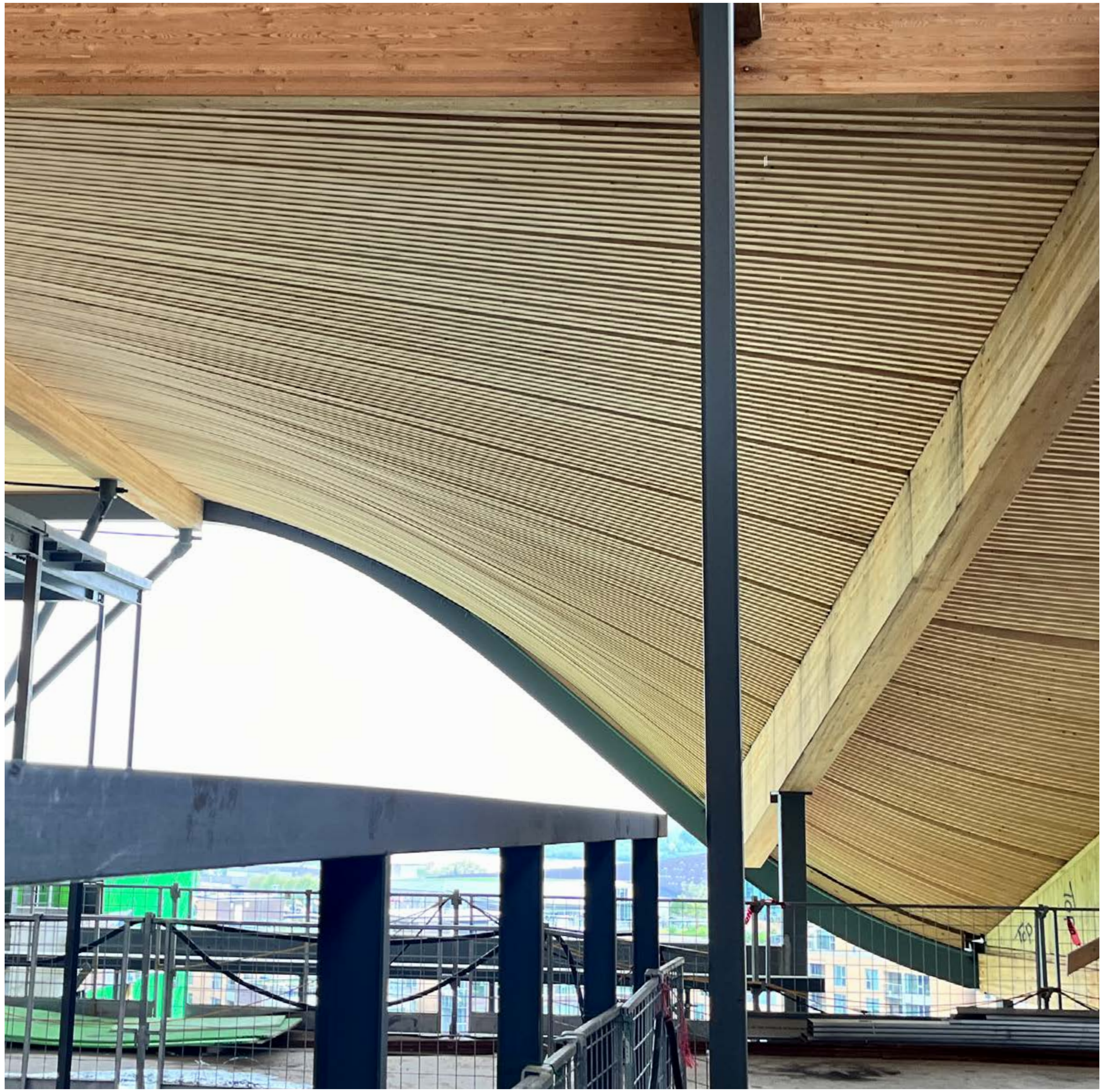
1. Continuous air barrier such as concrete topping
2. Plywood/OSB diaphragm sheathing
3. Initial bearing length (l_b)
4. Remaining bearing length ($l_{b.fire}$)
5. Remaining NLT depth (d_{fire})
6. Char depth (x_c)
7. Zero-strength layer (x_t)

4.2.2 Fire design at walls

For heavy timber or other types of construction designated combustible construction with fire-resistance rating requirements of no more than 1.5-hour, an NLT wall can be designed for fire based on a minimum thickness approach. Refer to the NBC 2020 and Chapter 3 for minimum thickness requirements. Although not explicitly required, it is recommended to provide encapsulation or plywood/OSB on at least one face of the wall to minimize smoke movement in the gaps between laminations.

For EMTC construction or construction with 2-hour fire-resistance, refer to Chapter 3 for further implications and discussion and coordinate the approach with the project fire engineer.

4.3 Lateral load design procedures



Above Ādisōke Public Library, Ottawa, ON
Architecture by Diamond Schmitt *Photo courtesy of* Fast+Epp

NLT/M-NLT can be used as both floor/roof elements or walls, though wall applications are less common in the current market.

The lateral design of sheathed NLT/M-NLT walls or floors is not explicitly discussed in CSA O86, guidance for design follows the Standard's principles for light-wood frame diaphragms and light-wood frame shear walls.

The total lateral resistance of a sheathed NLT system is provided based on the contributions of the nailing of structural panels (plywood/OSB) to the NLT laminations. If gypsum wallboard or diagonal lumber are also employed, further lateral resistance contribution from the nailing between gypsum wallboard to the NLT elements and diagonal lumber on NLT elements can be added. Refer to CSA O86 guidance for light-wood framed shear walls and diaphragm for sheathing and nailing. The edge and interior nailing requirements generally follow the spacing used for light-wood framed, with only laminations aligning with that panel edges and typical interior nailing.

Beyond the scope of CSA O86, additional guidance is provided based on research to evaluate the added strength and stiffness resulting from the nailing between NLT laminations [09] [10].

4.3.1 Shear walls

Sheathed NLT shear walls can be approached using the base information for light-wood framed shear walls.

The approximation of a sheathed NLT shear wall to a light-wood frame shear wall is a generalization that is not explicitly addressed in CSA O86 CL 11. The standard does not discuss the strength, stiffness, or ductility of sheathed NLT shear walls. In the absence of code guidance, the theory for an NLT shear wall remains the same with the shear strength carried primarily in the sheathing, transferred between sheathing elements with nails into supporting studs/laminations. Ductility of these systems is based on yielding of the nailing in the sheathing. The same general approach for resistance and ductility design can be used to evaluate an NLT shear wall. Research from UBC has shown that sheathed NLT shear walls provide similar cyclic behaviour for seismic applications (hysteretic form, deformation capacity, nail yielding modes, and failures mechanisms) as those shown for traditional light-wood framed shear walls [09].

Research shows some additional lateral resistance and stiffness from the NLT panel itself due to the nailing between laminations [09] [10]. This increased lateral resistance and stiffness is shown not to significantly impact the ultimate deformation or deformation at failure, nor cause major changes in the hysteretic form. It is important to note that this information is based on research. Where additional strength and stiffness is considered, the system is, at the time of writing, beyond the scope of CSA O86 and the prescriptive lateral systems provided in NBC 2020.

NLT shear wall resistance

A simple and conservative design considers an NLT shear wall as a equivalent fully blocked light-wood frame shear wall per CSA O86, considering only the contribution from the stud-to-sheathing connections. Hold-downs, base shear connections, and connections to diaphragms also require consideration per CSA O86.

Best practice for any NLT wall is to include some form of hold-down at all wall ends. However, recent studies have shown that the contribution from nail laminated studs increases the resistance of the walls based on the full-scale shear wall test results [09] [10]. The reported increase is evaluated to correspond to an increase in specified design resistance of 2 kN/m. At this stage no specific guidance is available for engineers to develop strength values for different nail spacings, or other conditions not included in the testing.

Currently, testing is limited to:

- single lamination nailing spacings of two rows of nails spaced at 300 mm (or one row at 150 mm),
- solid walls without openings or discrete panel,
- single long panel with NLT-1 type construction only,
- OSB sheathing, and
- single storey walls (i.e. platform framed construction).

For further research on NLT shear walls, refer to the research on UBC's Timber Engineering Applied Mechanics group.

The resulting NLT shear wall resistance can be evaluated as follows:

$$V_{rs} = \phi(v_d J_d n_s J_s + 2.0\ \text{KN/m})\ J_{hd} L_s$$

where

ϕ = As per CSA 11.6.2
2.0KN/m = Contribution of the nails between the laminations

$$v_d = N_u/s, \text{kN/m}$$

where

- N_u = lateral strength resistance of sheathing-to-framing connections along panel edges, per shear plane per fastener, N
- s = fastener spacing along panel edges, mm
- J_D = adjustment factor for diaphragm and shear wall construction (taken as 1.3)
- n_s = number of shear planes in sheathing-to-framing connections
- J_s = fastener spacing adjustment factor per CSA O86 CL 11.5
- J_{hd} = hold-down-effect factor for shear wall segment per CSA O86 CL 11.5
- L_s = length of shear wall segment parallel to the direction of load with nails provided between each lamination

Despite limited test data on OSB sheathed walls, this design approach could also be applied of plywood, and likely also for gypsum board and diagonal lumber sheathing as the additional strength is inherent from the contribution of the nailing between the laminations. Comparatively, direct application for walls construction from multiple panels is likely more complex. For long walls consisting of multiple panels, the panels would need to be joined to one another with fasteners of equivalent strength and stiffness to those in the rest of the NLT panel. If this is not possible due to construction limitations or swelling gaps between panels, each section would be required to be considered and have separate shear and hold-down connections at its base.

Because the sheathing is generally carrying most of the load, the strength of the entire wall is limited to the sheathing buckling strength.

$$V_{rs.max} = \phi v_{pd} K_D K_s K_T L_s$$

where

ϕ = As per CSA 11.6.2

v_{pb} = panel buckling strength of the most critical structural panel within the segment, kN/m, as per CSA 11.6.2

Overstrength, hold-downs, base-shear, and diaphragm design loads.

Hold-downs, base shear connections, and connections to diaphragms should be designed to be capacity protected. For light-wood framed shear walls simple overstrength factors are provided in CSA O86 to accommodate this design. For a sheathed NLT shear wall, additional in-plane strength is present even if it is ignored during the evaluation of the wall resistance. Accordingly, regardless of whether the limitations of the currently available tests are met, it is recommended to include this additional capacity when developing the baseline values to be used for evaluating the capacity protected loads for the hold-downs.

Design of nominal capacity protection of hold-downs and shear transfer elements is straightforward in CSA O86, requiring the hold-down force to be evaluated based on the load corresponding to the full design resistance of the shear wall, with an additional 20% (overstrength factor of 1.2). Base shear connections and anchorage should follow the same principle.

The design loads for diaphragm systems need to consider either the ratio of the resistance of the wall to the load it carries, or an upper limit over overstrength of 1.2, like that developed for hold-downs and base shear connections. Connections between the wall and the diaphragm are generally considered drag elements or load transfer elements, requiring and additional 20% increase over the design load for the diaphragm (i.e. overstrength factor of 1.44).

Shear wall deflections

Shear wall deformations to understand the drift of the building are considered in the same manner presented in CSA O86. The testing completed on sheathed NLT walls also showed an increase of in-plane shear stiffness of 15 KN/m/m under the limitations tested to date. This could be included in the stiffness if those limitations are met, but in the absence of additional testing for all typical nailing and jointing patterns, care should be taken.

To incorporate the additional stiffness in the calculation, first determine shear wall deflection, using the blocked shear wall deformation calculations in accordance with CSA O86 CL 11.7.1.

$$\Delta_d = \frac{2vH_s^3}{3EAL_s} + \frac{vH_s}{B_v} + 0.0025H_s e_n + \frac{H_s}{L_s} d_a$$

- $\frac{2vH_s^3}{3EAL_s}$: vertical elongation of wall end panel
- $\frac{vH_s}{B_v}$: panel shear deformation
- $0.0025H_s e_n$: nail slip
- $\frac{H_s}{L_s} d_a$: hold-down slip

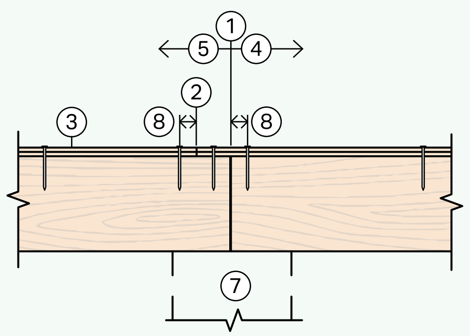
From this, determine the effective stiffness of the wall and add the NLT lamination nailing stiffness. This stiffness can be used to effectively reduce the deformation of the wall.

$$K_{wall} = \frac{v}{\Delta_d} + 15KN/m/m$$

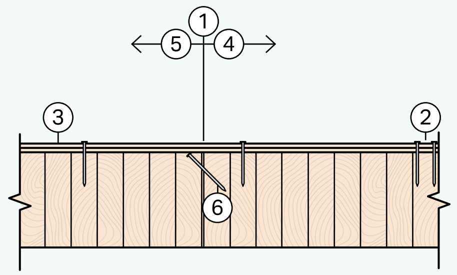
The stiffness is used primarily to assess the drift of the system. When determining the buildings period, follow the guidance provided in NBC for evaluation of the period. Where FEM modelling is used to assess a more refined period, and accurate model for the shear walls, including the stiffness of all components is required. Guidance on this modelling is beyond the scope of this guide. Some guidance of modelling of mass timber buildings can be found in the "Modelling Guide for Timber Structures" [11].

4.3.2 Diaphragms

Figure 4.11
Prefabricated NLT panel sheathed on-site



Panel joint perpendicular to NLT span



Panel joint parallel to NLT span

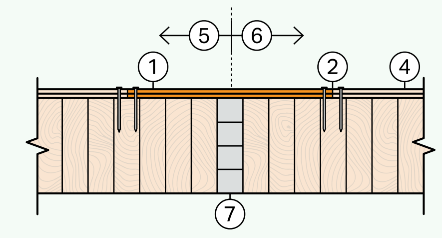
1. NLT panel joint location
2. Plywood/OSB panel joint location with panel edge nailing
3. Field-installed plywood/OSB diaphragm with immediate support nailing
4. Prefabricated NLT panel A
5. Prefabricated NLT panel B
6. Toe nail at NLT interface where no expansion gap is required
7. NLT support element
8. Diaphragm nail edge distance requirements as per CSA 086

In-plane load transfer across lamination joints for an in-plane NLT element behaving as a deep beam is not generally well understood, nor is the contribution of those joints to the in-plane shear and bending stiffness of NLT. Testing that incorporate the stiffness and strength of the lamination nailing has been limited to much smaller NLT shear walls (refer to Section 4.3.1); in the absence of research and testing of diaphragm behaviour, and given that diaphragm would almost always be composed of numerous panels joined together without nailing between them, relying on diaphragm capacities given in CSA O86 for plywood/OSB diaphragms is an appropriate, conservative approach. CSA O86 also recognises diagonal lumber sheathing for diaphragms which could also be used here.

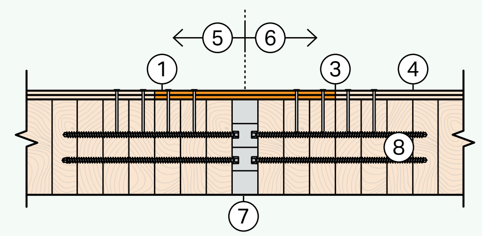
In addition to the guidance available in CSA O86, plywood/OSB diaphragm design and detailing considerations are available in a series of CWC design examples [12]. Most of these provisions can be directly applied to sheathed NLT diaphragms. For further discussion of specific consideration additional guidance for mass timber diaphragms on design and performance is available in the FPInnovation guide(s) [13].

Generally, the diaphragm over NLT is considered fully blocked where the plywood/OSB is affixed directly to the NLT panels as shown in **Figure 4.11**. Where over-framing or an inverted staggered cross-section is provided to accommodate venting as discussed in Chapter 5 Section 5.4.1, the connection between the plywood/OSB diaphragm and the NLT is provided in only one direction, and the diaphragm should be designed as unblocked. If additional blocking between the staggered laminations or over-framing is provided, a fully blocked diaphragm design is appropriate.

Figure 4.12
Prefabricated pre-sheathed panels



Diaphragm with single row of nails at panel edge



Diaphragm with two rows of nails at panel edge

1. Field-installed plywood/OSB
2. Plywood/OSB splice location with single row panel edge nailing
3. Plywood/OSB splice location with two rows panel edge nailing
4. Shop-installed plywood/OSB diaphragm sheathing
5. Prefabricated NLT panel A
6. Prefabricated NLT panel B
7. NLT expansion gap location fire stopped as required
8. Self-tapping screw pairs crossing plywood/OSB splice location

NLT panel and sheathing layout and nailing

Follow the approach provided in CSA O86 for fully blocked diaphragms to design plywood/OSB and its fastening to the support structure. For diaphragms with nail spacing that can be accommodated in a single line, centre the plywood/OSB panel joints parallel to the direction of the NLT span on an individual lamination to allow for proper load transfer across the joint, as shown in **Figures 4.11** and **4.12**, similar to light-wood-framed systems, the alignment of panel edges at the center of the lamination is important to achieve the nail strength required.

For high load diaphragms where multiple rows of fasteners are required at panel edges and boundaries, requiring thicker laminations or built-up members in a typical diaphragm, the NLT laminations in those locations must act as built-up sections. This is achieved by having sufficient nailing between laminations to transfer the shear load across the joint. A simple approach is to provide equal or equivalent nailing between the laminations at the plywood/OSB panel splice locations to that provided between the plywood/OSB and the NLT at the diaphragm panel edges (i.e. nailing between laminations of equal or greater strength to that provided in the diaphragm panel edge nailing). Another common approach is to provide long screw reinforcement, typically self-tapping screws at the NLT edges near plywood/OSB splices, as shown in **Figure 4.12**.

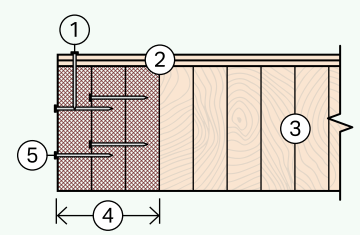
For curved or warped panels, the plywood/OSB must be able to curve and warp to suit the shape of the NLT. Thick plywood/OSB may have difficulty curving easily to the form of the NLT. For tighter curvatures, use thinner plywood/OSB panels. Where thicker plywood/OSB is required for diaphragm design strength for example, use thinner layers glued together on side and nailed down. For instance, a 19 mm (3/4 in.) plywood/OSB could be replaced with two layers of 9.5 mm (3/8 in.) plywood. This does come at some cost due to additional material handling, cost of glue, and application of glue on site. No clear guidance is available for the maximum reasonable curvatures for which each type of plywood/OSB is capable. Consider requiring the final plywood/OSB assembly as part of the mock-up in the project specifications.

Chords and collectors

Like the approach for light-wood frame diaphragms, chords and collectors in an NLT assembly should be designed for seismic loads of at least 1.2 times the diaphragm design load as per CSA O86 CL 11.8. However, the forces need not exceed those determined using an RdRo of 1.3. The connection between the NLT and the lateral force resisting system should be taken as a collector, regardless of whether an additional drag element is required. The tension and compression forces in these chords and collectors can be resisted in several ways. Using beams as axial force members is one option. If the design does not include beams at the edges of the diaphragm, chord forces must be resisted within the floor assembly. One approach is to assume the NLT laminations act as discrete tension and compression elements that resist the full chord force at the extreme edges of the diaphragm. Design the NLT laminations in this case as combined axial and bending members, with the axial forces due to lateral loads and the bending forces due to gravity loads for each load combination; use the modification factors provided in **Section 4.1.1**.

Where multiple laminations are required for the compression case, carefully consider the shear load transfer between the laminations. Where multiple compression laminations are required in chords, additional nailing between those laminations may be required to consider the chord a built-up member, as shown in **Figure 4.13**. This additional nailing is particularly important where nailing between the plywood/OSB and each lamination in the chord is not provided. Refer to the slenderness factor section of this chapter for further discussion of built-up sections within NLT.

Figure 4.13
Effective discrete chord element



1. Diaphragm perimeter nailing
2. Plywood/OSB sheathing
3. NLT
4. Built-up cord width
5. Chord fastening for load share

Compression force transfer across the lamination butt joints is provided by direct end-grain bearing. Transferring tension across a lamination butt joint is possible by transferring the force into the adjacent lamination and then back into the original lamination on the other side of the joint, using nails in shear. This load path becomes complicated where multiple laminations are needed to resist the tension force and for layups with frequent butt joints in between supports. A common approach to ensure a robust load path is the use of steel straps, light-gauge or thin steel plate as required.

For chords perpendicular to the direction of the NLT span, one option is to provide a rim board to take compression and potentially tension forces. This rim board would need to be sufficiently connected to the diaphragm to carry the full load, and sufficiently restrained against buckling for the axial loads, usually through nails to the NLT. Where a single rim board does not provide sufficient compression strength, a similar built-up approach like in **Figure 4.13** can be considered. Where a single rim board does not provide sufficient tension strength, or tension across but joints required considerations, consider steel straps as discussed previously.

If a rim board is not considered, and the perpendicular-to-grain bearing between laminations is considered but should be done with caution as this approach significantly impacts the flexibility of the diaphragm as discussed in the Diaphragm Deflection and Load Distribution section of this chapter. Chord-splice slip values must be accounted for; in the case of perpendicular-to-grain bearing, the elastic modulus is much lower than for parallel-to-grain loading; gaps due to shrinkage should also be considered making this approach prohibitive for all but the smallest diaphragms. If this approach is taken, calculate the width required to resist the compression force in accordance with CSA O86 CL 6.5.7 and evaluate the result for reasonableness.

Design collector elements using the same approach. Where additional nailing is difficult to locate accurately, for example at interior shear walls, consider using separate elements such as beams, straps, or wall top plates as the collectors.

Diaphragm deflection and load distribution

Distributing shear to the vertical lateral-resisting elements is more complex than for typical joist floors. The connections between laminations likely creates a stiffer diaphragm than a typical plywood/OSB diaphragm. Because more fasteners can be used, the NLT diaphragm may be designed as a rigid or semi-rigid plate. Currently there is little data on the relationship between fastener density and diaphragm stiffness, and calculating a semi-rigid diaphragm stiffness is difficult to do accurately. A simplified approach to determine load distribution is to perform two separate analyses, one assuming flexible diaphragms and one assuming rigid diaphragms. A full enclosure design (taking the worst case from both analyses) may be overly conservative; use engineering judgment to determine final design forces. Further guidance for enclosure design of typical plywood/OSB diaphragms is provided in the CWC white paper, Diaphragm Flexibility [14].

To determine system deflection, the diaphragm deformation must be considered alongside the vertical lateral system drift, diaphragm defection calculations in accordance with CSA O86 CL 11.7.2. For NLT diaphragms, these deflections can be applied as a conservative estimate on the deformation the diaphragm will observe. Stiffness from the in-plane nailing can be conservatively ignored if an enclosure approach for load distributions as described above is implemented.

$$\Delta_d = \frac{5vL^3}{96EAL_D} + \frac{vL}{4B_v} + 0.00061Le_n + \frac{\Sigma(\Delta_c x)}{2L_D}$$

chord elongation | panel shear deformation | nail slip | chord slip

The design of diaphragm deflection completed very similarly to that of light-wood framed diaphragm with four terms contributing to the deformation as shown above. The design approach is identical to a typical light-wood framed diaphragm for panel shear deformation and nail slip.

For NLT floors and roofs where the chords are considered through rim boards and built-up elements at the perimeter, chord elongation can be considered in the same manor as for light-wood framed diaphragms. For cases where the perpendicular-to-grain bearing is used instead of a rim board, the stiffness of the pendicular-to-grain sawn lumber must be considered and can be taken as follows:

$$E_{90} = \frac{1}{16} E_0$$

The chord slip should be considered based on the stiffness of the joints between tension chords and/or the small gaps between butt jointed panels or rim boards, similar to the approach taken for light-wood framed diaphragms. In cases where the perpendicular-to-grain bearing in used instead of a rim board, gaps of up to 2 mm should be considered between each lamination. For MLT this can be simplified to an average gap size of 1 mm between each lamination. The resulting chord slip will be large, making the approach to an NLT diaphragm without a rim board infeasible for large diaphragms.

4.4 Connections

A complete NLT design includes details and specifications for connections, both within the NLT and from the NLT to its supports. Unless specifically discussed, the guidance here applies regardless of panel classification NLT or M-NLT.

4.4.1 NLT panel fastening

Provide requirements for NLT lamination nailing in the structural contract documents. Where NLT is prefabricated in panels, also include requirements for panel-to-panel connections.

Lamination nailing

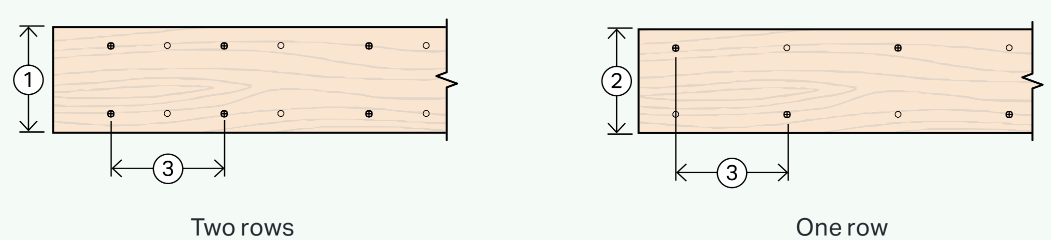
Lamination-to-lamination nailing provides shear transfer, forces the laminations to deflect equally, and pulls the laminations tight together. M-NLT has specific nailing requirements for different panel types provided in the fabrication standard. These nailing patterns generally coincide with nailing recommended for NLT, which is modified from the nailing provisions of CSA O86 CL 6.5.10.3.1, which requires 102 mm (4 in.) nails at 450 mm (18 in.), these nailing requirements are difficult or impossible to meet with standard pneumatic nailers [9]. All these recommendations or requirements are based on panels fabricated with 2x lamination stock (38 mm [1-1/2 in.] actual thickness). A summary of the nailing patterns is provided in **Table 4.7** and **Figure 4.14**.

For butt jointed NLT, the structural purpose of the nails is to share load among the laminations to provide continuity across the joints, loading the nails in shear. In this case, the proposed alternative nailing matches the shear strength of the standard-prescribed nailing.

For NLT without butt joints, where all the laminations are supported on all supports, any load transfer between the laminations that may be required to ensure deflection compatibility is easily accomplished with plywood/OSB; the nails are not required to perform a structural purpose. In this case, the proposed nailing provides a nominal clamping mechanism to ensure that any gaps between laminations that result from shrinkage will remain small and well-distributed across the overall NLT width.

In cases where NLT is required to have a fire-resistance rating, preventing large gaps helps mitigate the risk of an integrity or insulation failure, as described in Chapter 3.

Figure 4.14 Lamination nailing



1. > 140 mm (6 in. nominal)
2. ≤ 140 mm (6 in. nominal)
3. Nailing spacing

- • Nailing in face layer
- ◦ Nailing in layer beyond

Table 4.7 Lamination nailing patterns

Laying pattern	Minimum fastener diameter (1,3)	Panel depth	Lamination fastening pattern
Continuous or simple span lams (NLT-1, NLT-2)	3.00 mm nail	≤ 140 mm	one row at 450 mm o.c. staggered
		> 140 mm	two rows at 450 mm o.c. staggered
Butt jointed with Layup (2) (NLT-3, NLT-4)	3.66 mm nail	≤ 140 mm	one row at 175 mm o.c. staggered
		> 140 mm	two rows at 350 mm o.c. staggered
	3.00 mm nail	≤ 140 mm	one row at 125 mm o.c. staggered
		> 140 mm	two rows at 250 mm o.c. staggered

1. Nails or spikes used in NLT panels must be at least 76 mm long for 38 mm thick laminations or 152 mm long for 64 mm thick laminations
2. Provide two additional nails on each side of every butt joint
3. Nails are smooth shank galvanized steel nails

Panel-to-panel connections

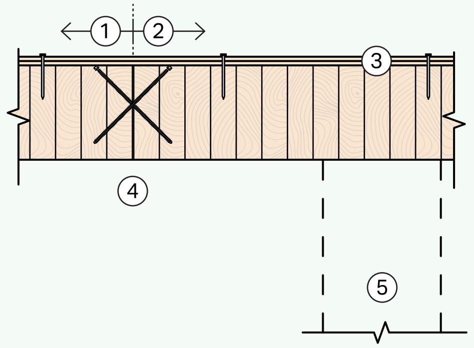
Panel-to-panel connections for M-NLT/NLT are provided primarily by the plywood/OSB. To maintain diaphragm continuity and in-plane shear transfer, plywood/OSB joints must be located a sufficient distance from NLT panel splices. The sheathing joint approach is discussed in greater detail in the diaphragm section for panels sheathed both on and off-site, refer to Figures 4.11 and 4.12 for examples of panel-to-panel connections. For plywood/OSB joints parallel to the NLT span, the offset from the NLT panel joint must also be sufficient to prevent differential gravity deflection between NLT panels.

For large areas of NLT, make allowances for swelling due to changing moisture content during construction; these allowances are needed to avoid inducing large stresses and deformations into the supporting structure. An effective strategy is to leave an 8 mm gap every 1.8 m (6 ft.), alternately another approach is to leave a 38 mm (1-1/2 in.) gap (one lam) approximately every 6 m (20 ft.), as shown in Figure 4.12. After the building is operational and the NLT reaches its equilibrium moisture content, the gap can be filled if desired for aesthetics or to maintain fire separation between floors, as discussed in Chapter 3. Filling these gaps during construction is time consuming because fastening must be done from below after the panels are in place but can provide a seamless appearance in critical areas. Alternatively, if larger gaps in the NLT are being provided to accommodated building services, they can be used to accommodate swelling.

Support conditions may create discontinuities in deflection between adjacent panels. In such cases, provide additional panel-to-panel connections to create continuity in the overall deflected shape of the floor or roof and to prevent withdrawal of the plywood/OSB nails at the NLT panel joint.

An example of this would be a residential construction with intermediate supports for only a portion of the floor area, like closet wall framing. In such a case, one panel might clear span 5 m (16 ft.) while an adjacent panel has intermediate wood stud walls every 1.2 m (4 ft.) around closets. At the centre of the 5 m (16 ft.) span, the first panel will deflect more than the second panel if the two are not sufficiently connected. Similarly, if a wall support is parallel to the NLT span, as illustrated in **Figure 4.15**, the adjacent unsupported panel will experience a larger deflection unless the two panels are tied together.

Figure 4.15
Prefabricated NLT panels with varying support conditions



1. Prefabricated NLT panel A
2. Prefabricated NLT panel B
3. Plywood/OSB diaphragm sheathing over screw heads
4. Self-tapping fully threaded screws inclined at 45°
5. Proximate support

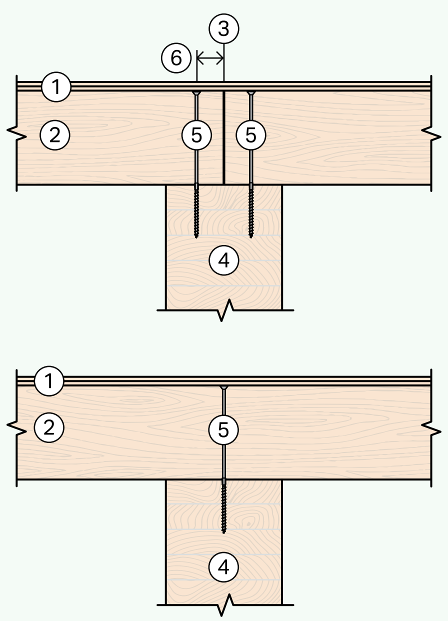
4.4.2 NLT floor support connections

Detailing connections between NLT and its supports varies with the type of load being transferred (gravity, uplift, lateral) and the type of support. Common supports include wood shear walls, wood beams, steel beams, and concrete walls.

NLT gravity support connections

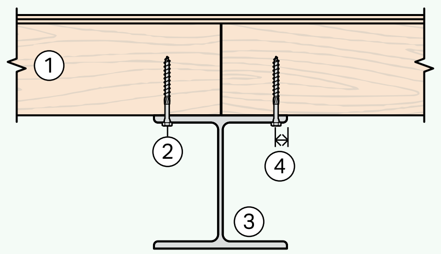
For gravity cases, direct bearing of the NLT on the supporting element is the most common approach for transferring load. If net uplift is not a concern, which is typical for floors and some roofs, nominal connections with either self-tapping screws or nails ensure the NLT stays in place, as shown in Figures 4.11 through 4.16. For NLT built in place, minimum toe-nail requirements are given in CSA O86 CL 6.5.11.3.1. Prefabricated NLT panels, however, cannot be toe-nailed. One common approach is to provide partially threaded self-tapping screws through the NLT into the support beams, as shown in **Figure 4.16**. Alternatively, at steel beam supports, provide screws up through the steel top flange into the NLT from below, as shown in **Figure 4.17**. Screws installed vertically should be centred on laminations; another option is to install self-tapping screws on an angle so that multiple laminations are engaged, and the screws need not be located with precision. For inclined self-tapping screws installed through steel beam flanges, 45-degree washer heads are an economical way to accommodate the angle while ensuring proper bearing of the screw head on the steel. Connections to supports should have at minimum, equivalent shear and uplift resistance to toe-nail connections calculated in accordance with CSA O86 provisions. If wind forces are sufficient to cause net uplift on the NLT, the fasteners must be designed to resist the uplift load in withdrawal as well. If beams are used as drag elements, design the screws to transfer the necessary forces into the beam.

Figure 4.16
NLT connections to wood beam



1. Plywood/OSB installed over countersunk screws
2. NLT
3. Prefabricated NLT panel joint
4. Wood support beam
5. Self-tapping partially threaded screws with countersunk heads
6. Self-tapping screw fastener end distance

Figure 4.17
NLT connection to steel beam



1. NLT
2. Partially threaded screws
3. Steel support beam
4. Minimum edge distance for ease of screw installation

4.4.3 NLT floors/roofs to wood walls

In general, where NLT is supported on shear walls (light-wood framed, NLT, or other any other types of shear walls) the connection needs to consider a positive connection for gravity and out-of-plane wind pressures, as well as the transfer of shear loads from the diaphragm into the shear walls. In both cases the connections are provided with screws from the NLT panel to the shear wall in some fashion. The lateral load path between the plywood/OSB in the diaphragm, the NLT floor or roof panel, and the shear wall must be considered.

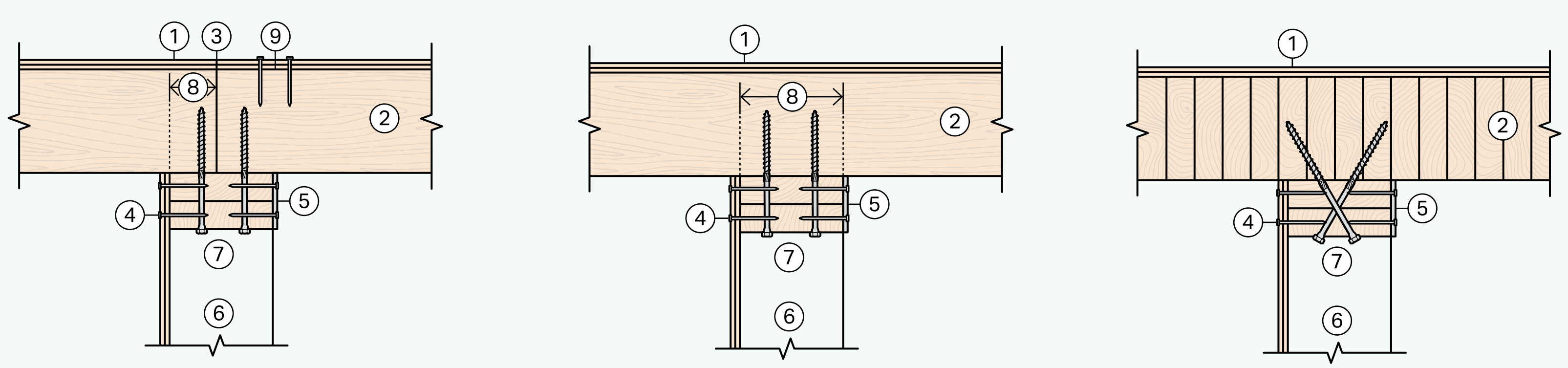
NLT floors/roofs supported by light-wood framed shear walls

To accommodate both the gravity connection, out-of-plane with load connection, and in-plane shear wall connection for light-wood framed shear walls supporting NLT, screws between the NLT panel to the shear wall below are typically provided, fastened from within the wall cavity to minimize required screw lengths. Typical connections where NLT passes over an interior shear wall are shown in **Figure 4.18**.

Connections between NLT and perimeter walls are shown in **Figure 4.19**. For interior shear walls, provide screws from the underside of the top plate through the NLT. Similar to connections at beams, the screws should be either installed vertically and centred on the laminations or installed on an angle to engage multiple laminations. For large lateral forces, inclined self-tapping screws will provide higher capacities by loading the screws in tension rather than pure shear. Ensure that there is sufficient connection between the diaphragm sheathing and the NLT laminations connecting them using either a local strap or simply extra nails locally. Where drag elements are required beyond the wall, use the same approach discussed for chords and collectors in Section 4.3.2.

Where NLT connects to a perimeter shear wall, make a direct connection between the horizontal and vertical plywood/OSB wherever possible. The lateral load path should pass through the rim board, like any typical light-wood frame wood building. Ensure that the vertical plywood/OSB is sufficiently nailed to both the wall framing and the NLT or rim board for the shear transfer.

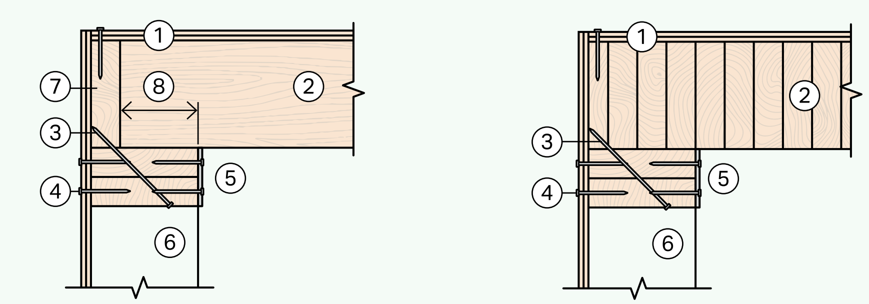
Figure 4.18
NLT connections to interior wood shear walls



NLT span perpendicular to shear wall at panel joint — NLT span perpendicular to shear wall — NLT span parallel to shear wall

1. Diaphragm plywood/OSB sheathing
2. NLT
3. Prefabricated NLT panel joint
4. Shear wall plywood/OSB edge nailing to top plate
5. Shear wall top plate with straps to act as drag
6. Wood shear wall
7. Screws through top plat to NLT
8. NLT bearing length
9. Diaphragm plywood/OSB sheathing joint with diaphragm nailing

Figure 4.19
NLT connections to exterior wood shear wall



NLT span perpendicular to shear wall — NLT span parallel to shear wall

1. Diaphragm plywood/OSB sheathing
2. NLT
3. Toe-nail of edge lam/rim board to shear wall
4. Shear wall plywood/OSB edge nailing to top plate
5. Shear wall top plate with straps to act as drag
6. Wood shear wall
7. NLT rim board
8. NLT bearing length

In cases where a perimeter shear wall continues past the NLT (balloon frame), wood ledgers are an option, as shown in **Figure 4.20**. Provide a ledger connection to the shear wall designed for full transfer of the gravity and shear forces with either nails or screws. In addition, provide tension ties between the top of the NLT and the shear wall to resist out-of-plane loading. Ensure the studs are blocked in line with the ledger to provide a direct load path to the plywood/OSB sheathing.

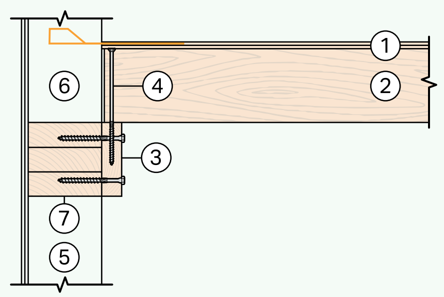
NLT supported by NLT shear walls

To accommodate both the gravity connection, out-of-plane with wind pressure connection, and in-plane shear wall connection for NLT shear walls, screws between the NLT panel to the shear wall below are typically provided, fastened from the top of the panel through the floor/roof panel and into the wall below. Small diameter screws should either be installed vertically and centred on the floor laminations or installed on an angle to engage multiple laminations. Commonly a rim board will be present at the top of the NLT wall to facilitate a simple and flat connection to the floor panel and allow a direct load transfer from the rim board to the wall sheathing, however they are not required and will increase cumulative shrinkage for taller buildings. For large lateral forces, inclined self-tapping screws will provide higher capacities by loading the screws in tension rather than pure shear. Centering the screws of the floor and wall laminations can be very difficult to achieve and would be required for screws installed vertically if no rim board were present or if the additional lamination nailing strength is considered as discussed in Section 4.3.1; in these cases, provide inclined screws as shown in **Figures 4.21** and **4.22** below.

For platform framed shear walls ensure a load path from the floor sheathing to the wall sheathing, and from the floor sheathing to the studs where additional strength is being counted as contributing from the NLT nailing. At interior conditions, sufficient nailing is required to transfer the plywood/OSB load into the laminations, and then sufficient fastening is required between the NLT floor and the NLT wall to transfer the full shear load into the NLT wall laminations and any sill plate at the top of the wall.

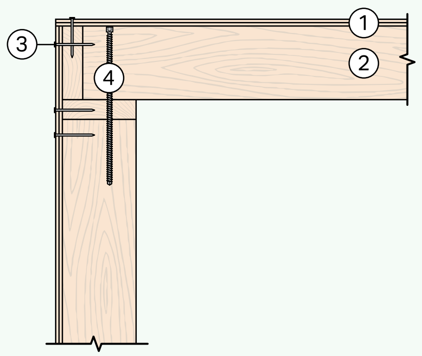
Figure 4.22 shows nailing to transfer the plywood/OSB load into the floor laminations, and screws to transfer load from the floor NLT to the NLT laminations in the wall below. Nailing between the rim board and the wall sheathing would then transfer load from the wall rim board to the wall sheathing. **Figure 4.21** shows a similar load path using a rim board; if the strength of the nails between the laminations is being accounted for, either additional connection directly between the floor diaphragm and the NLT wall laminations is required, or additional nailing as needed to transfer the loads is required.

Figure 4.20
NLT support at ballon-framed shear wall



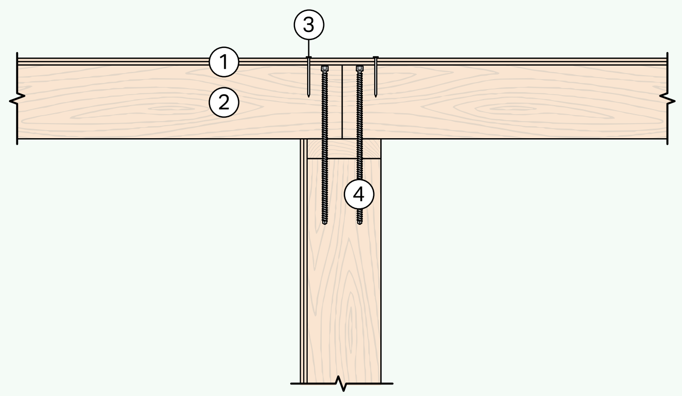
1. Plywood/OSB diaphragm sheathing
2. NLT
3. Wood ledger connected to shear wall studs
4. Self-tapping screws from NLT to ledger support
5. Double-height wood shear wall (balloon framed)
6. Tension tie at top of NLT
7. Wood blocking for diaphragm shear transfer into wall

Figure 4.21
NLT floor supported at perimeter NLT wall



1. Plywood/OSB
2. NLT
3. Nailing needed to transfer loads into plywood
4. Nailing to rim board to transfer loads
5. Fully threaded self-tapping screws inclined 45° only if additional load transfer is required to the NLT wall below

Figure 4.22
NLT floor supported at interior NLT wall



1. Plywood
2. NLT
3. Panel edge nailing at ends of panel, even where plywood/OSB ends don't align
4. Fully threaded self-tapping screws inclined 45° only if additional load transfer is required to the NLT wall below

4.4.4 NLT wall base connections

Solid NLT walls share many design characteristics with light-wood framed walls; the most significant difference is the absence of a cavity within the wall.

This has significant effect on the detailing approach of both NLT gravity and NLT shear wall detailing. Specific guidance for NLT shear walls is not currently provided in CSA O86. Refer to Section 4.3.1 for further discussion of NLT shear walls and shear wall connection design loads.

Base connections

The solid NLT wall does not have room for the anchor bolts like a light-wood frame wall, so base connection needs careful consideration. These can be achieved using angle brackets or a wood sill plate thick enough to accommodate a countersunk bolt into the supporting floor or foundation. In all conditions it is important to provide a sill gasket between concrete and wood at support locations to protect from moisture and maintain durability.

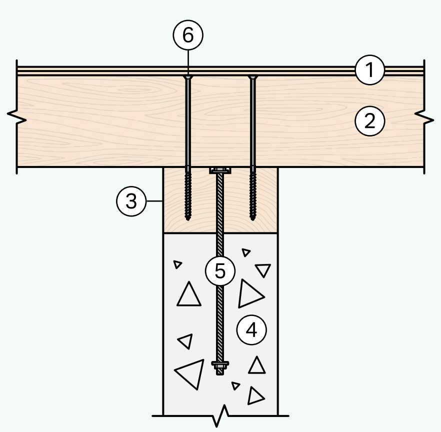
Where a wood sill plate is used, as shown in **Figure 4.24**, toe-nails or toe-screws from the vertical NLT laminations are recommended to provide a positive connection for walls carrying only gravity loads. For NLT shear walls where only the contribution of the sheathing is considered for the lateral resistance of the system, the nailing pattern between the sheathing and the sill plate, and the fastening of the sill plate to the supporting floor of foundation should be designed using the same approach used for a typical light-wood framed shear wall. For NLT shear walls where the additional shear strength from the nailing between laminations is considered based on the research provided in Section 4.3.1 of this guide, it is critical to provide a connection directly between the laminations and the sill plate to transfer this portion of the lateral shear load, in addition the connection between the plywood/OSB and the sill plate.

Another approach uses angle brackets, more like a CLT wall, as shown in **Figure 4.25**. NLT walls do not behave the same as a CLT wall and this approach requires careful consideration of the load path between the laminations, sheathing, sill plate where applicable, and angle bracket. Bracket placement and how the fasteners in the angle bracket interact with the individual laminations is also critical to consider. It is important to ensure fasteners are not placed in gaps between laminations, or too close to the edge of each lamination. It can be difficult to achieve perfect alignment of fasteners to the center of laminations while also allowing tolerance for the connection into the concrete.

NLT supported by concrete shear walls

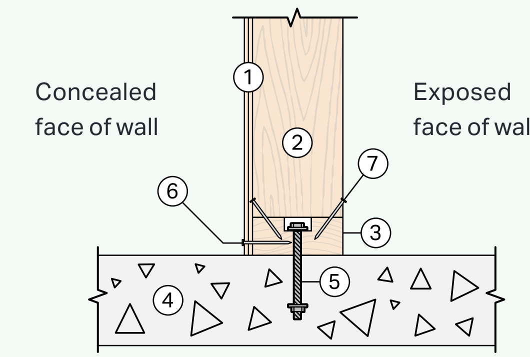
For NLT connecting to a concrete wall, install a continuous wood ledger at the top of the wall. For site-built NLT which is toe-nailed to the ledger, a single 2x is sufficient. For prefabricated NLT, install a thicker ledger to accommodate self-tapping screw connections as shown in **Figure 4.23**.

Figure 4.23
NLT connection to concrete wall



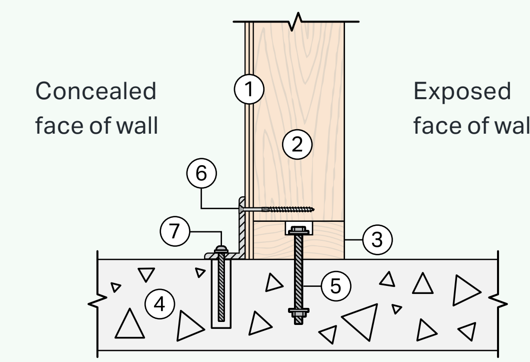
1. Diaphragm plywood/OSB over screw heads
2. NLT
3. Sill plate, depth to accept screws
4. Concrete wall
5. Sill plate anchors to concrete wall
6. Self-tapping partially threaded screws into sill plate

Figure 4.24
NLT shear wall with sill plate shear connection



1. NLT wall sheathing
2. NLT
3. Sill plate wall base (gravity only)
4. Foundation or concrete support
5. Sill plate anchors to foundation
6. NLT sheathing nailing to sill plate
7. Toe nails between NLT laminations and sill plate

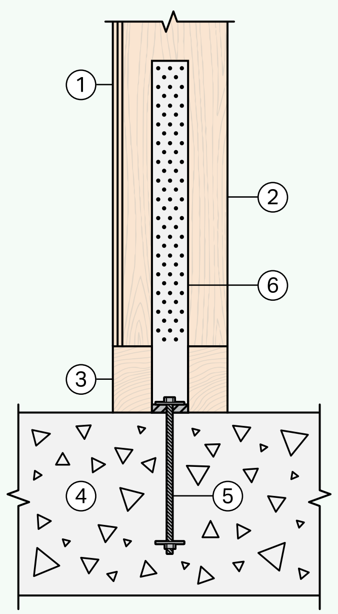
Figure 4.25
Angle bracket base connection with sill plate



1. NLT wall sheathing
2. NLT
3. Sill plate wall base (gravity only)
4. Foundation or concrete support
5. Nominal anchorage to foundation for placement
6. Angle connection to sheathing and NLT Fasteners placement to avoid gaps between lamination
7. Discrete angle brackets w/ post installed connection to concrete

Shear wall hold-downs and end studs

Figure 4.26
Hold-down into end of NLT wall



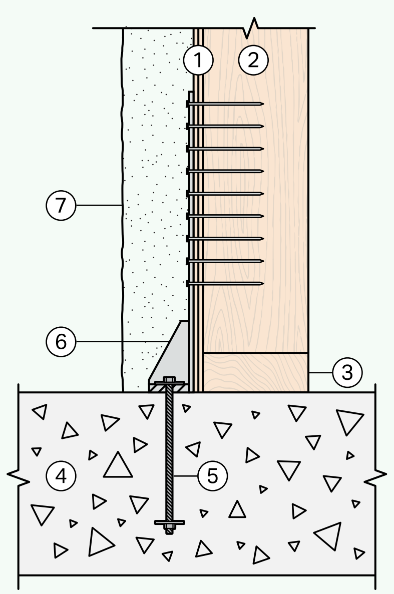
1. NLT wall sheathing
2. NLT shear wall
3. Sill plate wall base (gravity only)
4. Foundation or concrete support
5. Hold-down anchor
6. Hold-down bracket fastened to end of wall (coordinate with architect to conceal)

Shear wall hold-downs into end of NLT wall

Like a light-wood framed wall, it is important to ensure that the overturning in the shear walls can be resisted by a combination of built-up end members and hold-downs at the ends of walls. Providing build-up end members to resist the compression at wall ends is straight forward and can be provided using the same approaches as those considered in the Axial compression and the Stability factor sections of this chapter. Hold-down placement is more complicated for NLT shear walls because there is no cavity within the wall; hold-downs used in light-wood framed shear walls are typically provided within the wall cavity.

One approach is to place hold-downs outboard of the panel off the ends of the walls. These allow the hold-downs to be installed into the face of the lamination like a light-wood framed wall but require detailed coordination with the architect to conceal them as they would project past the end of the wall. It is critical to ensure that the group of laminations to which they are fastened can share the tension load as required for the specific hold-down. Ensure sufficient fasteners are provided between those end laminations to achieve built-up section behaviour. Refer to **Figure 4.26**.

Figure 4.27
Hold-down into face of NLT wall

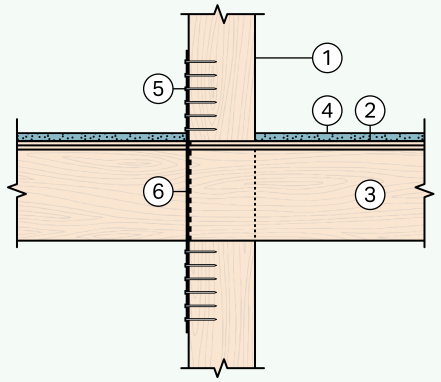


1. NLT wall sheathing
2. NLT shear wall
3. Sill plate wall base (gravity only)
4. Foundation or concrete support
5. Hold-down anchor
6. Hold-down bracket
7. Exterior cladding

Shear wall hold-downs into face of NLT wall

Another approach for NLT hold-downs is to place them on the concealed face of an NLT wall within a wall cavity or buried in an exterior enclosure. These applications are more complex as the locations of the nails relative to the laminations is critical to ensure that nails are not placed within gaps between laminations, and the fastener edge distances within the laminations are met. In practice, this means that small diameter fasteners are the only acceptable option, and that there is very little tolerance in the placement of the hold-down which may be difficult to achieve with the foundation anchorage. Refer to **Figure 4.27**.

Figure 4.28
Strap hold-down connection between floors

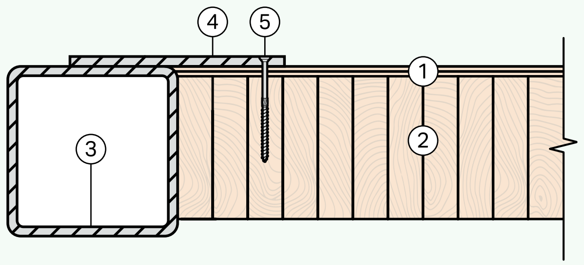


1. NLT wall
2. NLT floor sheathing
3. NLT floor
4. Floor topping
5. Proprietary hold-down with nailing pattern (coordinate with architect to conceal)
6. Slot hold-down through floor

Strap hold-down connection between floors

For hold-downs connected through NLT floors, a connection between the hold-downs above and below is required. This can be achieved with methods like those used in light-wood framed walls (e.g., a continuous strap through the floor, or hold-downs above and below the floor with a thru-rod between them). Consideration for concealment of the hold-down, like the hold-downs at the base of the wall is important. Additionally, the opening through the floor panel to accommodate either the strap or the rod is important. These can be considered as openings as discussed in Section 4.5.2 section of this chapter; in most cases these openings will be small enough to avoid any reinforcement or other action. Refer to **Figure 4.28**.

Figure 4.29
Alternate continuous steel post hold-down



1. NLT wall sheathing
2. NLT shear wall
3. Steal column
4. Welded plate to transfer overturning forces to steal column
5. Screws perpendicularly centered to lamination to transfer overturning forces to steal column

Alternate continuous steel post hold-down

Another option for hold-downs at all levels is to provide a continuous multi-level hold-down. Typical light-wood-frame continuous hold-downs would be difficult to conceal in an exposed wall condition. One option is the use of solid columns at the ends of walls that could accommodate a shear connection to the NLT wall panel as shown in **Figure 4.29**. The columns would then carry the tension through a column-to-column connection.

4.5 Additional considerations

Give special consideration to NLT systems with concentrated loads, openings, and cantilevers.

4.5.1 Point loads

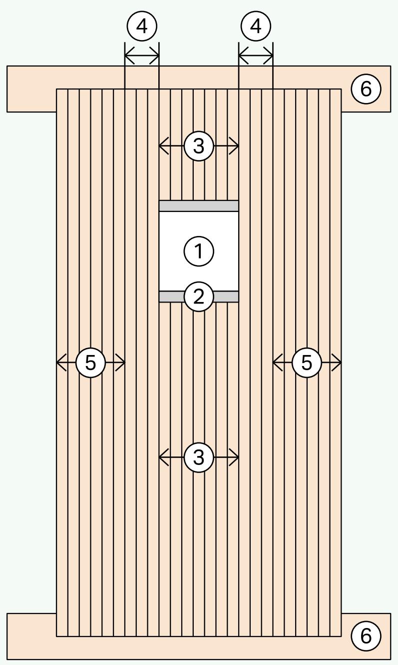
Point loads on NLT will be shared by multiple laminations but must be checked independently from uniform loads. A reasonable lower limit for the effective width of NLT resisting a point load can be taken as the load area plus 50% of the NLT panel depth (d) on either side of the loaded area. Treat line loads parallel to the NLT span in a similar fashion. For large point loads or line loads near supports, shear or bearing may govern the NLT design.

4.5.2 Openings

NLT is a one-way system, which means that openings often require additional analysis and reinforcement. The terminated laminations will deflect equally to the adjacent full-length courses. When considered as shorter laminations supported on a header or effective header, the laminations will be much stiffer than the adjacent laminations spanning the full panel span length, attracting significant additional load. A simplified grillage model study, like the one shown in **Figure 4.30**, can help define the loads that need to be transferred with either additional framing of connections between laminations [15].

This Guide defines small openings as 228 mm (9 in.) wide or less (up to six laminations for NLT fabricated from 2x material); other openings are considered large.

Figure 4.30
Idealized grillage model around panel openings



1. Opening
2. Opening support "beam" element. In some cases a steel framing member or support member below, in other cases a screw reinforced zone
3. Short NLT supported on opening support "beam" element
4. Opening edge member spanning between supports, support the opening support "beam" element. In some cases may be a steel or wood beam in line or below the panel, in other cases it may be a group of continuous NLT laminations.
5. NLT panel
6. NLT supports

Small openings (228 mm [9 in.] wide or less)

Small openings are considered in three categories:

1. Openings that can be provided without modifying the panel.
2. Openings that may require additional connection between laminations.
3. Openings that will require an explicit member to share the load between the support laminations.

Below UniverCity Childcare Centre, Burnaby BC
Architecture hcma *Photo courtesy of* hcma

The first group, consisting of small cores up to 114 mm (three laminations) diameter, such as for conduit or small pipes, can often be accommodated without reinforcement.

The second group, for openings up to 228 mm (9 in.) wide, provide reinforcement with fully threaded self-tapping screws or supplementary steel framing. Fully threaded self-tapping screws are a simple way to transfer shear around an opening. Installing inclined screws designed per CSA O86 Chapter 12.12 for inclined self tapping screw shear connections. The resistance of the shear connection between each lamination can be evaluated based on all the screws crossing that joint between laminations. Calculate the withdrawal resistance of the screws based on the threaded length on either side of the joint as discussed in CSA O86.

Approximate the applied shear load based on the shear force diagram of the opening end effective support member from the grillage model. The applied shear at the lamination joint at the edges of the opening can be taken as the total shear transferred to the effective opening support members. Ensure that at least one screw is fully penetrating all the laminations terminated at the opening and that all the laminations assumed to be supporting the terminated laminations are fully penetrated by at least one screw.

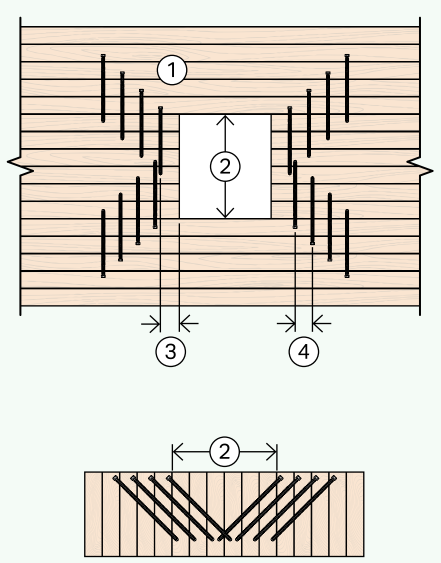
Refer to **Figure 4.31** for an example of an opening reinforced with fully threaded screws acting primarily in tension. The fastener pattern should ensure that every terminated lamination is fully penetrated by at least one screw, all screw heads are positioned outside the width of the opening, and the screw spacing meets the requirements of CSA O86, or the manufacturer's minimum requirement where they differ.

The last group, for openings up to up to 342 mm (nine laminations) steel reinforcement of small openings, as shown in **Figure 4.32**, is another option. The steel framing supports the terminated laminations and spreads the load onto the continuous laminations adjacent to the opening. Extend the supplementary framing at least half the width of the opening on both sides and check the laminations supporting the steel framing for the additional load determined per the grillage model. The extent of the steel support helps to ensure load transfer and stiffness compatibility of a sufficiently large number of adjacent laminations.

Where exposed steel on the underside of the NLT is undesirable for either architectural or fire-resistance purposes, an angle can be provided as shown in **Figure 4.32**. If the vertical leg can be embedded in a topping slab or other floor build-up, orient the leg upward for easier fabrication and installation. If projection above the NLT cannot be accommodated, the vertical leg can be oriented downward but will need to be coped at the edges of the opening. Use self-tapping screws that penetrate a minimum of 70% of the NLT depth to prevent splitting of the laminations.

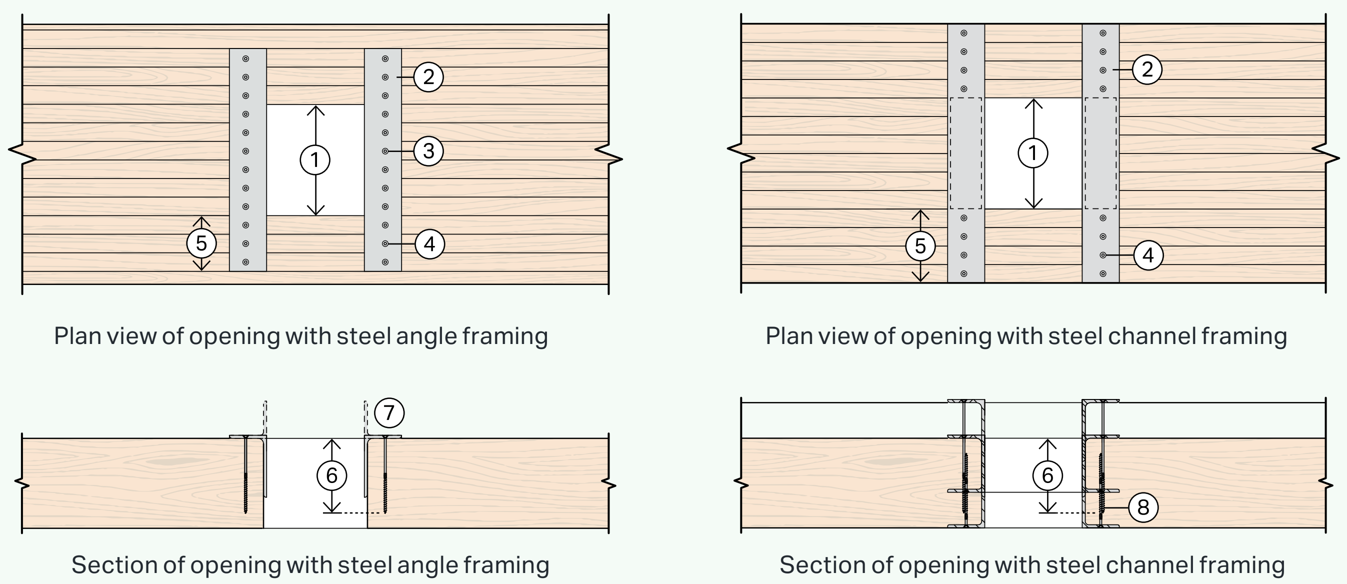
Alternatively, **Figure 4.32** shows a steel channel supporting the terminated laminations through a simple bearing connection with nominal screws provided. For this approach, the terminated laminations are supported by partially threaded self-tapping screws installed through the horizontal leg and centered on each lamination. In either case, only the top flange/horizontal leg is extended over the continuous courses to provide support through bearing on each lamination; provide nominal attachment with screws to each lamination.

Figure 4.31
Small opening with fully threaded screw reinforcing



1. Self-tapping fully threaded screws inclined 45°
2. Opening width
3. Fastener edge distance
4. Fastener spacing

Figure 4.32
Supplementary steel framing at small openings



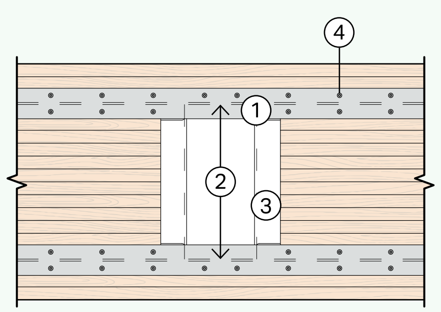
1. Opening width
2. Steel support framing coped at edgeof opening to extend top plate only
3. Self-tapping screws in withdrawl at opening
4. Nominal screws away from opening
5. Bearing over supporting continuous laminations
6. Screw length at 80% of NLT depth
7. Upturn leg to close concrete topping pour (if required)
8. Nominal screws from underside of NLT at opening

Below Fir ribbed NLT
Photo credit Wade Comer Photography
Photo courtesy of NaturallyWood

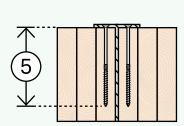
Large openings (greater than 342 mm [13.5 in.])

Larger openings require additional framing in both directions to support the terminated laminations, because the adjacent laminations are insufficient to carry the load. If added beams below the NLT are not desired, consider framing the opening within the depth of the NLT with steel members as shown in **Figure 4.33**. The members parallel to the NLT span extend from support to support and can be concealed by providing a T-section with the vertical web extending between laminations; provide nominal screws between the top flange and the continuous courses. The steel members supporting the terminated laminations can be detailed like those for small openings.

Figure 4.33
Supplementary steel framing at large openings



Plan view of opening



Section beyond opening

1. Steel T-section spanning between supports
2. Opening width
3. Steel framing at opening (channel or angle)
4. Nominal screws into NLT laminations
5. Screw length at 80% of NLT depth

4.5.3 Overhangs

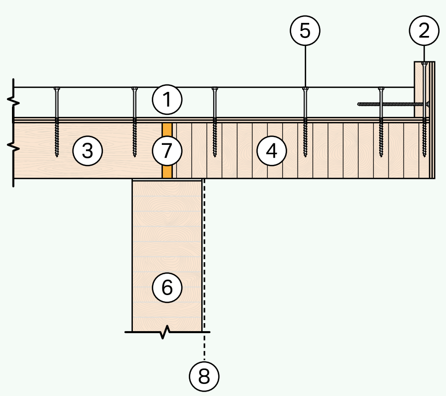
NLT cantilevers in the direction of the span are structurally straightforward; cantilevering in the weak axis direction is more challenging. Short weak-axis cantilevers can be accommodated using fully threaded self-tapping screws installed at a 45-degree angle, like the screw-reinforced openings shown in Figure 4.31. A suggested weak-axis cantilever of 228 mm (9 in., six laminations) is a reasonable limit for this type of detail.

NLT cantilevers that cross the building enclosure, such as eaves and entrance canopies, require special attention as discussed in Chapter 5. In cases where is it not possible, or not architecturally preferred to wrap the entire overhang, take special care to accommodate air barrier continuity, this can be challenging while maintaining an exposed underside. In these cases, ensure air barrier continuity in one of two ways: provide some type of flexible sealant between each lamination at the enclosure line, as discussed in Section 5.2.1, or provide a continuous break in the NLT and hang the cantilevered portion from outriggers installed above as shown in **Figure 4.34.**

Providing sealant between each lamination requires careful coordination with the fabricator and installer. One option is to leave all the laminations fully intact and use a thin sealant tape at each interface. This is complex from a fabrication perspective, particularly for M-NLT or NLT built in an automated fabrication facility. Another option is to kerf each lamination over its full height at the enclosure line and inject sealant into the kerfs. This approach eliminates the "bulge" problem but reduces the structural strength and stiffness of the NLT, which must be accounted for in the design.

Where a continuous break is provided in the NLT at the enclosure line, a secondary element is required to support the NLT. At roofs, this is done by hanging the NLT from outriggers using self-tapping screws, as shown in **Figure 4.34**, so the NLT can span in either direction. Details with upstand outriggers such as these are especially susceptible to moisture and must be designed accordingly: if improperly detailed, the increase in tensile stress in the screw resulting from moisture-induced wood swelling could cause brittle fracture of the screw. Where wood outriggers are provided, partially threaded screws ensure threads engage only in the NLT and not in the outrigger, as shown in **Figure 4.34**. This approach will ensure that extreme cases of swelling will result in crushing below the head of the screw, preventing excess tensile stress in the screws. Capacity can be increased somewhat by providing washer head screws or using separate washers below the screw heads. If steel outriggers are necessary, provide a compressible material between the outrigger and the plywood/OSB. The material should be strong enough to resist the design loads on the connection but weak enough to crush or deform sufficiently at a load below the screw's tensile strength.

Figure 4.34
Wood outrigger support for NLT overhang



1. Intermittent outrigger
2. Perimeter/Parapet member at outer edge
3. Interior NLT
4. Exterior overhang NLT
5. Self-tapping partially threaded washer or hex head screws supporting NLT overhang
6. Structural support
7. Insulation and air/vapour barrier
8. Building enclosure

Below
Tsleil-Waututh Administration and Health Centre, North Vancouver, BC
Architecture by Lubor Trubka Associates Architects
Photo credit Dr. Roman Trubka
Photo courtesy of NaturallyWood

4.6 Specifications

The new provisions in CSA O86 for MLT are intended to work alongside the new manufacturing standard, CSA O125 for certified panels. CSA O125 provides a fabrication standard for a certified MLT product, including both M-NLT and Dowel Laminated Timber (DLT). Specification references to the fabrication standard should be used with care and only on projects where M-NLT is required; be sure to discuss in-depth and coordinate with the consultant team accordingly. In some cases, certified panels may be aesthetically preferable as discussed in Chapter 2, or they may be preferred or even required for certain building classifications to meet the building code requirements as discussed in Chapter 3. In other cases, it may be best to exclude M-NLT, to achieve specific construction considerations (e.g., site-built conditions) or to achieve a certain form (e.g., panel curvatures); take care to ensure that the specification does not unintentionally preclude the type of NLT fabrication required to achieve the desired project outcomes.

Coordinate with the projects architect and building code consultant prior to the development of the specifications to discuss the classification of M-NLT or NLT, or the acceptance of either. If M-NLT is required it is recommended to contact local suppliers to confirm certification and availability. For projects requiring NLT to achieve specific construction conditions, architectural form, or other requirements, there may be a larger pool of manufacturers available. In either case, or if both options are acceptable, ensure the specifications are structured to suit. Refer to Appendix B for a sample specification.

Additional requirements in the specifications are critical for successful delivery of a project, including aesthetic requirements, for a weather protection plan during construction appropriate to the local climate and the specific project, and clear requirements for samples, mock-ups, and site review.

Refer to Appendix B for a sample NLT specification section, including both M-NLT and NLT approaches.

Below Fir end grain
Photo credit Wade Comer Photography
Photo courtesy of NaturallyWood

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5.0 Enclosure

5.0 Enclosure

Where NLT is used as part of the building enclosure, it works together with several other components to manage heat flow, air flow, and moisture loads.

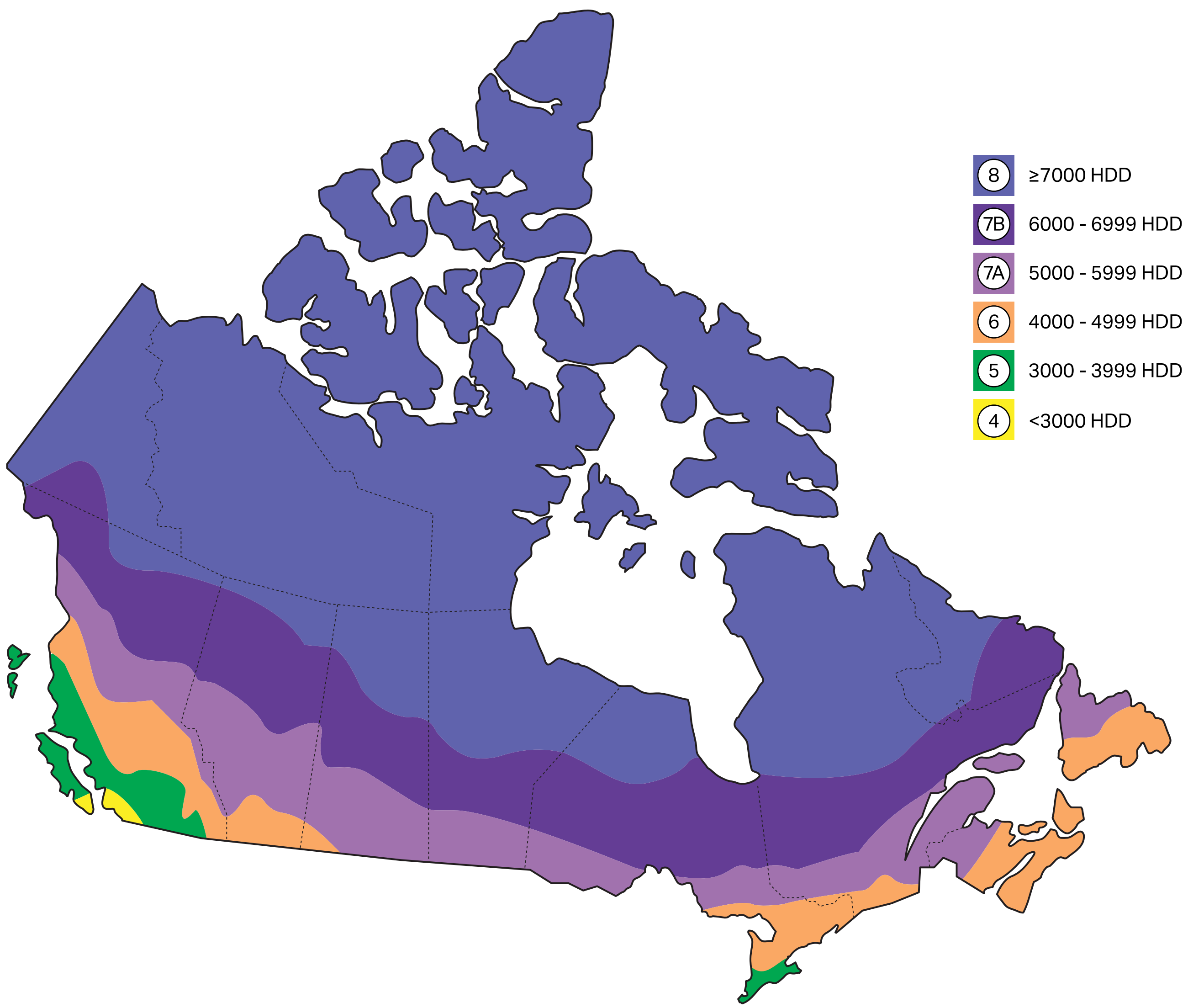


Figure 5.1 Climate zones across Canada based on NECB 2020 heating degree days [02]

A well-designed building enclosure accounts for climate specific conditions and building occupancy conditions both during construction, and throughout the service life of the building. Climate conditions across Canada vary widely (refer to **Figure 5.1**). Accordingly, properties and placement of control layers and components used with NLT will vary by project location. Control layers are stand-alone materials or systems of materials in the building enclosure that manage the indoor and outdoor loads of a building.

Control layers are designed to manage a specific load or loads; this chapter discusses the control of the heat, air, water vapour, and liquid water load respectively. For more information on the control layer concept discussed in this chapter refer to the Mass Timber Building Enclosure Best Practice Design Guide [01]. Careful consideration of the control layers and enclosure assembly interfaces and transitions are critical for the performance and durability of a building.

This chapter includes general discussion on the use of NLT in the building enclosure; unless specifically stated otherwise where "NLT" is referenced, information applies to both M-NLT and NLT as defined in the introduction to the guide.

5.1 Managing heat-flow

Managing heat-flow across the enclosure is important to reduce energy consumption, minimize condensation risk, and address occupant thermal comfort.

The National Energy Code of Canada for Buildings (NECB) [02] or project-specific energy performance targets will dictate the required thermal resistance (R-values) or thermal transmittance (U-factors) for the enclosure assemblies. For NLT assemblies, the heat flow path is predominantly across the grain of each lamination and is controlled by the inherent thermal resistance of the wood; thermal insulation, other enclosure layers, and surface air films also all provide resistance to heat flow.

Wood has a relatively low thermal conductivity compared to other structural building materials. Thermal conductivity and resistance values for common NLT lamination thicknesses and sheathing types are detailed in **Table 5.1A** through **Table 5.1C**.

Below Prince George Fire Hall No.1, Prince George, BC
Architecture by hcma *Photo credit* Ed White *Photo courtesy of* NaturallyWood

Table 5.1 Thermal conductivity and resistance values of common NLT softwood species, laminations, and sheathing

A Thermal conductivity values for common NLT softwood species

Species	Thermal conductivity		Thermal resistance - RSI (R-value)	
	W/m-K	Btu-in/h-ft²-°F	m²K/W	ft²°Fhr/Btu
Spruce-Pine-Fir	0.11 - 0.13	0.74 - 0.90	0.0085	1.23
Douglas Fir-Larch	0.14 - 0.15	0.95 - 1.01	0.0069	1.00
Hemlock-Fir	0.11 - 0.13	0.74 - 0.90	0.0084	1.21

B Typical NLT lamination R-values

Wood lamination nominal dimension		Actual thickness		Thermal resistance - RSI (R-value)	
		mm	inches	m²K/W	ft²°Fhr/Btu
2 x 4		89	3.5	0.61 - 0.76	3.50 - 4.31
2 x 6		140	5.5	0.97 - 1.19	5.50 - 6.77
2 x 8		184	7.25	1.27 - 1.56	7.25 - 8.92
2 x 10		235	9.25	1.62 - 2.00	9.25 - 11.38

C Typical sheathing R-values

Sheathing type	RSI/mm	R/inch	Thickness		Thermal resistance - RSI (R-value)	
	m²K/W	ft²°Fhr/Btu	mm	inches	m²K/W	ft²°Fhr/Btu
Plywood/OSB–Douglas Fir	0.0111	1.60	12.5	1/2	0.14	0.80
			15.5	5/8	0.17	1.00
			18.5	3/4	0.21	1.20
OSB	0.0098	1.41	11.0	7/16	0.11	0.62

* All material properties referenced from 2021 ASHRAE Handbook – Fundamentals [06] and NECB 2017 Users Guide [07].

In some climates, the mass of the NLT itself may contribute to moderating or potentially reducing heating and cooling loads. NLT may also contribute to overall thermal comfort as demonstrated in modelling exercises performed for CLT, a mass timber product of similar mass [03].

In all climate zones in Canada, it is best practice to locate the thermal insulation of NLT assembly on the outboard (i.e. on the predominantly cold side) of the NLT to best protect the wood from temperature fluctuations and related changes in moisture content. This stable environment will increase long-term durability of the NLT. Placing insulation on the outside also allows the NLT to remain exposed on the interior where desired, refer to discussion in Section 2.3 of this guide. In some circumstances, all or a portion of the thermal insulation may need to be located on the interior side of the NLT or both the interior and exterior of the NLT; however, this arrangement increases moisture accumulation and long-term durability related risks and needs to be carefully evaluated by a qualified design professional.

When a more highly conductive element, such as metal, bridges an insulation layer, it creates a path of lower resistance to heat flow. This path is commonly called a thermal bridge and will degrade the thermal performance of the insulation layer and overall assembly. Thermal bridging (i.e., a change in heat flow) may also occur at the interface between assemblies such as window-to-wall or roof-to-wall. This is often the result of additional conductive materials such as flashing or framing at the interface, reductions or even gaps in the insulation, or changes in geometry like corners. To meet the minimum insulation R-value or maximum assembly U-factor requirements of the NECB [02] provisions, thermal insulation is usually required with NLT, and the calculation of thermal transmittance must account for thermal bridging (refer to NECB 3.1.1.7).

At the exterior face-of-wall, cladding attachments through exterior insulation are thermal bridges and impact the overall thermal performance of the enclosure. The significance of the impact can vary widely based on the attachment system used. Generally, more thermally efficient options rely on lower thermal conductivity materials, such as stainless steel, fiberglass, and/or intermittent attachments through the insulation (e.g., clips or fasteners). For more information on the comparative performance and application of various cladding attachment systems, refer to Cladding Attachment Solutions for Exterior-Insulated Commercial Walls and the Building Envelope Thermal Bridging Guide [04] [05]. Other examples of common thermal bridges to consider include roof fasteners, windows, parapets, balconies, and canopies.

Tables 5.2a and 5.2b describes conventional and inverted roof membrane assemblies commonly used with NLT respectively. Where tapered roof insulation is used, calculating the assembly's effective thermal performance becomes more complex. Refer to Technical Bulletin "Effective U values (R values) for Tapered Insultation" available online for additional discussion and for effective R value design tables [08]. For a simplified, conservative approach, the tapered portion of the insulation could be neglected in the roof assembly calculation. Table 5.3 describes common NLT floor/soffit assemblies. In some conditions the temporary moisture management systems (TMMS) may serve as the permanent air or vapour barrier, refer to Section 8.6 for more information on construction moisture management and TMMS.

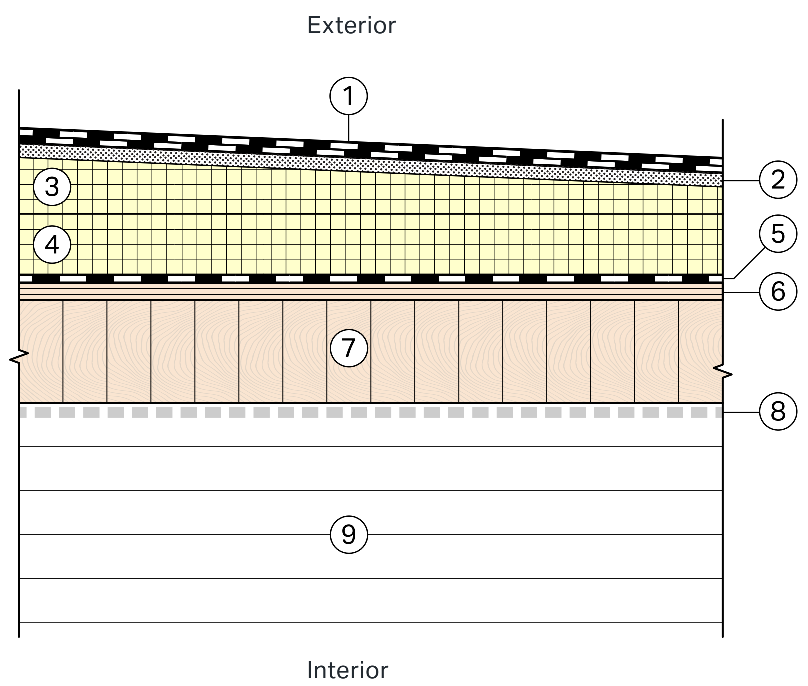
Table 5.4 describes wall assemblies commonly used with NLT. This guide recommends the use of a drained and ventilated rainscreen assemblies and details for all NLT walls in all climate zones. Table 5.5 describes an NLT wall that separates a conditioned and unconditioned space but is not exposed to exterior water loads (e.g., in a fully sheltered garage space).

Right Steveston Fire Hall No. 2, Richmond, BC
Architecture by hcma *Photo courtesy of* hcma

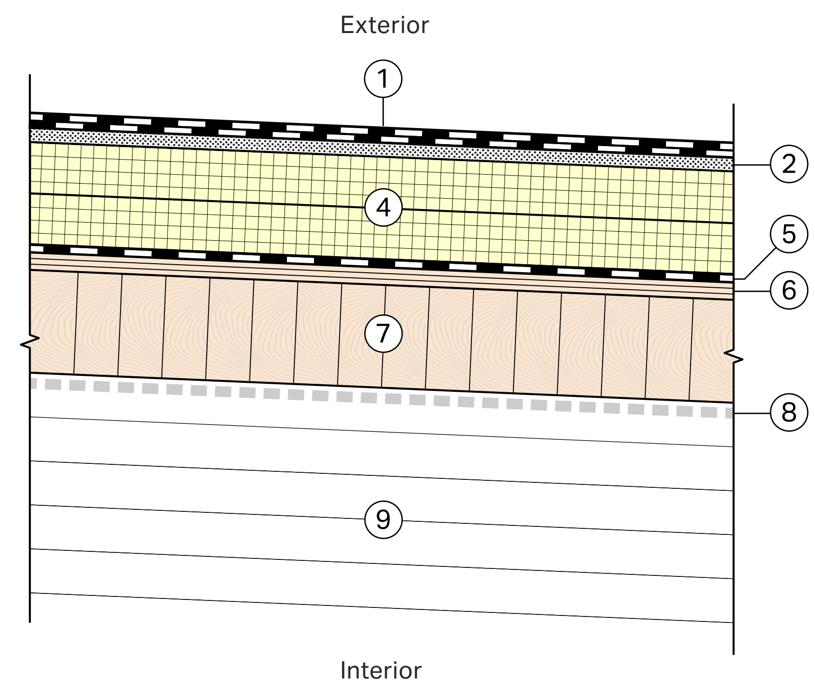
Table 5.2a Conventional roof assemblies

Typical assembly layers

Conventional roof with tapered insulation



Conventional roof with sloped structure



Legend

1. Roof membrane
2. Coverboard
3. Tapered rigid insulation
4. Continuous rigid insulation
5. Air/vapour control membrane/TMMS
6. Structural sheathing (plywood/OSB)
7. NLT
8. Encapsulation material (where required*)
9. Roof support (beyond)

Assembly enclosure considerations

The air and vapour control membrane is an applied membrane and exists on the warm side of the insulation. The air and vapour control membrane may also serve as a temporary moisture management system (TMMS), as further discussed in Section 8.6.

Carefully consider the vapour permeance of all assembly layers relative to the NLT and interior/exterior environmental conditions. Electronic leak detection is recommended in unvented NLT roof systems. See Section 5.4.1 for more information.

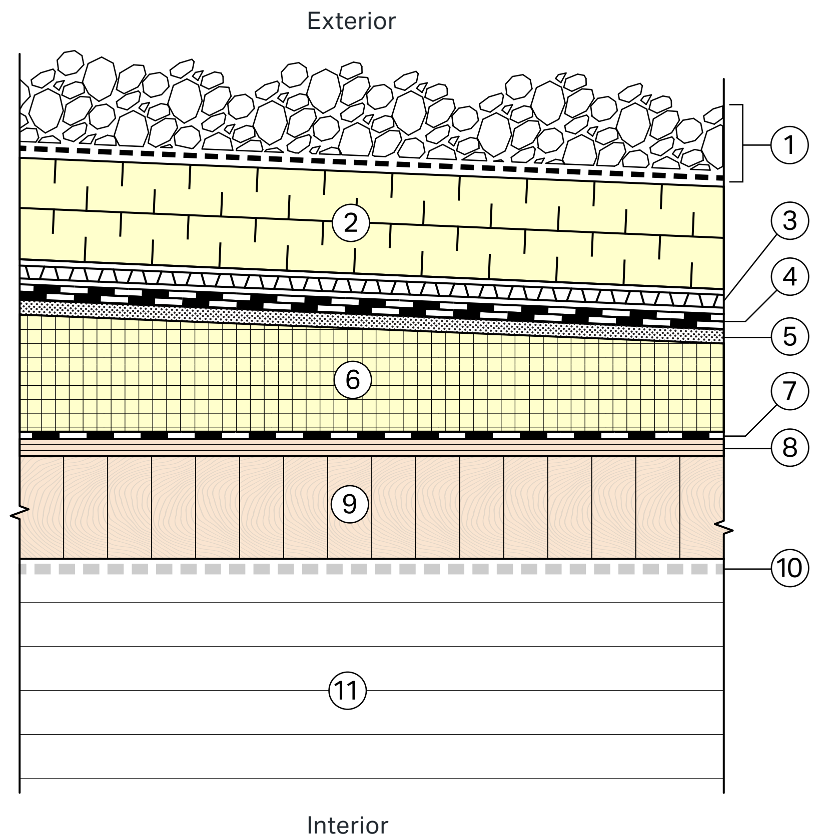
EMTC considerations

* Encapsulation materials may be required. The fire protection requirements of NLT are based on occupancy, building area, building height, and the presence of a sprinkler system. Refer to Chapter 3 Sections 3.1 and 3.2 for more information. Encapsulation materials are often moisture sensitive and/or reduce the drying capability of the NLT once installed. Include protection of encapsulation materials in a project's moisture management plan. Refer to Chapter 8 Section 8.6.

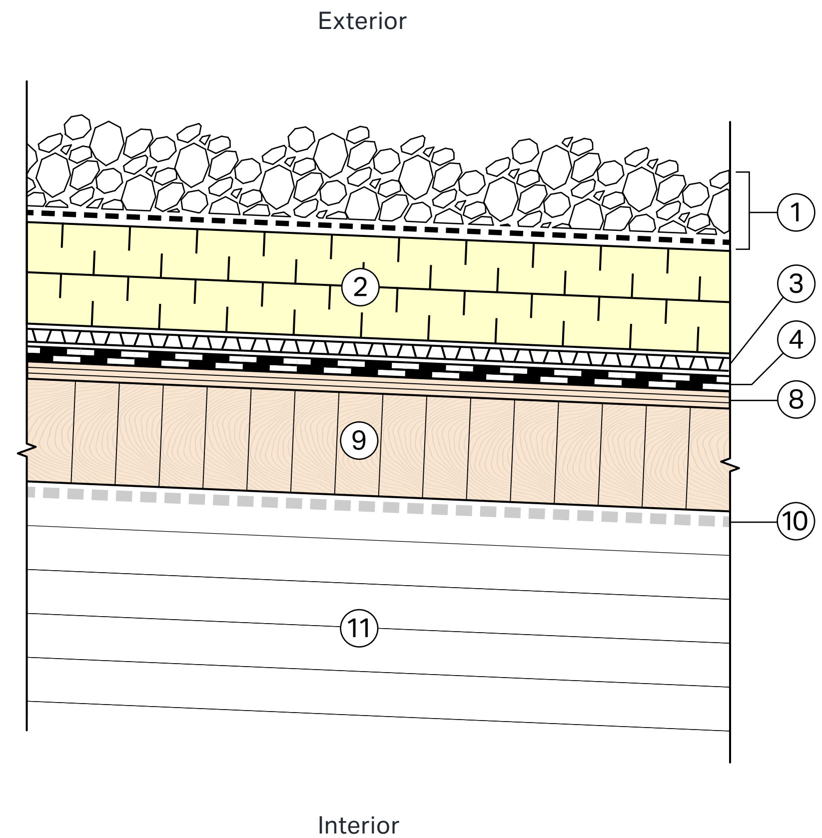
Table 5.2b Inverted roof assemblies

Typical assembly layers

Inverted roof with tapered insulation



Inverted roof with sloped structure



Legend

1. Overburden/ballast and filter fabric
2. Extruded polystyrene (XPS) insulation
3. Drainage composite
4. Roof membrane
5. Coverboard
6. Tapered rigid insulation
7. Air/vapour control membrane
8. Structural sheathing (plywood/OSB)
9. NLT
10. Encapsulation material (where required*)
11. Structural support (beyond)

Assembly enclosure considerations

- The roof membrane or air and vapour control membrane may also serve as a temporary moisture management system (TMMS), as further discussed in Section 8.6.
- Some structural sheathing substrates or TMMS (where the TMMS does not serve as the final roof membrane) may not provide an appropriate roof membrane substrate due to chemical or adhesion incompatibility; an additional sheathing layer may be required.
- Evaluate the risks of construction phase moisture where the TMMS is not located directly on the structural sheathing of the NLT.
- Carefully consider the vapour permeance of all assembly layers relative to the NLT and interior/exterior environmental conditions.
- In the sloped structure assembly, the fully adhered roof membrane serves as the air and vapour control layer.
- Inverted assemblies may be used for green roof assemblies. Electronic leak detection is recommended in unvented NLT roof systems, and strongly recommended for green roofs. See Section 5.4.1 for more information on interior-vented roof assemblies.

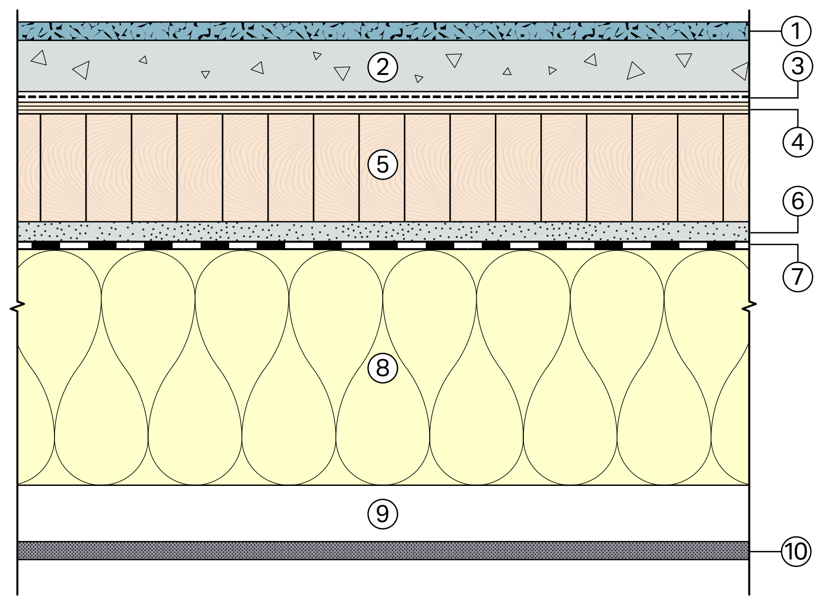
EMTC considerations

* Encapsulation materials may be required. The fire protection requirements of NLT are based on occupancy, building area, building height, and the presence of a sprinkler system. Refer to Chapter 3 Sections 3.1 and 3.2 for more information. Encapsulation materials are often moisture sensitive and/or reduce the drying capability of the NLT once installed. Include protection of encapsulation materials in a project's moisture management plan. Refer to Chapter 8 Section 8.6.

Table 5.3 Exterior floor/soffit assembly

Typical assembly layers

Floor/soffit with air permeable insulation



Legend

1. Interior finish and acoustic components
2. Concrete topping or similar encapsulation material, (where required*)
3. Temporary Moisture Management System (where required) Refer to Section 8.6.
4. Structural sheathing (plywood/OSB), sealed
5. NLT
6. Encapsulated material, (where required*)
7. Air barrier and water-resistive barrier membrane (vapour-permeable)
8. Exterior insulation (between structure beyond)
9. Furring/Air cavity (vented to exterior)
10. Soffit panel

Assembly enclosure considerations

- The preferred air control layer of the soffit assembly is the structural plywood/OSB sheathing. This requires the sheathing to be continuously sealed at joints and transitions to the air control layer at walls above and below. However, in small soffit areas, it may be suitable for the air control layer to be an air barrier membrane over a sheathing layer at the underside of the soffit.
- Thermal insulation in this assembly may be batt, rigid board, or spray applied insulation to fit tightly to the structure.
- Consider a waterproof finish floor coating where wet conditions or risk of plumbing failures exist at interior space.
- Carefully consider the vapour permeance of all assembly layers relative to the NLT and interior/exterior environmental conditions.

EMTC considerations

* Encapsulation materials may be required. The fire protection requirements of NLT are based on occupancy, building area, building height, and the presence of a sprinkler system. Refer to Chapter 3 Sections 3.1 and 3.2 for more information. Encapsulation materials are often moisture sensitive and/or reduce the drying capability of the NLT once installed. Include protection of encapsulation materials in a project's moisture management plan. Refer to Chapter 8 Section 8.6.

Table 5.4 Exterior wall assemblies (shown in plan view)

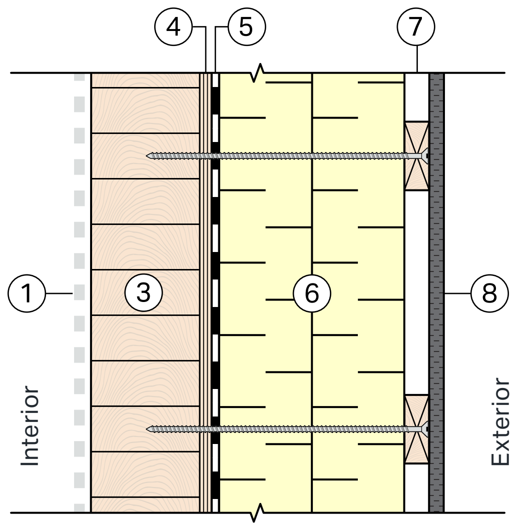
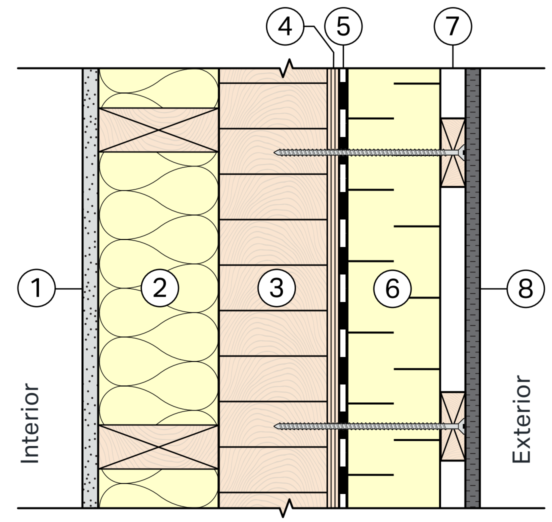
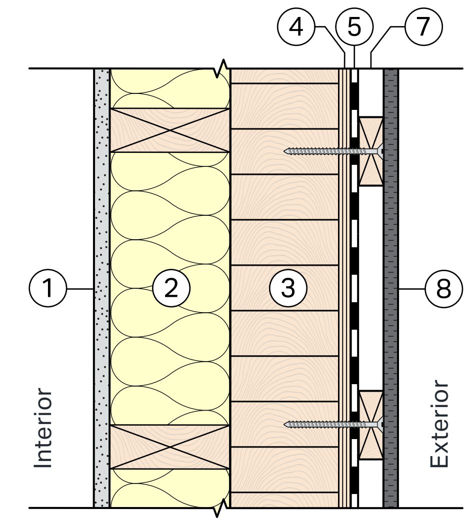
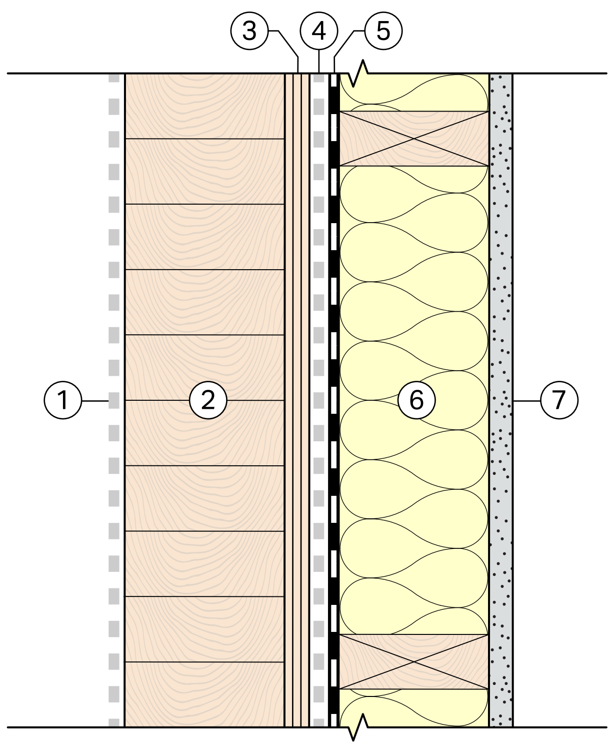
	Exterior-insulated	Split-insulated	Interior-insulated	Legend
Typical assembly layers				1. Encapsulation material/interior finish (where required *) 2. Interior insulation 3. NLT 4. Structural sheathing (plywood/OSB) 5. Air barrier and water-resistive barrier (vapour-permeable) 6. Exterior insulation 7. Furring / Air cavity (vented and drained to exterior) 8. Cladding
Assembly enclosure considerations	• The NLT and sheathing on the interior provides sufficient vapour resistance to outward vapour drive, eliminating the need for further vapour control. The use of vapour-permeable exterior insulation (>10 perms) and a self-adhered vapour-permeable air barrier and water-resistive barrier (WRB) membrane outboard of the NLT is the most durable approach because it allows for outward drying of initially wetted NLT or the drying of small leaks in service. • The use of either vapour-impermeable exterior insulation or a vapour-impermeable air barrier and WRB membrane can significantly limit outward drying and therefore should only be used with extreme caution with very dry NLT. • Caution must be taken where the indoor relative humidity is expected to be elevated, such as in densely occupied housing, museums, and pools.	• The use of both exterior and interior insulation may be desirable in some wall designs. This approach improves the overall effective R-value with less exterior insulation. It also benefits acoustics considerations by not leaving the NLT exposed. • The guidance for exterior-insulated wall assemblies applies to this design approach; however, care must be taken to assess the ratio of exterior to interior insulation and material properties of the selected materials. The addition of interior insulation keeps the NLT cooler than the exterior-insulated case. Too much interior insulation could make the surface of the NLT drop below the dewpoint of the indoor air and make the assembly at risk for condensation or moisture accumulation. As a result, this type of wall assembly should be assessed by a design professional. • To reduce this risk, the insulation R-value of the exterior insulation should generally be 50% or more of the wall assembly total R-value for low- humidity spaces, and over 65% for moderate- and high-humidity spaces. This ratio can be conservatively determined by assessing the dewpoint temperature or more accurately using hygrothermal modelling. • The interior insulation is vapour permeable, and no supplemental vapour control layer is included on the interior. The interior insulation can be used for acoustic and/or fire protection purposes.	• The use of interior insulation improves the overall effective R-value of the assembly without the use of exterior insulation. This option still benefits acoustic considerations by not leaving the NLT exposed. • Interior-insulated NLT wall assemblies are not generally recommended in Canadian climate zones (i.e., Climate Zones 4 through 8) except in unique indoor climatic situations and with special attention to the selection of materials and details. These exceptions may include cold-storage facilities and other unique indoor uses. In typical exterior conditions, this assembly design keeps the NLT cold and damp (it will come into approximate equilibrium with the average outdoor relative humidity) and prone to air leakage and vapour diffusion condensation, further increasing moisture levels above ambient. Therefore, the interior insulation needs to be vapour impermeable to control wetting from the interior; as such, interior drying is not possible, and outward drying through the cold, damp NLT is very slow. In all cases, a rainscreen cladding is highly recommended due to this highly sensitive design. This type of wall assembly should typically be assessed by a design professional.	**EMTC considerations** * Encapsulation materials may be required. The fire protection requirements of NLT are based on occupancy, building area, building height, and the presence of a sprinkler system. Refer to Chapter 3 Sections 3.1 and 3.2 for more information. Encapsulation materials are often moisture sensitive and/or reduce the drying capability of the NLT once installed. Include protection of encapsulation materials in a project's moisture management plan. Refer to Chapter 8 Section 8.6.

Table 5.5 Interior wall assembly at unconditioned spaces (shown in plan view)

Interior wall at unconditioned spaces

Typical assembly layers



Legend

1. Encapsulation material (where required*)
2. NLT
3. Structural sheathing (plywood/OSB)
4. Encapsulation material (where required*)
5. Air barrier membrane
6. Insulation
7. Finish (optional)

Assembly enclosure considerations

- The purpose of these interior wall assemblies is to isolate conditioned spaced from unconditioned spaces that are not exposed to rain, sun, and wind exposure. Examples include a wall assembly that separates an unconditioned garage or cold storage space from a common interior conditioned space such as an office, retail, or residential unit. As a result, this assembly typically does not need a water resistive barrier but likely requires air, thermal, and vapour control to adequately perform.
- Insulation requirements for this assembly could be optional depending on the space heating requirements on either side of the assembly. This wall as shown behaves similarly to the Exterior Insulated Wall in Table 5.4.

EMTC considerations

* Encapsulation materials may be required. The fire protection requirements of NLT are based on occupancy, building area, building height, and the presence of a sprinkler system. Refer to Chapter 3 Sections 3.1 and 3.2 for more information. Encapsulation materials are often moisture sensitive and/or reduce the drying capability of the NLT once installed. Include protection of encapsulation materials in a project's moisture management plan. Refer to Chapter 8 Section 8.6.

5.2 Air-flow

Managing air flow across the building enclosure is a requirement of the National Building Code of Canada (NBC) [09], and is key for reducing energy consumption, increasing thermal comfort, and minimizing the movement of water vapour into an assembly (refer to Section 5.3 for more on managing water vapour transport). Addressing air flow also minimizes the transfer of sound, smoke, fire, and contaminants between environments.

Managing air flow across the building enclosure is accomplished by using an air barrier system: a three-dimensional system of materials designed and constructed to control air flow across the building enclosure. An air barrier system has five basic requirements as described by Straube [10]; consider these requirements specific to NLT assemblies as follows:

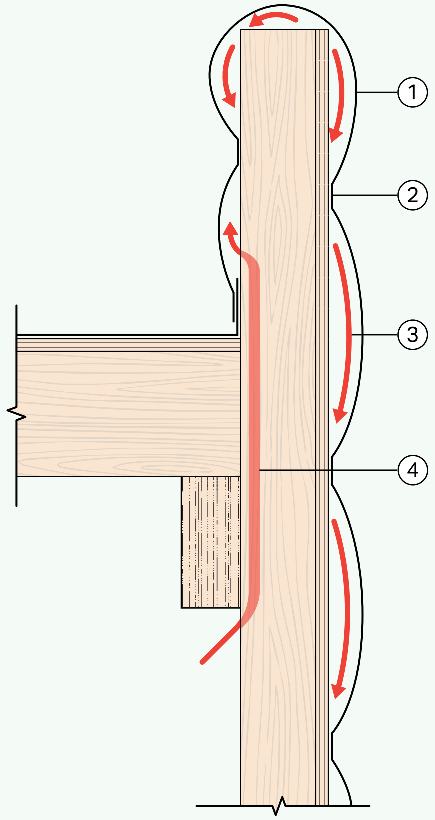
1. **Stiffness:** The air barrier system must withstand the air pressure forces acting on it without deforming or deflecting in such a way that inhibits the system's ability to perform as intended (refer to Figure 5.2). Mechanically attached exterior sheathing membranes are not fully adhered and are therefore more likely to be damaged by wind loads if not adequately secured. In walls, the risk of damage by wind loads can be reduced by promptly installing strapping or exterior insulation to secure the membrane. In walls or horizontal NLT assemblies, the risks can be overcome by substituting a mechanically attached membrane for a fully adhered or constrained air barrier membrane, or by using the structural plywood/OSB over the NLT and continuously air sealing/taping joints and transitions.
2. **Impermeability:** Air barrier systems must be impermeable to air flow. Typically, NLT laminations alone are not part of the air barrier system. While individual laminations may have a very low air permeability, the spaces or gaps between each lamination and between laminations and sheathing allow the passage of air. To address this, an air barrier system independent of the NLT is needed. Often, continuously sealed sheathing or membranes are used as part of the air barrier system.
3. **Continuity:** The materials within the air barrier system must form a continuous boundary. Ensure that the air barrier system of the NLT assembly is continuous at all joints and penetrations, and interfaces with other assemblies. Examples of air barrier transitions between typical NLT assemblies are shown in Figures 5.3, 5.4, and 5.5. Where the NLT is part of the air barrier system as shown in Figure 5.5, refer to Section 5.2.1 for guidance on special considerations.
4. **Strength:** The air barrier system must be strong enough to transfer air pressure differentials back to the structure. Where the NLT structure is strong enough to carry this load, the membrane and components that serve as the air barrier system should be fully adhered or mechanically attached to the NLT structure.
5. **Durability:** The air barrier system must perform over the service life of the building. The air barrier system must withstand temperature fluctuations, building movement, air pressure differentials, and environmental exposures (e.g., UV and site contaminants) which may occur during the building's service life.

The five attributes detailed above are specific to building service life; however, if installed as part of the Temporary Moisture Management System (TMMS), air barrier materials must also be strong and durable during the construction phase to ensure long-term performance of the system. Carefully consider UV exposure, moisture exposure, wind pressures/gusts, and trade activities.

The location of the air barrier membrane within typical NLT assemblies is shown in Tables 5.2a, 5.2b, 5.3, 5.4, and 5.5.

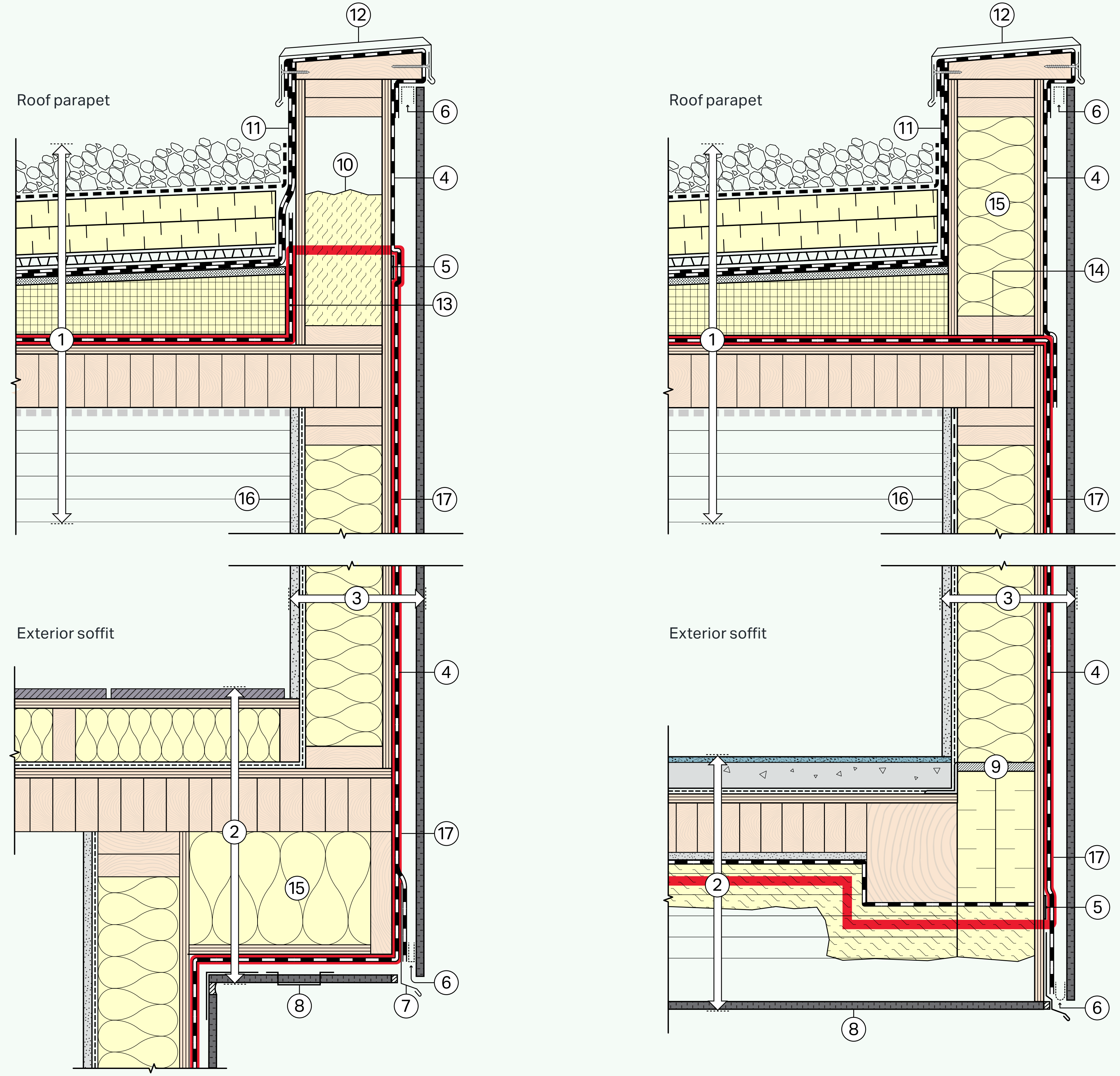
Left
Steveston Fire Hall No. 2, Richmond, BC
Architecture by hcma *Photo courtesy of* hcma

Figure 5.2
Potential deformation or deflection of air barrier system from forces of air pressure at balloon framed parapet



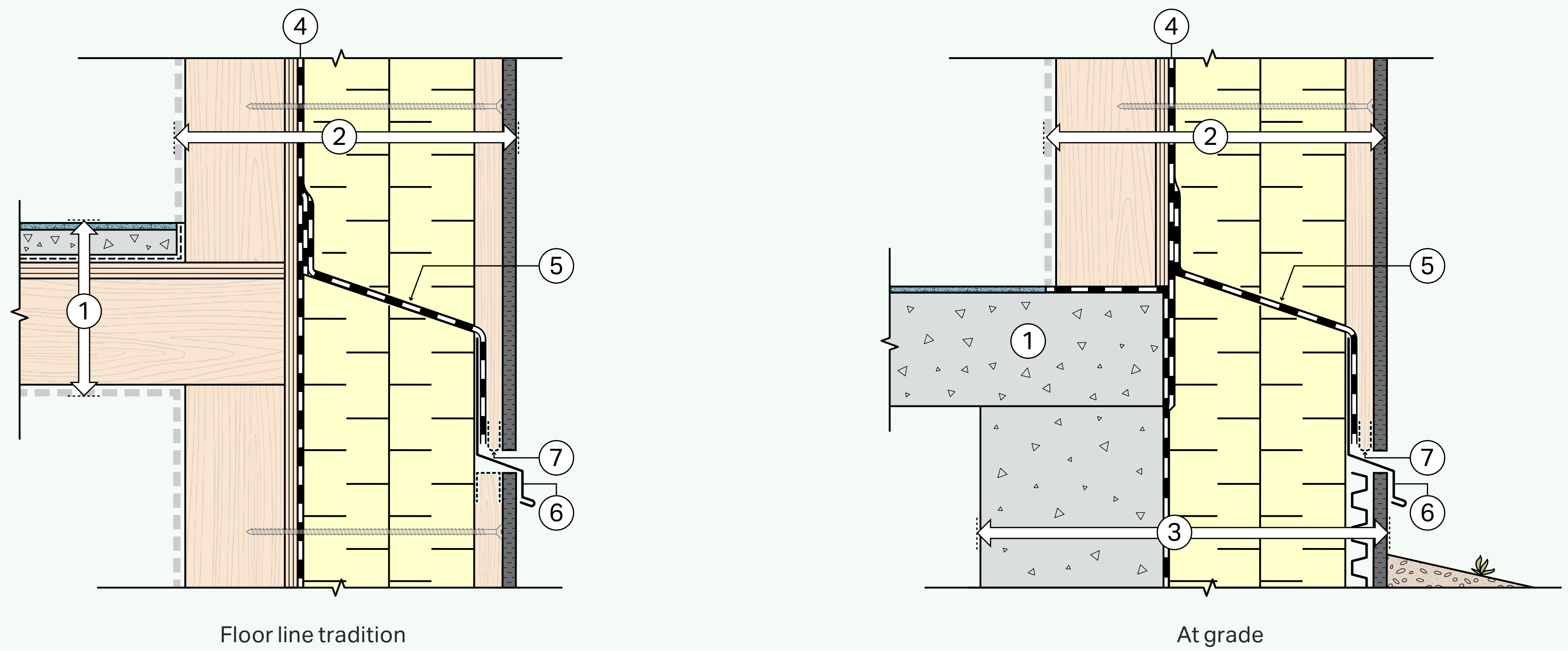
1. Mechanically attached air barrier membrane
2. Intermittent fasteners per manufacturer requirements
3. Airflow causing billowing and potential membrance damage
4. Airflow pathway through joints and piles

Figure 5.3
Example horizontal NLT assembly details



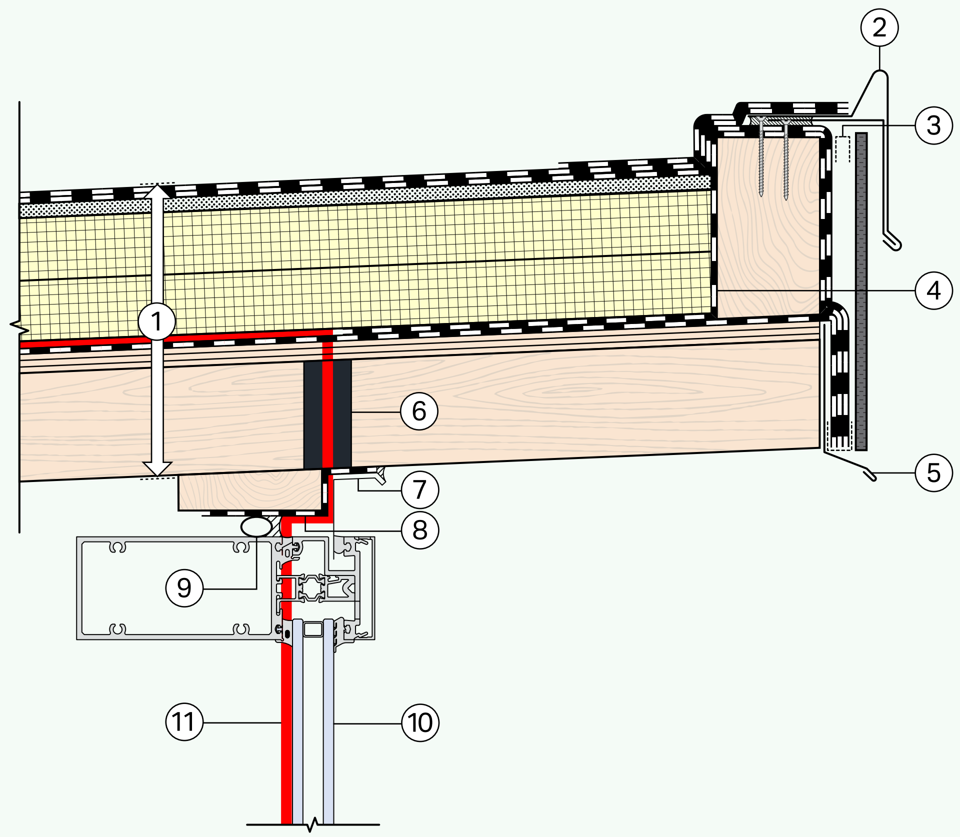
1. Inverted roof assembly (refer to **Table 5.2b**)
2. Exterior soffit assembly (refer to **Table 5.3**)
3. Framed exterior wall assembly with drained (and often vented) cladding
4. Water-resistive and air barrier membrane, shingle lapped and continuously taped/sealed
5. Air barrier transition seal
6. Insect screen
7. Sheet metal drip flashing, shingle lapped by item 4
8. Soffit panel (often vented)
9. Approved smoke seal
10. Continuous air impermeable insulation
11. Roof membrane up parapet
12. Sheet metal coping over high temperature membrane and sloped treated blocking
13. Air/vapour control membrane, upturned at parapet
14. Air/vapour control membrane, continuous under parapet with a sealed lap over item 4
15. Air permeable insulation
16. Drywall
17. Continuous air barrier system (red)
    NOTE: details may vary by climate zone and building use

Figure 5.4
NLT wall floor line detail with base of wall detail



1. Interior floor assembly
2. Exterior insulated NLT wall assembly (see **Table 5.4**)
3. Below grade wall
4. Air barrier and water-resistive barrier membrane (vapour-permeable)
5. Cross cavity flexible flashing
6. Sheet metal flashing with hemmed drip edge
7. Insect screen

Figure 5.5
Example horizontal NLT roof assembly to soffit transition detail at window head



1. Conventional roof assembly (refer to Table 5.2a)
2. Roof termination detail
3. Insect screen
4. Air/vapour control/TMMS membrane
5. Sheet metal flashing with hemmed drip edge
6. NLT panel air seal
7. Sheet metal closure flashing with crimp, sealed
8. Water-resistive and air barrier flashing membrane
9. Continuous air barrier backer rod and pre-formed sealant extrusion joint
10. Window system
11. Continuous air barrier system (red)

Note: Details may vary on climate zone and building use

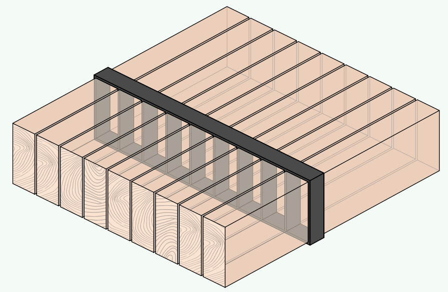
5.2.1 Special detail considerations

In some instances, the NLT may become part of the air barrier system, such as in a cantilevered condition as shown in **Figure 5.5**. In this instance, the NLT extends through the primary enclosure plane and can allow air flow across the enclosure, resulting in heat loss and movement of water vapour. To manage this, carefully detail gaps between each lamination, between NLT and structural sheathing, and between NLT and continuous blocking (e.g., a fenestration or wall head). Be aware that the introduction of air sealing materials between laminations and/or sheathing will likely inhibit NLT from meeting CSA O125 certification. Successfully sealing these gaps for long-term air barrier system performance can be challenging. The protruding NLT shown in **Figure 5.5** also creates a thermal bridge at the wall and should be considered.

The air sealing materials are used to create an air seal as shown similarly in **Figure 5.5**. These materials need to withstand mechanical pressures between each layer while maintaining continuity and adhesion throughout shrinkage/swelling (refer to Appendix C) to be effective over the long term. Preformed butyl tape and expanding foam tape products as shown in **Figure 5.6** may provide better performance when installed between laminations and between sheathing and NLT interfaces. While preformed tapes are easier to control throughout the fabrication process, they increase the overall gap dimension between laminations and can distort alignment; to maintain straightness and overall uniform panel dimensions, it may be necessary to install tape or shims throughout the NLT. Sealant and spray foam products commonly used for air sealing are typically avoided; they have a limited ability to accommodate movement when sandwiched between materials and can be difficult and messy to install effectively during the fabrication and/or construction process.

Alternate soffit/overhang transitions, such as the outrigger support concept presented in Section 4.5.3, may be considered. However, the NLT roof and soffit panel interface, as shown in Figure 4.34, can allow air to infiltrate if air barrier tape or membrane products are not carefully detailed. This transition can also be difficult to execute due to construction sequencing and material limitations. Furthermore, as noted in Chapter 4, outrigger support connections can be sensitive to moisture.

Figure 5.6
NLT panel with preformed tape



Applied example

Air leakage at DLT soffit

Project context

The project includes DLT panels for the roof system with large overhangs beyond the glazed storefront window system (**Figure 5a**). While the product used here is DLT, the example and lessons learned are applicable to NLT and M-NLT. The soffit with exposed DLT is running continuously from interior to exterior of the building, interrupting the continuous air barrier at the interface between the storefront window head and the soffit. There is a visible gap at the DLT panel joint.

The issue

Air leakage was identified as a concern for the enclosure of the system, leading to investigation of the performance at the interface between the wall and/or window head, and the continuous DLT roof soffit. Air leakage can negatively affect the thermal comfort of occupants and increase heating and cooling loads of the building. Air leakage can also increase risk of condensation, which can impact durability of the structure and potentially degrade the DLT panels.

Figure 5a DLT soffit
Photo courtesy of RDH Building Science

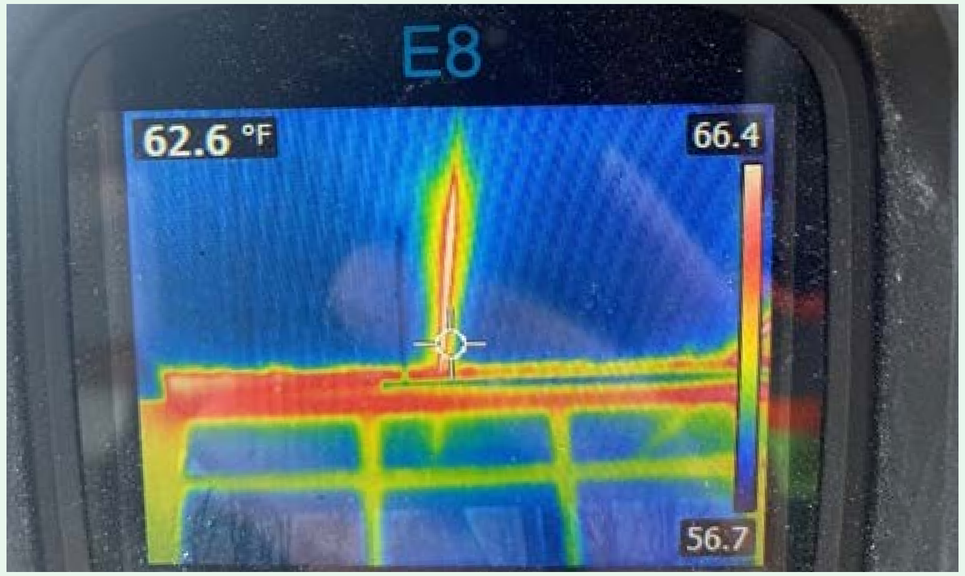
Investigation

The interior building space was pressurized with air warmer than the exterior air, and infrared scanning was utilized at the interface locations to identify potential air leakage paths. At the soffit, striations in the blue lines correspond to the location of panel laminations (**Figure 5b**) and two significant thermal anomalies were observed:

- A thermal anomaly appears which corresponds to the panel joint, shown in red, white and yellow.
- A thermal anomaly is observed along the interface between the window header and DLT soffit indicated in red and yellow.

Diagnostic smoke testing was done to further define the air leakage problem and its extent.

Figure 5b Infrared image identifies thermal anomaly suggesting air leakage between lamella and through the DLT panel joint *Photo courtesy of* RDH Building Science



Remediation

After the degree of air leakage is defined, remediation should include sealing of the gaps with appropriate sealant. Testing would be repeated as necessary to verify that the remediation air sealing achieved an acceptable level of airtightness. It may also be necessary to implement a long-term maintenance plan to monitor the development of new air leakage locations, given the inherent properties of DLT systems that swell and shrink with variations in humidity.

Lesson learned

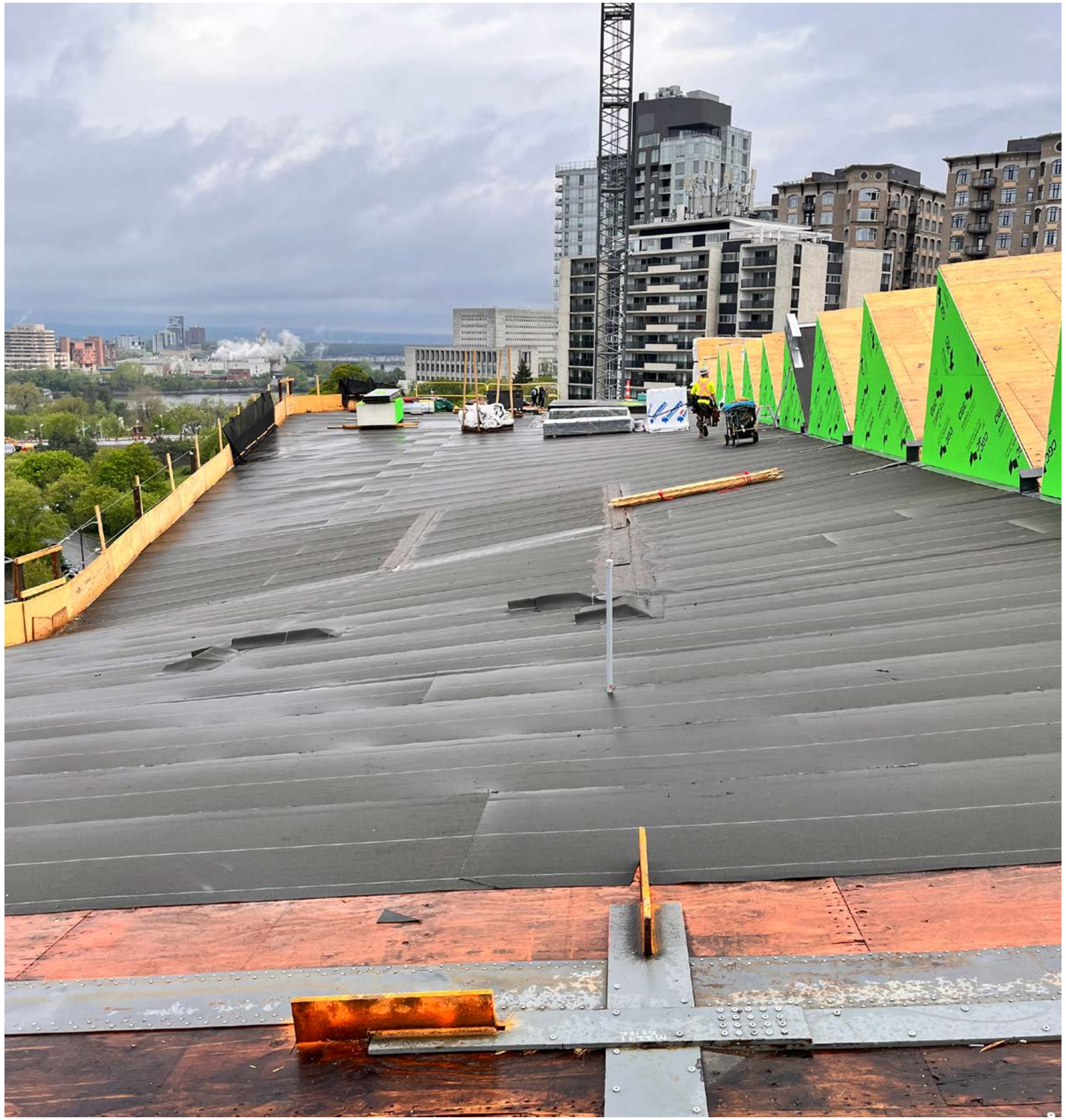
Detailing to manage or prevent air leakage at panel overhangs can help avoid potential air leakage after the building is completed. Where the appearance of continuous DLT or NLT is desired from interior to exterior, consider these two approaches:

- Design panels to avoid DLT panel continuity from interior to exterior and instead include a continuous air barrier above the window head to prevent air movement, per Figure 4.34 in Chapter 4.
- Carefully detail the continuous DLT panel to create a continuous air barrier with adjacent assemblies (refer to Figure 5.5) and seal between laminations with sealant and/or preformed butyl tape (refer to Figure 5.6). It is recommended that a mockup of this approach is built and tested for each project-specific application to verify the installation will appropriately manage air movement.

Designs that appropriately manage air leakage will generally offer improved performance and avoid costly retrofit after the building is complete and occupied.

5.3 Water vapour transport

Below Partially installed air/vapour membrane, Ādisōke Public Library, Ottawa, ON
Architecture by Diamond Schmitt *Photo courtesy of* Fast + Epp



Managing water vapour transport across an NLT assembly is accomplished with a water vapour control layer (e.g., vapour barrier), and by managing air flow with an air barrier system.

Air flow transports significantly larger amounts of water vapour than water vapour diffusion alone; however, both transport mechanisms should be carefully considered relative to the building's interior and exterior environmental conditions.

At thicknesses used for NLT laminations, wood has a water vapour permeance value of less than 0.1 perm-inch. Although NLT laminations are relatively vapour impermeable, gaps and checks within the laminations minimize the effectiveness of the NLT to manage water vapour transport; air flow can still occur through the lamination interfaces and panel joints as noted in Section 5.2.

To avoid water vapour accumulation and minimize condensation risks within NLT and to facilitate long-term durability, consider the vapour impermeability of the NLT relative to the assembly's insulation and air barrier system layers and locations. The vapour barrier control layer will vary with building occupancy; an example is shown in Table 5.2a, Table 5.2b, Table 5.3, Table 5.4, and Table 5.5, but is generally located on the warm side of the wall to minimize condensation risks.

Be aware that a vapour control layer and air barrier system in an NLT assembly can limit the ability of the NLT to dry, should it become wet during construction. Other low-permeability assembly layers and components can also limit drying. Accordingly, it is important that NLT laminations and sheathing are sufficiently dry prior to installing any subsequent enclosure layers, exposure to liquid water during construction is limited, and that the assembly is specifically designed for drying of construction moisture.

5.4 Liquid water

NLT exposure to liquid water can occur both during construction and once the building is in service.

Liquid water exposure can increase the risk for:

- **Dimensional changes due to shrinkage and swelling**: these changes can disrupt gaps between the NLT laminations and/or between NLT and penetrating or surrounding elements such as columns and wall structures.
- **Checking and warping due to rapid dimensional changes**: the changes can impact the aesthetic appearance of the NLT and/or disrupt panel alignment with structural elements.
- **Corrosion of mechanical fasteners:** corrosion may reduce the services life of some fasteners or create unsightly staining.
- **Staining:** surface corrosion of metal structures, fasteners, or their metal shavings can result in surface staining of the NLT that may need to be cleaned and removed.
- **Fungal growth**: surface fungal growth that does not lead to decay of structure can still cause aesthetic disruptions and increase the risk of negatively impacts on indoor air quality.
- **Decay of the NLT lamination and sheathing**: decay can impact the serviceability of the NLT lamination and sheathing should prolonged moisture exposure occur.

Due to the associated risks exposure to moisture, it is critical to minimize the exposure of NLT to moisture to maintain an NLT moisture content consistent with moisture in construction and in the final service condition. NLT will inevitably experience changes in its moisture content during construction but large fluctuations should be avoided by either protecting the NLT or removing standing water. The moisture content should not exceed 19% during construction and should be as close as possible to in-service conditions when it is being fully enclosed. Some drying should be expected for NLT within a conditioned space as the final service condition moisture content will be consistently below the moisture content of lumber used in construction. For more information on construction moisture management refer to Section 8.6 of this guide.

Liquid water at the roof is managed by the roof membrane; the location of this membrane and additional considerations are discussed in Tables 5.2a, 5.2b, and 5.3. To help ensure the long-term performance of the NLT roof during building occupancy, a durable, fully adhered (e.g., multi-ply) roof membrane installed on the NLT roof is recommended, especially where a TMMS is not used (refer to Section 8.6). Refer to the local provincial roofing contractor's association roofing practices manual or the roofing membrane manufacturer literature for more on best practices.

Floor assemblies are generally not exposed to liquid water during a building's service life except for plumbing and appliance failures and wet in-service building conditions. Where the risk of wet interior conditions exists, consider a waterproof floor coating over top of the plywood/OSB sheathing and, where possible, provide a means for slope and drainage; avoid a waterproof floor covering directly over the NLT. Managing liquid water at NLT soffit assemblies is also accomplished by managing water at the adjacent perimeter wall interfaces using deflection mechanisms such as base-of- wall sheet-metal flashings as shown in Figure 5.4.

When concrete toppings are to be installed at floor assemblies, maintain the moisture content of the NLT below approximately 16% prior to concrete placement. Concrete toppings trap moisture within the NLT for extended periods of time, so coatings or membranes on the top side of the NLT may be necessary prior to concrete placement. Refer to Chapter 4 for structural considerations for the placement of concrete topping.

Liquid water at wall assemblies is managed first by the water-shedding surface, which includes cladding, flashings, and other surfaces facing the exterior environment. Water is managed secondly by the water-resistive barrier (WRB) membrane system, the location of this membrane and additional considerations are discussed in Table 5.4. The best practice strategy for water control in NLT walls is the use of a drained and ventilated cladding (i.e., rainscreen cladding). This is a common construction practice in the wetter regions of Canada. While this strategy may seem excessive in some climates, it provides necessary redundancy in the water management design for NLT walls. This design approach also provides an outlet for inward-driven moisture from more absorptive claddings (i.e., reservoir claddings)—such as stucco, brick, and stone masonry—and other porous cladding materials.

In a rainscreen cladding design, the water-shedding surface, including the cladding, sheds most of the water load from the exterior surface of the wall. Moisture that penetrates the water-shedding surface will run down the backside of the cladding, the strapping, the exterior insulation (where present), or the WRB system before it reaches the flashings at floor levels and around wall penetrations, such as windows. The WRB is a secondary plane of protection against liquid water and the innermost plane that can safely manage and drain any incidental moisture load.

In many cases, this same WRB membrane is also sealed and detailed as the air barrier system of the building enclosure. Refer to Section 8.6 for discussions on managing liquid water during the construction phase.

5.4.1 NLT venting and leak detection in roofs

Visually detecting a roof leak can be difficult in an NLT roof assembly because the NLT can absorb moisture; structural sheathing can further mask the presence of water. One option to consider is venting to the building interior to facilitate drying of the topside of the NLT. While wetting and leaks should be avoided wherever possible, if possible, include a space above the NLT components to improve the for drying and therefore minimizing the risk of exposing the NLT to long-term moisture and mitigating the associated effort and cost to correct it. The same space is also a convenient access to visually identify a leak location.

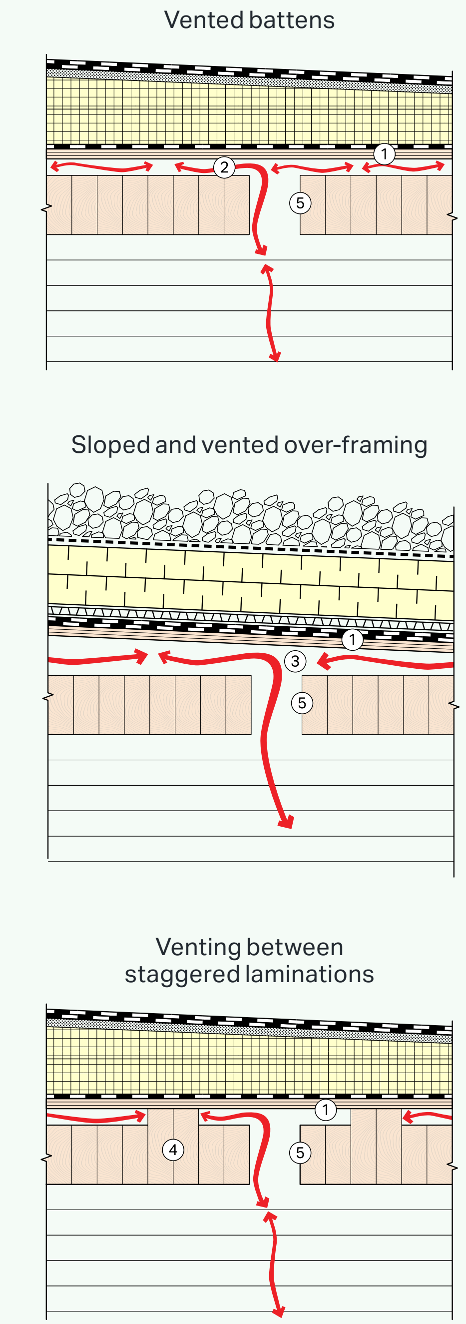
When a ventilation cavity is used, locate the structural plywood/OSB on top of battens or sloped over-framing as described in **Figure 5.7**. Either omit the TMMS within the assembly or locate it on top of the structural plywood/OSB. Carefully consider the implications of omitting or relocating the TMMS against the project specific climate conditions discussed in Section 8.6.

In supplement or alternatively, the use of an electronic leak detection system within the roof assembly can help identify the presence and location of leaks should one occur. An active electronic leak detection is recommended when a temporary roof membrane over the NLT is not provided, when a ventilated cavity is not included, or when a green roof system is used. Locate the leak detection system below the roof membrane or as recommended by the roof manufacturer.

Limitations to confirm with local AHJ for code compliance requirements for vented NLT assemblies:

- The air cavity vented to the interior may exclude the NLT from the assembly effective thermal performance calculations.
- Vented cavities are not suitable where building codes require encapsulated material for fire control within the concealed space. Encapsulated material such as gypsum is moisture sensitive and reduces the drying capability of the NLT, thus negating the purpose of the vented cavity.
- Building code may require the air cavity to be filled with insulation or fire blocking, negating the purpose of the vented cavity. Note that if insulation were to be placed within this cavity limiting the cavity insulation R-value to less than one third of the total assembly insulation R-value generally minimizes the risk of condensation within the assembly. However, this assembly configuration should be reviewed by a design professional for moisture accumulation risk.
- In some applications structural requirements may not accommodate structural sheathing to be located over top of the over-framing; if sheathing is located directly on top of the NLT laminations, air from the vent will not be able to effectively dry the NLT, negating the benefit of the ventilated cavity.
- Structural sheathing perimeter attachment requirements may prevent a clear air cavity connection to the interior, negating the benefit of the ventilated cavity.

Figure 5.7
Interior venting options for NLT roof assemblies*



1. Structural sheathing
2. Intermittent battens, beyond
3. Intermittent sleeper framing, beyond
4. NLT laminations, staggered lamination depth
5. NLT panel, vented

*in all cases venting occurs between the NLT laminations and sheathing and is vented to the building exterior

Below Ts'kw'aylaxw Cultural and Community Health Centre , Lillooet, BC
Photo credit Ema Peter *Photo courtesy of* NaturallyWood

Below Whistler library, Whistler, BC, during construction
Architecture by hcma *Photo courtesy of* Fast + Epp

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Below Time Winery, Kelowna, BC
Architecture by HDR *Photo credit* Dan Schwalm *Photo courtesy of* NaturallyWood

Below Time Winery, Kelowna, BC
Architecture by HDR *Photo credit* Dan Schwalm *Photo courtesy of* NaturallyWood

6.0 Supply

6.0 Supply

6.1 Materials

Material selection and fabrication techniques will affect the finished aesthetic and performance of any project specifying NLT and M-NLT. Understanding material attributes and the supply and the fabrication process for NLT and M-NLT helps inform all aspects of design and construction. Material supplies for NLT and M-NLT production include wood materials (lumber and plywood/OSB), fasteners, and coatings.

Below Yellow cedar end grain *Photo credit* Wade Comer Photography *Photo courtesy of* NaturallyWood

Above NLT panel end grain *Photo credit* Wade Comer Photography *Photo courtesy of* NaturallyWood

6.1.1 Lumber

The primary factors in determining wood species and grades for NLT and M-NLT are availability, cost, structural performance, and aesthetics. Consider the following details to inform lumber choices for your project.

Lumber grades and species

Lumber species and grade affects both strength and appearance of NLT and M-NLT. Colour, uniformity of appearance, and presence of visual defects differ between species. In addition to aesthetic or structural considerations, species also vary in other important ways. Species absorb and release water at different rates, which should be considered if NLT or M-NLT will be exposed to significant moisture during construction. For example, SPF will absorb water more quickly than Douglas Fir. Workability and hardness also differ between species and generally relate to density; for instance, Douglas Fir is denser than SPF, which can result in more resistance when nailing or cutting, although only slightly.

Grade also matters where NLT/M-NLT is exposed as an interior finish. For instance, although visually graded No. 2 lumber may meet structural requirements, a higher appearance grade can minimize visual defects (wane, holes, large knots) to better address aesthetic criteria. Using Select Structural grade lumber will provide improved structural properties and reduce visual defects compared to No. 2 lumber, but availability may be limited, and Select Structural is typically more expensive. Although visually graded lumber is more common than Machine Stress Rated (MSR) lumber, MSR lumber can improve the strength and stiffness of the panels.

Figure 6.1 NLT Showing blue staining from beetle-killed wood
Photo courtesy of Perkins&Will

Figure 6.2 Example of aesthetic grade boards for NLT panels
Photo courtesy of StructureCraft

Figure 6.3 Finger jointed lumber
Photo courtesy of F3 Timber Technologies

Research and consider locally available lumber grades before ordering lumber for your project. In some regions, SPF may include a significant supply of beetle-killed wood, which typically has blue stain through the grain, refer to **Figure 6.1**. While staining is often acceptable and sometimes even desired as an aesthetic feature, distributing it evenly throughout all panels in a project can be challenging.

Where high-quality, exposed NLT or M-NLT is desired, fabricators ordering No. 2 and better material should expect to visually cull it for consistent quality and anticipate a waste factor of 15% to 20%. To assist with visual culling, it may be helpful to identify visual characteristics of acceptable lumber in advance to facilitate a consistent look. Where M-NLT is required, the manufacturing requirements (discussed in Chapter 7) will resolve some of the visual defects, allowing for a reduction in waste. Refer to **Figure 6.2** for an example of board selection criteria for NLT panels used in the T3 project in Minneapolis. Refer to Appendix A for examples of visual defects which may or may not be acceptable depending on the architectural requirements.

Some lumber mills offer specific appearance grades in addition to visual grading for structural performance. Request information on availability and differences between appearance grades from local lumber suppliers. Some higher appearance grades of lumber include Hi- Line (or Home Centre) grade, and J Grade. J Grade is generally the highest quality of these options. A waste factor of 5% to 10% is typical for higher appearance grades, which may offset the increased cost of the lumber. The waste factor may be further reduced if M-NLT is provided as discussed previously. The appearance chart in Appendix A provides further examples of different grades of visual quality.

Other important considerations for selecting grade and species include fabrication efficiency and cost, such as labour required to grade and handle extra material, and space required to store additional material and culled lumber. Some lumber yards may agree to buy back culled lumber at a reasonable rate if negotiated in advance.

Supply for layup patterns

Prefabricated panels less than 6 m (20 ft.) in length are typically made with continuous boards cut to the panel length. Where longer panels are needed, either create staggered splice patterns in the panel with a specific butt joint location patterns or use structurally finger jointed lumber.

For panels created with layup patterns, often called "spliced" panels, shorter length boards can be used, but fabrication complexity and cost will increase. Refer to Section 4.1 for further discussion on structural design for different panel layups and Section 7.2.2 for more on layup pattern fabrication. Be sure to understand minimum board length requirements for controlled random staggered patterns, as they are typically dependant on the structural spans of the system.

Finger jointed lumber is used widely for manufacturing other mass timber products such as GLT and CLT; it can also be used for NLT, and particularly M-NLT where butt joints may be undesirable. Fabrication may incorporate finger jointing into the automated process, refer to Chapter 7 for more on automation. Supply of finger jointed lumber for NLT or M-NLT without an on-site jointer will likely represent a cost premium. Moreover, it can impact the amount of material required, as the thickness of finger jointed lumber, after being four-side planed, will generally be 1.58 mm (1/16 in.) narrower than typical dimension lumber. Although narrower, planing dimension lumber is the only practical way to achieve the tolerances laid out in CSA 0125 for M-NLT. Structural requirements for the type of finger joint should be assessed and specified by the structural engineer; not all finger joints are intended for use in bending applications as per the ALSC finger jointing standards. The fabrication standard for M-NLT also provides guidance on finger jointing requirements that should be considered if finger jointed lumber is going to be used in an NLT panel. Appendix B provides a sample specification describing acceptable finger joints. If finger jointed lumber is used, stagger the joints from one course to the next (refer to **Figure 6.3**).

Material certification and chain of custody

Verification of environmentally responsible lumber and wood products is managed by several third-party programs which require certification of forest management, chain of custody, or both. Forest Stewardship Council (FSC), Sustainable Forest Initiative (SFI), and Programme for the Endorsement of Forest Certification (PEFC) are a few of the common certification standards. Projects pursuing LEED or other green building rating systems may require wood certified by one of these programs. Certified lumber may be more costly and can affect availability. Proof of chain-of-custody of the material is usually required by most rating systems and may include certification of the manufacturing facility and supplier and/or installer.

Plywood/OSB

Standard construction grades of plywood/OSB are generally used over NLT floors or roofs and on one or both sides of NLT walls, regardless of panel classification as NLT or M-NLT. The plywood/OSB provides vertical or horizontal diaphragm capacity and connects prefabricated panels together with a continuous substrate. Requirements for plywood/OSB thickness and layout should be described in the contract documents.

For curved NLT panels take care to consider and review requirements for multi-layered, glued plywood/OSB (these are usually applied on site) to accommodate curvatures.

Top right On-site NLT fabrication at The Exchange, Kelowna, BC
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood

6.2 Fasteners

Assemble exposed NLT and M-NLT using galvanized nails to join laminations and for fastening plywood/OSB. If galvanized nails are not used, iron staining will occur when exposed to moisture during construction.

The structural drawings and specifications will specify nail types and nailing patterns. If nails longer than 76 mm (3 in.) are specified, they will require more expensive pneumatic nailers and potentially a larger compressor. Although 8D (3.3 mm [0.148 in.]) nails are typical, engineers may specify 10D (3.7 mm [0.131 in.]) nails which may reflect a cost premium. If alternate nail sizes are preferred the engineer may accept the proposal of an alternate but will likely require additional nails to accommodate this.

For M-NLT, specific nail standards must be met including nail type, size, and spacing. The standard outlines specific alternate nails that are deemed equivalent and could provide a simple path for approval of an alternate nail size. Refer to the CSA O125 or Chapter 4 for discussions of specific nail spacing requirements.

Screws, either self-tapping or timber screws, are often used to connect panels to their supports and can be used to reinforce panels at other conditions in panel assemblies such as openings, overhangs, or weak-axis cantilevers. Where timber screws are needed, use zinc-plated screws to prevent iron staining; galvanizing this type of screw reduces the strength of the steel and should not be done.

7.0 Fabrication

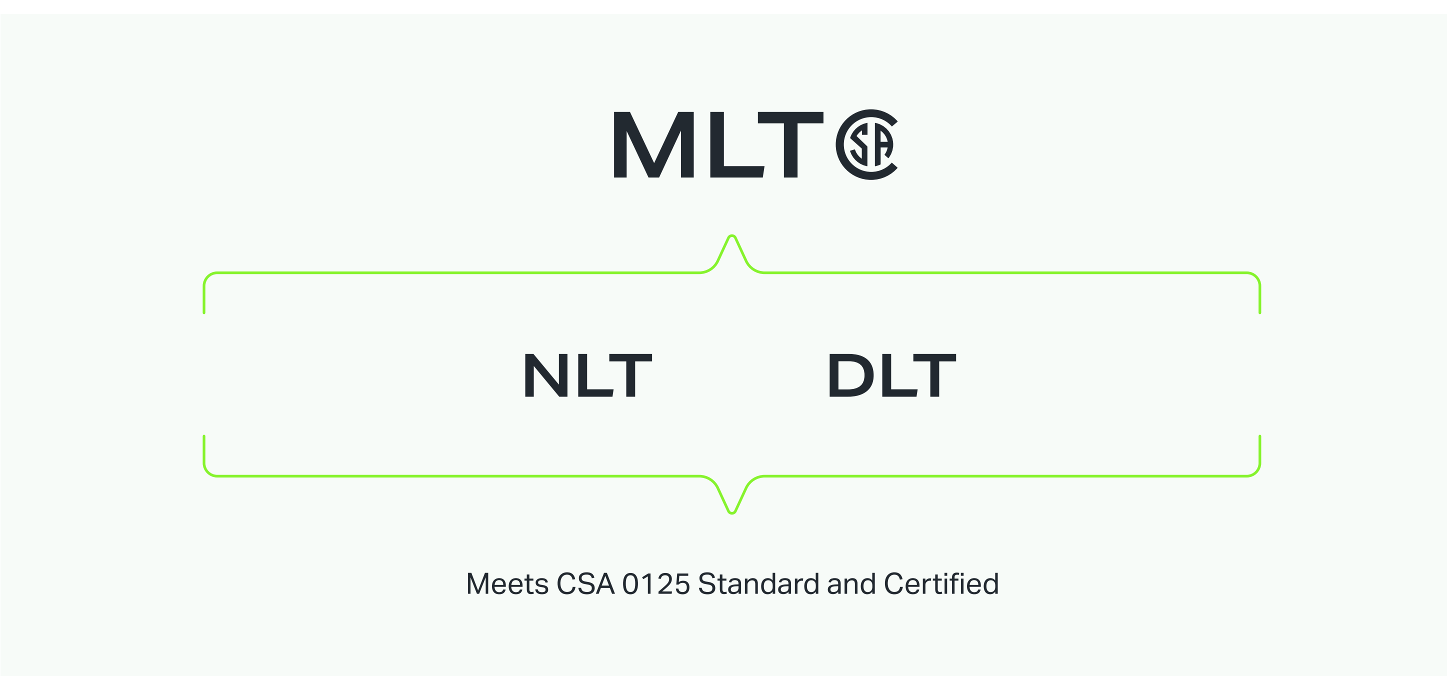
7.0 Fabrication

An important milestone for the mass timber industry is the introduction of MLT into the code in 2023.

MLT is any mechanically laminated timber product (NLT, DLT, etc.) that complies with the requirement of the new certification standard, CSA O125, and is certified. Refer to **Figure 7.1** for the CSA MLT certification mark.

M-NLT (nailed MLT) requires tighter tolerances, necessitating planning of individual boards and the use of a press for board placement. In addition, rigorous quality control procedures must be followed per the certification process, making automated manufacturing the likely default. NLT as fabricated in the past would not meet the current certification requirements of M-NLT. Conversely, it is possible to fabricate non-certified NLT panels using automation in a similar manner to M-NLT. This chapter aims to simplify the approach by outlining the process for automated fabrication of M-NLT and non-automated NLT; highly automated manufacture is not a requirement of M-NLT, but rather a practical consideration.

Figure 7.1 CSA certification mark for MLT



Below On-site NLT fabrication at The Exchange, Kelowna, BC
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood

7.1 M-NLT fabrication and automation

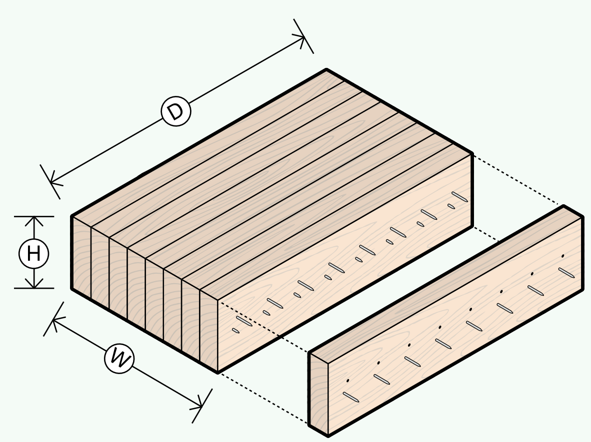
Manufacturing M-NLT requires tight tolerances, detailed and documented QA/QC, and certification stamps at regular intervals on every panel, like glulam or CLT. To earn certification, the certifying body evaluates the manufacturing facility, fabrication methods and QA/QC documentation. M-NLT that meets certification standards will almost certainly apply a high degree of automation, further discussed in in the following sections.

Below NLT panel mock up assembly at The Exchange, Kelowna, BC
Photo credit Wade Comer Photography *Photo courtesy of* NaturallyWood

7.1.1 M-NLT standard

CSA O125 sets out various types of M-NLT panels including different nailing patterns, different staggered butt joint splice patterns, finger joint requirements for fabrications and other tolerance requirements, and the certification and QA/QC requirements.

Figure 7.2
M-NLT panel manufacturing tolerances



H = +/- 1/16 in. (1.6 mm)
W = +/- 1/4 in. (6.4 mm)
D = +/- 1/8 in. (3.2 mm)

Panel tolerances

To earn certification, M-NLT panels need to achieve tolerances in line with CLT or GLT tolerances. The plan dimension and squareness tolerances, the tolerances on gaps between lamination faces, and between lamination ends require tight placement of boards during fabrication and frequent quality checks. Squareness in particular, practically requires the faces of the boards to be planed so each board is very flat.

The tolerance on the depth of the panel is less than the tolerance allowed for depth of 2x sawn lumber elements. Practically, the impact of the tolerance requirement on the depth of the panel results in either four-side planing of each board or planing of the panel after fabrication (refer to **Figure 7.2**).

Quality control

Quality control (QC) is a requirement for certification. The QC process is defined in CSA O125 and is to be established with the certification body including routine inspection of processes, regular testing of elements such as finger joints, and maintenance of all QA/QC records.

Requirements for QA/QC are assumed to include but not be limited to:

- Monitoring/Review/Checks for panel layups.
- Monitoring/Review/Checks for nailing (size, spacing, placement).
- Testing for glued end-joints (i.e. finger joints).
- Monitoring/Review/Checks for thickness, depth, and length tolerances of boards and panels.
- Labeling and as-built dimensions recorded on shop drawings.

When testing and inspection is complete, the certifier will share the results with the manufacturer. Manufacturers are required to maintain all QA/QC accordingly. Once QA/QC requirements are confirmed to be met, marking/stamping specifications for each panel are generated, after which the panel can no longer be substantially modified. Penetrations and openings would require pre-coordination and be cut as part of the manufacturing process prior to final certification. After the panel is stamped and certified it is not acceptable to apply different support conditions or different openings, particularly for butt jointed layups (NLT-3, NLT-4).

7.1.2 M-NLT automation

Automated fabrication processes will vary depending on the type of M-NLT (NLT-1, -2, -3, or -4).

Board processing

To achieve the tight tolerances of M-NLT, four-side planing is likely required for each board given tolerances for the overall panel depth are tighter than the allowable tolerances for sawn lumber boards width. Planing is also an important step to facilitate finger jointing where required. An advantage of four-side-board planing is that it can reduce expected waste; by limiting visual defects such as wane, fewer boards are rejected for higher aesthetic grades. The selection process for board aesthetics is difficult to fully automate, so limiting defects will further improve the efficiency of automation. Board selection and waste are discussed further in Chapter 6.

Board processing can also include in-line coating used to six-side coat each board before it is nailed in the panel, resulting in better stain protection and easier clean up at the end of the installation. Coating of individuals boards, or coatings in general are not a requirement of CSA O125 but can be automated and may be required for some projects. The manufacturing standard provides guidance on when preservative and other treatments must be applied.

Layup patterns

The choice to provide a continuous lamination panel (NLT-1, NLT-2) versus a random staggered butt jointed panel (NLT-3, NLT-4) is a question of panel length, material supply, and finger jointing. Finger jointing is only required for long panels with continuous laminations (NLT-2). It reduces strain on availability of lumber supply as any length of board can be input into the system at any time. Finger jointing has stringent QA/QC and testing requirements, but it also has automation advantages because it allows for a consistent board length to be used, eliminating further sorting and associated complexities. It also accommodates higher strength and stiffness for design by eliminating layup reduction factors.

Conversely, controlled random butt jointed panels may limit the degree of automation. Butt jointed layups often require different lamination lengths which would need to be sorted and fed into the layup process at specific times. It may be advantageous to manually develop the specific layup patterns and manually feed in variable length pieces rather than set up a complex automated process capable of pulling from multiple bins of different lengths. Moreover, the lengths and layout of the butt joints depends on the design support locations, which would likely need to be custom made for each job. Testing is necessary to develop modification factors for M-NLT using different layup patterns than those described from NLT-3 and NLT-4.

Pressing and nailing

To achieve the tight tolerances on the width and skew of the panel, pressing the board together for a tight fit is critical and should be incorporated into the automation process. Press configurations should accommodate working with robots or other machines used for nailing.

Machines used for nailing are programmed to accurately place nails at the correct elevation and OC spacing, reducing over nailing, or missed nails, giving designers greater confidence that panels are built as specified. The automated nailing process can also more easily exclude nails in certain areas to facilitate cutting of openings and other panel modifications. Varied nailing patterns can be achieved with a high level of accuracy, limiting the impacts of cutting through nails which can be challenging (refer to Section 7.2.1 for more on cutting through nails).

NLT offers fewer opportunities for alternative nails than those specified in the manufacturing standard. Alternative nails other than those specified in CSA O125 (i.e. typical steel nails or 19 mm wood dowels) should be used with caution and in consultation with the certification body.

Cutting and CNC

There are several opportunities to automate cutting for M-NLT. Like the cutting process for CLT panels, allowing machine line CNCs to cut openings, notch panel corners, router in surface notches, and others is advantageous.

Cutting M-NLT requires more coordination, increasing the onus on consultants for a well coordinated set of documents. Products using wood dowels, such as M-DLT, do not face the same challenges as the CNC equipment and saws can more easily cut through the hard-wood dowels. Diligent coordination will allow for the process to exclude nailing where cutting is required. Manually cutting an M-NLT panel fabricated via automation is also possible. Refer to Section 7.2.1 for further discussion.

Other fabrication

Plywood installation is not a requirement of the manufacturing standard but can be added in the shop or on-site as needed. In a fully automated plant, installation of plywood/OSB is more difficult and may be more suitable to a semi-automated shop where it can be incorporated into the tail-end of the process, or be implemented in a different shop, or even on-site. If implimented in the shop it would be incorporated in much the same way as for NLT as discussed in Section 7.2.2 of this guide.

7.2 NLT fabrication without automation

Although the new CSA O125 manufacturing standard represents a significant change responding to the growth in mass timber construction across Canada, NLT built as it would have been prior to its release is still used in construction.

It is important to understand that where M-NLT is specified, NLT may not be a suitable substitution and should not be assumed as an alternate without explicit permission from the project consultants. There are still many instances where NLT may be preferred over M-NLT to achieve things such as curvature, facilitate on-site fabrication, or respond to a need for local material supply. There are also many projects that might allow either M-NLT with a lower degree of automation, or NLT. Review and sign off by the engineer-of-record will be required if it is not clearly and explicitly stated in the contract documents.

Left NLT fabrication setup
Photo courtesy of Kinsol Timber Systems

7.2.1 Tools and equipment

Even without an automated process, large areas are required to fabricate NLT with the correct tools and skilled trades people.

Figure 7.3 NLT fabrication setup
Photo courtesy of StructureCraft

Jigs

One of the best ways to assemble NLT without any automation, is on jigs made from pony walls, back and end stops, and back fences as shown in **Figure 7.3**. Consider the following tips for an efficient and comfortable setup:

Jig: Build pony walls at typical waist height 762 mm - 864 mm (30 in. to 34 in.) tall to provide a comfortable position for using a pneumatic nailer for long periods of time. For curved panels achieved by creating a slightly staggered layup panel as discussed in Chapter 2, different setups can be used to create NLT that is curved in plan or warped in elevation by creating curved jigs, or jigs with varying slopes.

Back Stop: Ensure a straight, sturdy back stop, built on top of the jig to withstand continuous battering over the course of manufacturing. Consider engineered wood (LSL or LVL) or steel angles. Unless the backstop is too thick, fasten the first board of a panel from the back side of the backstop for ease of panel removal after completion.

End Stop: Make the end stop straight and square with the back stop, built on top of the jig similarly to the back stop.

Back Fence: Build a back fence where nailing stations are set up back-to-back, to protect workers from misfired nails.

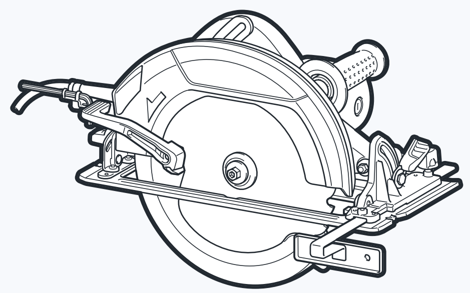
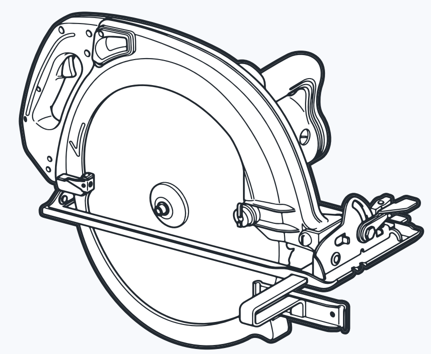
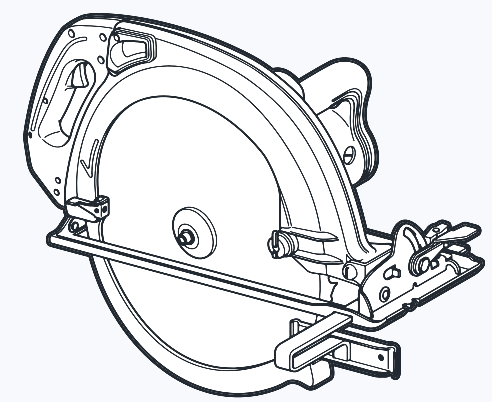
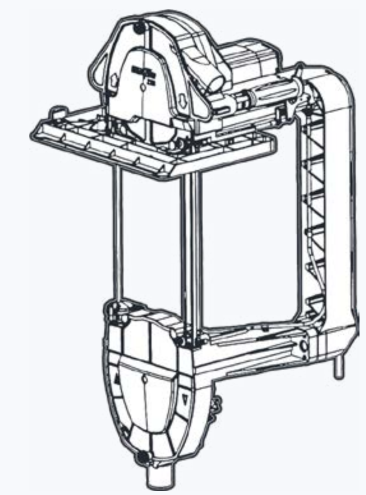
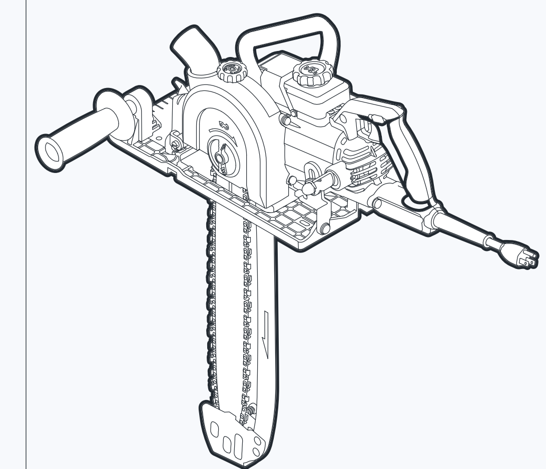
Fastening

Choose the appropriate nailer for the nails specified in the drawings. For typical three-inch pneumatic power nailers, a single compressor with air volume of five CFM should be used for every two pneumatic nailers. To prevent tripping hazards and protect equipment, run air hoses overhead, allowing them to drop down only over workstations wherever possible.

Where timber screws or long self-tapping screws are used, high-torque drills capable of driving large screws are required. Never use an impact drill to install these screws; doing so may overdrive or damage the screws, compromising the strength of the connection. Where predrilling is required (for example with larger diameter screws) take care to drill the correct sized pilot hole.

Where possible, identify zones where the NLT is expected to be cut after fabrication, for example at panel ends and openings; do not put nails in these zones. Where plywood/OSB is shop installed, nail the plywood/OSB to the NLT specified in the structural drawings with a pneumatic nailer. Where screws are required, install them after cutting or take special care to ensure no screws are present in the zones where cutting will occur as they are difficult to cut through.

Table 7.1 Saw types and cutting depths

Saw type	Beam saw						Portable saw		Carpenter's chainsaw	
										
Saw size	250 mm	10 1/4 in.	400 mm	16 5/16 in.	450 mm	17 11/16 in.				
Maximum vertical depth	89 mm	3 1/2 in.	165 mm	6 1/2 in.	187 mm	7 1/4 in.	317 mm	12 1/2 in.	406 mm	16 in.

Cutting

After fabrication, cut NLT panels to length and provide other cuts that can be coordinated in advance such as notching panel corners at column locations and mechanical openings. Cutting panels in the shop helps prevent erection delays on site. While it may be possible to identify zones without nails in advance of cutting (refer to Section 7.1), the steel nails located throughout NLT present a challenge for cutting. For this reason, NLT panels without tight control on exact nail placement (i.e. without automation) are not well suited for CNC fabrication.

Some circular saws can handle cutting through nails; however, it is best to consult a blade sharpening professional and select a blade that will cut through small amounts of steel. Even specialized "nail-cutting" blades will become dull and chipped but will last longer than standard wood blades. Circular beam saws range in cutting depth, accordingly deep NLT panels may need to be cut from both sides. Refer to **Table 7.1** for saw types and sizes with corresponding cut depths.

Cutting notches and penetrations is like cutting to length. Square penetrations will need plunge cuts with a circular saw or a combination of drilling holes and cutting with a reciprocating saw. Circular penetrations are more easily cut with a hole saw. Custom hole saw manufacturers can create saws up to 330 mm (13 in.) diameter; while custom saws are more costly, they may be a worthwhile investment if many identical penetrations are required.

Above Cutting on-site, The Exchange, Kelowna, BC
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

7.2.2 Fabrication process

The pattern of individual boards within a panel, the presence or absence of shop-applied plywood/OSB, and the layout of panels within a floor plate all affect the fabrication process.

Above Testing nail order on NLT mock-up, The Exchange, Kelowna, BC
Photo credit Wade Comer Photography
Photo courtesy of NaturallyWood

Board placement and splice pattern

When placing boards, pay close attention to the board lengths and orientations. Where NLT will be exposed in the finished space, choose the exposed face of each lamination with care. For boards with grading stamps present on the faces, make sure the stamps are not visible where NLT will be exposed.

Panels longer than 6 m (20 ft.) can be created from shorter sections of boards butt jointed to create continuous courses. The pattern of these joints is called a splice or layup pattern. Different layup patterns affect the efficiency of material usage as well as the structural capacity of the NLT. (Refer to Section 4.1 for examples of layup patterns). The structural drawings may supply a pattern or ask the fabricator to propose a pattern based on specified requirements. In cases where the pattern is proposed by the fabricator, it must be reviewed and approved by the structural engineer and architect before production. Incorrect splice patterns can impact deflection and strength. Square panels with a non-symmetrical splice pattern can easily be placed backwards on site.

Plywood/OSB installation

Plywood/OSB can be installed in the shop or on site. Shop installation provides a limited amount of moisture protection and adds stiffness to the panels, which can aid lifting. If plywood/OSB is installed in the shop, holding it back from the NLT panel edges, allowing infill strips to be installed on site to provide diaphragm continuity as shown in Figure 4.12 is common practice. Site-applied plywood/ OSB requires less pre-planning and is most efficient with narrow panels. Take care with site installation to place plywood/OSB joints per the structural drawings. Refer to Sections 4.3.2 and 4.4 for more.

Quality control checklists and pre-manufacturing checks

Prior to fabrication, check moisture content, fastener type, and jig setup.

Moisture content (MC): The moisture content of kiln-dried (KD) lumber is usually 12% - 16% but must be below 19% before laminating into a panel. Assess the moisture content of purchased material soon after it is received, and again before fabrication.

Fastener type: Incorrect nail diameter is the most common mistake. Also ensure that nails are galvanized.

Jig setup: Even with solid back and end stops, check frequently to ensure the jig remains square.

Quality control (QC) checklists should include information regarding appearance and tolerances.

7.3 Coatings

Coatings include sealers and stains often applied to exposed faces of NLT or M-NLT floors, roofs, and walls for aesthetic purposes. They can be applied in the shop, on site, or both.

Figure 7.4 Shop applied coating on NLT
Photo courtesy of StructureCraft

While coatings can mitigate water staining, they will not prevent swelling and are not an effective construction moisture control system. Site-applied coatings can be cost effective depending on size and complexity of the project, however, there may be restrictions on VOC content and will be more complex to navigate through other sub trades. Many different types of coatings are available, and the appropriate product is generally coordinated between the coating manufacturers and the project architect. The performance of coatings will vary with species, along with resistance to decay. Penetrating coatings usually perform better than film building coatings, as natural movement in the NLT or M-NLT with time can lead to shrinkage or expansion and cracking in the film. For exterior covered panels (i.e. canopy soffits) carefully consider coating specification and maintenance requirements.

Coatings may be applied in the shop or on site after the building is enclosed. If applied on site, the most important considerations are accessibility and coating ingredient attributes. Adequate ventilation may be difficult on some sites so coatings with high VOC content may present a challenge for on site application. If coatings are applied in the shop, account for added lead time and more stringent panel storage requirements. Avoid placing stickers and dunnage on exposed sections of a panel, to ensure they do not affect the final appearance.

When applying coatings in a non-automated shop, pony walls or scaffolding built to a height of between 1.8 m and 2 m (6 ft. and 6-1/2 ft.) make an effective coating jig (refer to **Figure 7.4**). Assemble jig walls to mimic the final bearing condition for panels so uniform coating can be achieved, avoiding exposed stripes of uncoated panel. Rolling on coatings is easy and cost effective, but spraying may also be considered. Where coating is applied on site, it is typically done after the panels are in place over the structural supports.

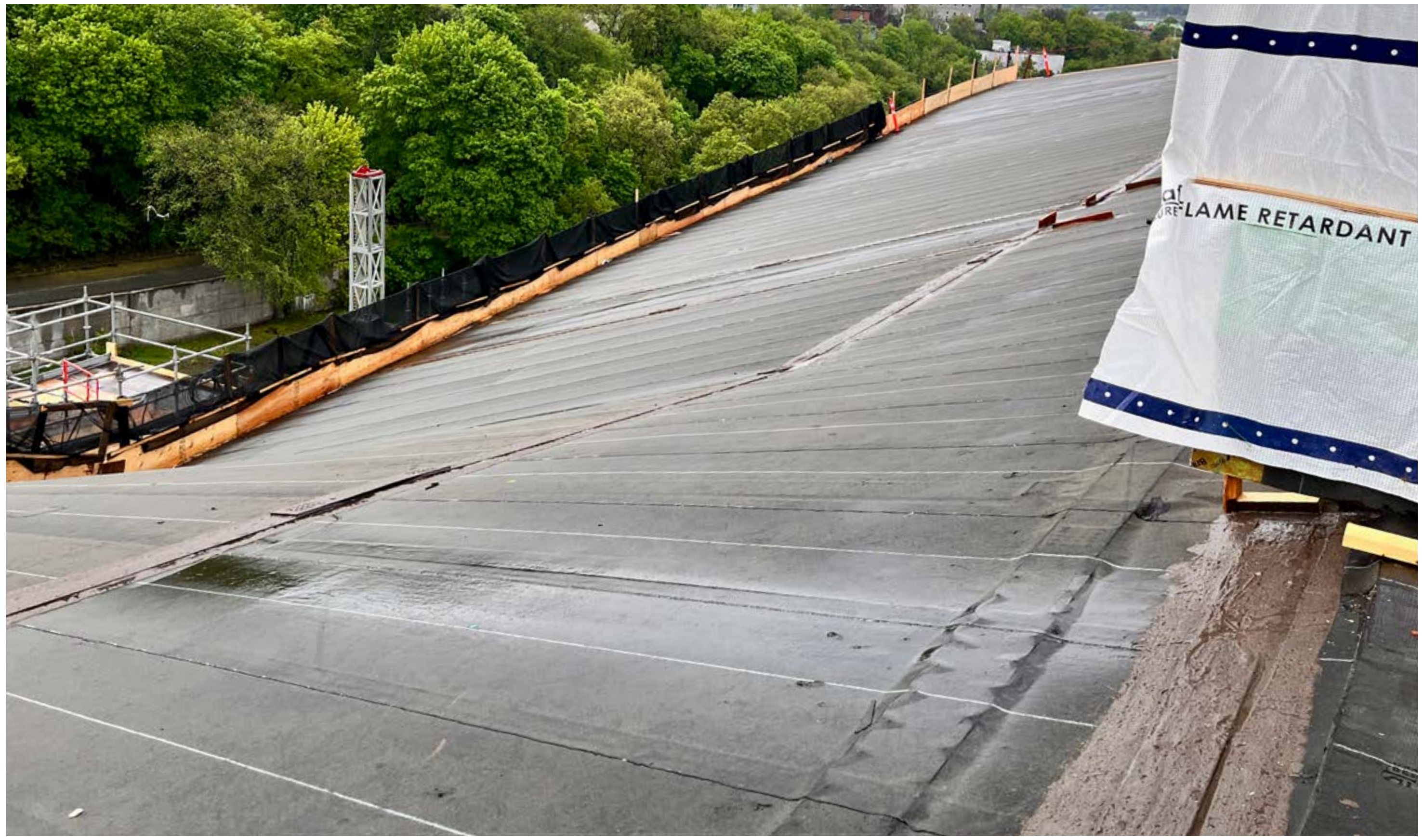
An in-line coating machine can be added to an automated set up to coat each lamination on six sides before it is assembled into the panel.

7.4 Temporary moisture management system installation

Where a temporary moisture management system (TMMS) requires partial shop installation, allow additional time for application and curing of the adhesive where necessary. The TMMS may require an independent qualified installer; this should be coordinated with the supplier. Refer to Section 8.6 of this guide for more discussion of TMMS and Construction Moisture Management in general.

Take care during storage and shipping to ensure the pre-installed TMMS is not damaged prior to panel installation. Refer to Chapter 8 for more on storage and shipping approaches.

Below NLT temporary moisture management during construction, Ādisōke Public Library, Ottawa, ON
Architecture by Diamond Schmitt *Photo courtesy of* Fast + Epp



Above The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

7.5 Panel handling

The mechanisms for handling NLT or M-NLT panels in the shop are often the same ones used on site. Consider lifting and handling strategies early, as the chosen approach will impact on shop setup and required equipment. Refer to Chapter 9 for more information on lifting and handling. After fabrication, panels may be handled in the shop using either an overhead crane or forklifts and telehandlers.

Overhead crane

Ensure an engineered lift plan is in place. Where overhead cranes are used in fabrication, consider the site lifting strategy early, allowing the same lifting plan to be re-used. Refer to Chapter 9 for more on lifting requirements.

Forklifts and telehandlers

Ensure that forks are clean and/or covered to prevent damage to the panels. Using thin hard plastic covers is recommended, not carpet or cardboard covers. Keep panel widths to a recommended a maximum of 1.8 m (6 ft.) where overhead cranes are not available. Although forklift fork extensions up to 2.4 m (8 ft.) can be purchased and used, the weight and COG of most NLT panels will be very limiting. Exercise extreme caution if 2.4 m (8 ft.) fork extensions are used.

7.6 Planning, documentation, and mock-ups

Shop drawings are an important tool to communicate fabrication criteria between the shop, the site, and the design team. Quality Control (QC) checklists should supplement shop drawings. Panel mock-ups are often required for architectural review and approval and can be the best way to communicate finish quality.

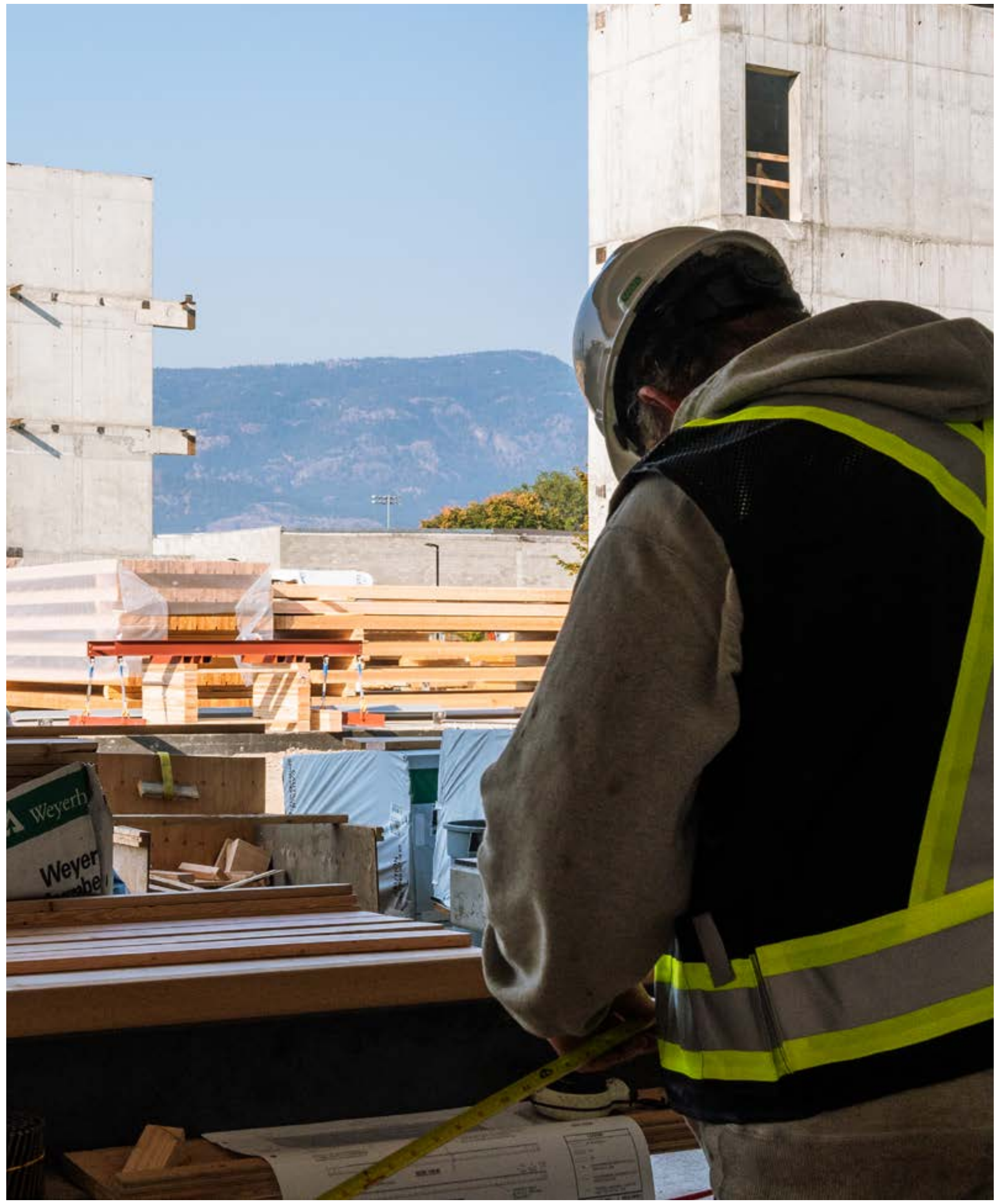
Plan layout of panels

Panels can be arranged in various ways within a roof or floor plate, with short spans offering more options. Long panels offer fewer picks on site but will increase complexity with shipping and lifting both in the shop and on site. Panel widths have an impact on stability and lifting requirements. Specific panel sizes for fabrication should always be coordinated with the General Contractor and on-site erection team, as well as with the contract documents and structural requirements for the panels.

It is also possible to consider integrating NLT or M-NLT panels with support members in the shop or on the ground prior to lifting (refer to **Figure 7.5**). This strategy will reduce the overall number of crane picks required on-site and can add out-of-plane stability to the panels. Though crane size requirements and transporting the combined beam/deck pieces to site may be less efficient than shipping NLT panels and supporting members separately. Lastly take care to ensure the combined system has sufficient strength to resist the lifting loads alongside the final design strength, as the forces can often be quite different. Refer to Chapter 9 for more information on erection engineering.

Left | **Figure 7.5** Combined NLT and support beams
Photo courtesy of Fast + Epp

Right On-site planning at The Exchange, Kelowna, BC
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood



Shop drawings

To create 3D models and 2D shop drawings, CAD platforms such as AutoCAD can be used, but timber-specific software packages such as cadwork, hsbCAD, Dietrichs, and SEMA provide advantages when automating shop drawing production. In some cases, 2D shop drawings will be sufficient, but for larger and more complex projects, 3D and occasionally 4D modelling (including construction sequencing) is critical to schedule work and coordinate with other trades. Simulation platforms such as Navisworks may be helpful to merge models from different trades and support clash detection (refer to **Figure 7.6**).

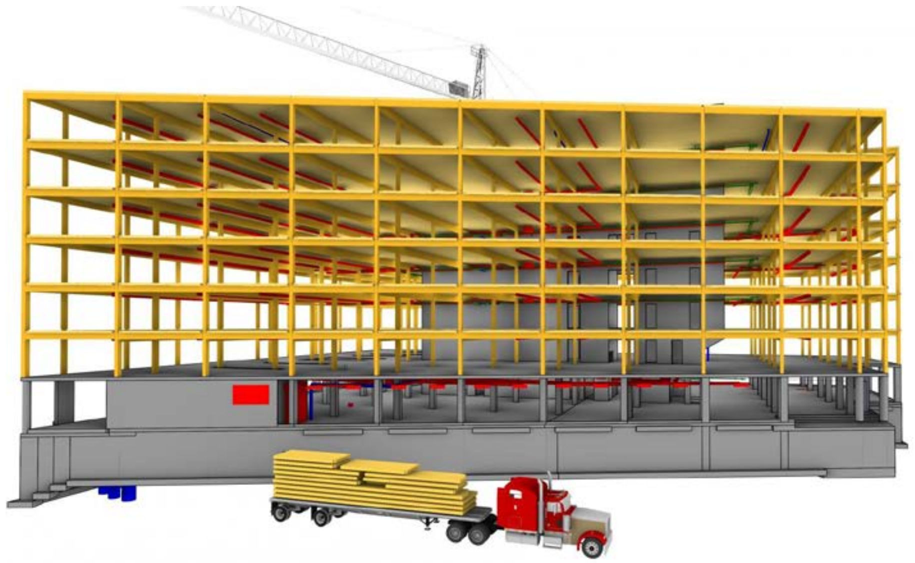


Figure 7.6 4D sequencing with Navisworks for the T3 project, Minneapolis, MN
Image courtesy of StructureCraft

Accurate and efficient installation requires good shop drawings that clearly communicate part numbering, placement, plan layout, and construction details. Sequencing panels for installation should be considered in the pre-construction phase. Identify panels required on-site first, and work backwards to plan and coordinate speed of manufacturing, panel storage, and truck loading.

Shop drawing packages, at a minimum, should include the following:

- Overall panel dimensions (including cuts and openings)
- Lumber species, size, and grade
- Splice pattern (if applicable)
- Fastener specifications and fastening pattern

In some cases, fabricators may also be required to provide their own engineering of the panels, including gravity and lateral design, which would require an engineer's stamp on the shop drawings. In all cases, shop drawings require review and approval by the architect and engineer of record.

Samples and mock-up panels

Samples or larger mock-up panels are often required by the architect for review and approval to confirm aesthetic requirements are met where NLT is exposed. Mock-ups can often be incorporated into the main structure. Where this is done, take care to protect the panel during storage until it can be installed. Refer to Appendix B for sample specifications for mock-up requirements.

Above NLT mock-up panel
Photo credit Wade Comer Photography *Photo courtesy of* NaturallyWood

Above The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

Above The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

8.0 Construction & Installation

8.0 Construction and installation

This chapter includes general discussion on the use of NLT in construction including installation of construction moisture management. Unless specifically stated otherwise where "NLT" is referenced, information applies to both M-NLT and NLT as defined in the introduction to the guide.

8.1 Organization

The most appropriate panel organization strategy depends on the size, location, and complexity of the project, but there are three common approaches for the most efficient installation:

1. **Just-in-time delivery;**
2. **Sorting and staging on site; and**
3. **Off-site storage.**

Just-in-time delivery offers the greatest advantage. Where it is possible to organize delivery just-in-time, load panels to allow for installation directly from trailers, and use truck stacking diagrams to ensure correct loading sequences for larger or more complex projects.

8.2 Shipping

Consider shipping constraints carefully to ensure the width, length, height, and weight limitations of transporting loads can be accommodated.

Width: Optimum panels are 1.2 m or 2.4 m (4 ft. or 8 ft.) wide. Loads wider than 3.5 m (11 ft.- 6 in.) require permits and generally have time-of-day restrictions at the discretion of local transportation authorities.

Length: Panels up to 18.3 m (60 ft.) long can usually be transported without restriction. Longer panels may require special trucks or permits.

Height: Maximum shipping height for a loaded truck is 4.1 m (13 ft.-6 in.) from the ground to the highest point of the load. Over-height permits up to 4.3 m (14 ft.-2 in.) are only granted to loads that are not divisible, so this would not be an option for NLT.

Weight: Trailer capacities and local transport authorities also impose limits on shipping. Typical tandem-axle trailers have a capacity of 20,000 kg to 23,000 kg (45,000 lbs to 50,000 lbs.), and typical triple-axle trailers have a capacity of 25,000 kg to 27,000 kg (55,000 lbs to 60,000 lbs). Local transport authority truck weight limits are usually 20,000 kg (45,000 lbs).

Most softwoods have a density of 480 kg/m3 to 560 kg/m3 (30 lbs to 35 lbs./ft.3), which can be used to estimate panel weights with reasonable accuracy. For more precise density values of specific species, refer to the NDS Supplement [01] which offers more specific guidance on a wide range of species compared to the Canadian standard. Be aware that: values provided in the supplement are over dry densities which need to be increased for higher moisture contents. Refer to Appendix C for more discussion of hygroscopic behaviour of wood.

It is best practice to use clean, dry lumber as dunnage and stickers, to raise the panels off the truck bed and separate them to allow air circulation, as shown in **Figure 8.1**. To avoid staining, dunnage and stickers should be free of grade stamps. Placing plastic, lumber wrap, or wax paper on the underside of panels to protect them from dunnage and stickers is usually ineffective and can cause moisture to accumulate. It can also have more dramatic consequences in shipping; wax paper, being the worst culprit, reduces the friction coefficient and increases the chances for panels to shift during transportation. Irregular panels often require specific engineering to review shipping stability. Refer to Chapter 9 Erection Engineering for more.

Reducing the thickness of the dunnage and stickers can maximize the number of panels that fit on a truck. Make sure that the thickness of the dunnage is sufficient to allow a fork between the panels. Most forklifts with fork extensions require a minimum of 100 mm (4 in.) of clearance. Other lifting devices may require the same consideration, or additional clearance between loaded panels to avoid damage to the undersides.

Figure 8.1 Shipping with dunnage and stickers
Photo courtesy of StructureCraft

8.3 Storage

Where NLT panels must be stored outside, panels should be stored off the ground and properly tarped for moisture protection. At least two forms of weather protection, such as lumber wrap and tarps, is highly recommended. Where lumber wrap is provided around the entire panel, slit the underside of the wrap to prevent moisture from being trapped inside the wrap. Lumber wrap or tarps should be opaque to prevent light from penetrating; UV light will fade the panels where exposed, leaving visible discolouration where dunnage and stickers were in contact with the panels. Slope the top of panel stacks to assist with drainage.

Renting trailers is a good way to gain storage space during manufacturing and to protect the panels from the elements, but the cost may add up quickly for multiple trailers or when there are schedule delays. Wherever the panels are stored, the panel stacking sequence should match the install sequence to prevent inefficiencies with repeat handling (refer to **Figure 8.2**). Depending on the irregularity in the NLT panels, an engineer may need to review and approve the panel storage and stacking.

8.4 Unloading

When clean, dry forklift forks are used, no additional protection during unloading should be required. If fork protection is desired, shrink wrapping a thin piece of hardboard or door skin over fork attachments offers the best fork protection without adding too much thickness. Forklift damage to NLT panels can be costly and difficult to remediate. Where cranes are used to unload/erect the panels, refer to Chapter 9 for erection engineering guidance. In either case, NLT-specific safety requirements would follow standard safety rules for loading, offloading, and general material handling. Where wall panels are unloaded/erected directly from the truck with a crane, refer to Chapter 9.

Figure 8.2 Storage setup with dunnage and stickers
Photo courtesy of StructureCraft

Below Storing NLT panels
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood

Below Unloading NLT panels
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood

8.5 Installation

The complexity of planning and coordination for NLT projects will vary with the scale and size, which can range from small-scale residential buildings to large multi-storey commercial projects. Consideration of sequencing, panel sizes and types, walls, and floor and/or roof placements are all critical considerations. A sequencing model is shown in **Figure 8.3**. Refer to Chapter 4 for structural details and to Chapter 9 for more on erection requirements for stability.

Figure 8.3 NLT installation sequencing
Photo courtesy of StructureCraft

8.5.1 Floor and roof panel installation

The typical installation sequence for floor and roof panels involves placing the panels, support attachment, panel-to-panel connections, and sheathing or infill-sheathing, and then installing integrated service runs within the NLT if necessary.

Follow the structural drawings and details for panel placement, which may include gaps as shown in **Figures 8.4** and **8.5**. Gaps allow the panels to grow when exposed to site moisture and are important to maintain control of the geometry as panels are placed. Refer to Section 4.4.1 for more discussion of gaps between panels.

Where gaps are not explicitly shown on the architectural and structural drawings, 10 mm (3/8 in.) gap between 1.2 m (4 ft.) panels have been used successfully. NLT panels are an engineered system; no notching or cutting is permitted without approval. Where high-strength screws are used for the connection to support structural elements, never use an impact drill, to avoid stripping the wood. Refer to Section 7.2.1 for more on high-strength screw installation.

Figure 8.4 Installed roof panels with gaps for expansion
Photo courtesy of StructureCraft

Figure 8.5 NLT install of prefabricated pre-sheathed panels
Photo courtesy of Seagate Structures Ltd.

8.5.2 Wall panel installation

Placement of wall panels has several complexities including the lifting requirements, the placement and positioning on-site, and temporary support of walls. The typical sequence of wall installation involves levelling of base conditions for the walls via a sill plate or other means, lifting and placing walls panels, providing temporary support, fastening walls to their base, placing sheathing as required, placing floors and/or roofs above, and fastening the floor/roof panel to the walls below.

Ensuring the correct placement of the walls in both elevation and location in plan is critical to achieving the necessary construction tolerances for mass timber construction. Consider placing sill plates or angle brackets before landing the walls at their base to allow them to be fully levelled and located before erecting the wall panels themselves. Take care when lifting to avoid damage to the wall panels where visually exposed.

Like floor and roof panels, NLT wall panels are also subject to expansion due to exposure to construction moisture. Gaps are similarly needed to allow the panels to grow when exposed to site moisture, and gaps between panels is important to maintain control of the geometry as panels are placed. For plywood/OSB sheathed shear walls, refer to the contract documents for any gap location requirements and consider the locations of gaps relative to the connections at the base and plywood/OSB placement. Lifting and shoring techniques for walls differ somewhat from lifting and shoring for floors and roofs. Refer to Chapter 9 for further discussion.

8.5.3 EMTC construction impacts

The current EMTC provisions require that encapsulation be installed as the project is erected for taller timber construction. A maximum of four storeys are allowed to be erected without this protection in place. Consider sequencing accordingly in the construction schedule.

To meet the code requirements without an alternate solution, the underside of floor panels and faces of timber walls must be encapsulated with 12.7 mm, Type X gypsum board. Installing gypsum board before upper levels are in place and the building is enclosed has obvious complexities and carries a likely possibility of water damage. To avoid this challenge, consider an alternate solution, which have been used successfully to reduce or eliminate the encapsulation for construction fire safety requirements. Refer to Chapter 3 for more on construction fire management and alternate solutions.

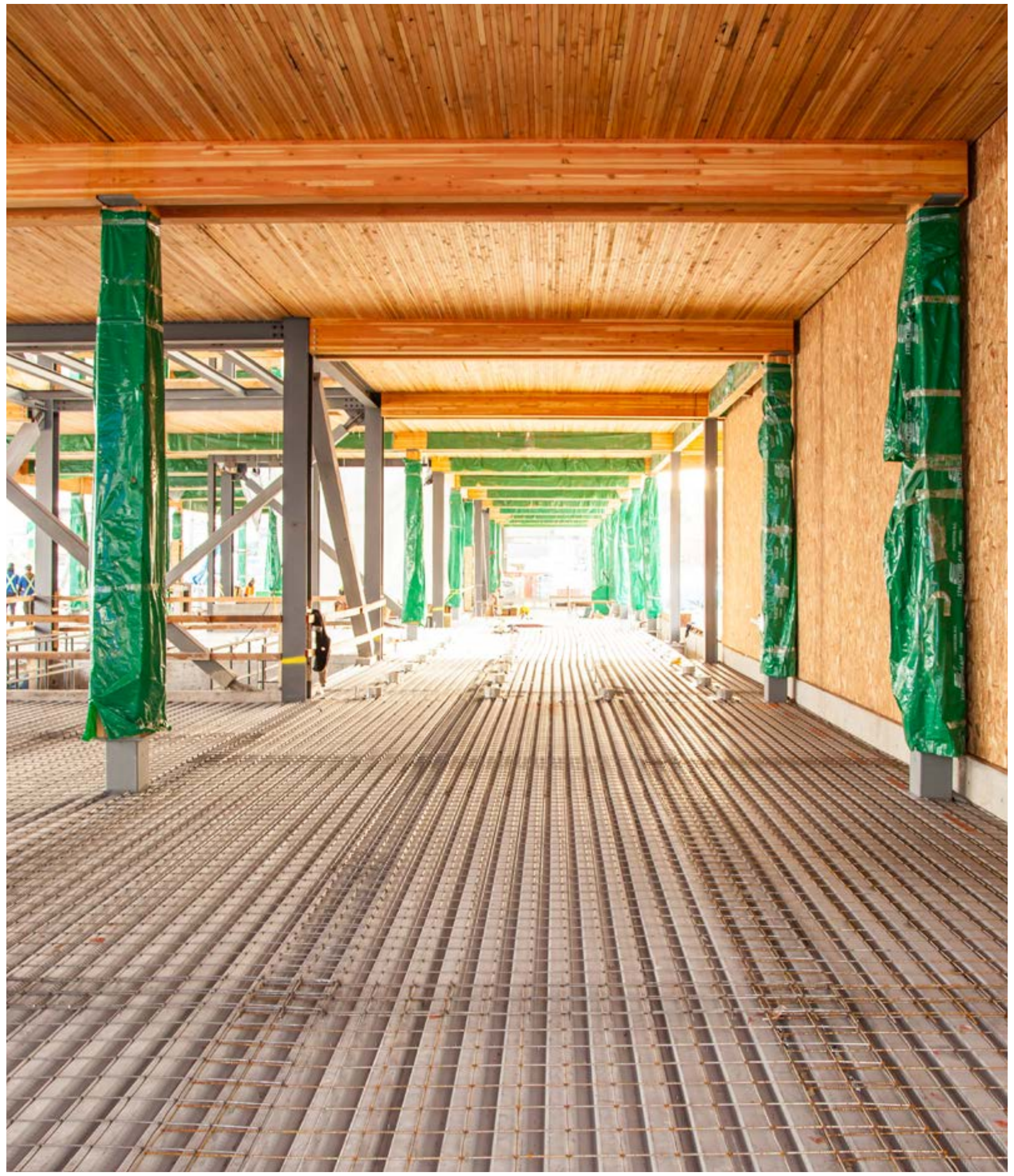
8.6 Construction phase moisture management

NLT has high potential for moisture entrapment at multiple locations: prefabricated panel interfaces, lamination interfaces, splices, exposed end grain, and the interface between NLT and plywood/OSB [02]. Refer to **Figure 8.6** for an example of NLT exposed to moisture during construction. Moisture can be properly managed during construction with the right design and construction practices. Mitigating moisture risks associated with NLT buildings and enclosures requires attention to moisture management during design, manufacturing, shipping, construction, and occupancy. A lack of proper care during any project phase can affect project outcomes including aesthetics, structural capacity, dimensional tolerances, enclosure integrity, and even indoor air quality.

Sources of manufacturing and shipping phase moisture may include wetting from rain, snow melt, or splashback on unprotected elements during transport or storage. Sources of construction phase moisture include rainfall, snow melt, night-sky condensation, and plumbing leaks. Because moisture absorption is not instantaneous, long-term or persistent exposure is likely to be more problematic than the overall quantity of water [03]. When NLT assemblies are subjected to long-term exposure or standing water, moisture can penetrate deep within the wood, significantly increasing the time required for drying [02]. Attempting to fix this problem retroactively with tenting or large-scale drying is costly and can delay the construction schedule.

Left | **Figure 8.6**
NLT exposed to excess moisture during construction. Wetting occurred on the NLT between laminations and staining on the NLT and structure below. Water dripping on the underside of the panel and beam froze and formed icicles.
Photo courtesy of RDH Building Science

Right Head Office, Vancouver, BC showing NLT over glulam framing during construction. Temporary wrapping left on glulam to protect against construction moisture and UV exposure.
Photo credit KK Law *Photo courtesy of* NaturallyWood



8.6.1 Moisture management process

A best practice approach to this risk mitigation is to follow a moisture management process and develop a moisture management plan to be executed during the construction phase of the project.

The moisture management process includes three steps:

1. **Complete a moisture risk assessment**
   During the design phase, identify all factors that may contribute to an assembly's moisture exposure risk over the construction and occupancy of the project such as climate, rainfall, construction schedule, length of exposure to moisture, use of encapsulation material (if required), and type of mass timber element. Use this assessment to identify temporary moisture management systems (TMMS) and additional assembly design features and detailing needs.
2. **Develop a moisture management plan**
   This plan should anticipate the sources of moisture identified in the moisture risk assessment and outline ways to address moisture exposure when it occurs during construction.
3. **Execute the moisture management plan**
   Monitor and evaluate the NLT components to assess the effectiveness of the moisture management plan to protect the NLT structure. The moisture management plan should be updated according to any unanticipated site conditions.

For step-by-step guidance on moisture management process and a moisture management case study refer to "Moisture Risk Management Strategies for Mass Timber Buildings" [04] published separately by RDH Building Science.

Moisture management plan

The moisture management plan identifies and documents moisture control measures to be executed during the construction phase. A moisture management plan commonly includes the following materials and is submitted to the design team prior to construction:

- A written plan documenting all moisture control measures planned.
- Checklists for monitoring or performing checks at regular intervals, such as review of TMMS, or moisture content readings. Checklists may be developed to manage moisture at specific milestones, for example:
  - Mass timber delivery acceptance checklist
  - Pre- and post-concrete pour checklist
- Site plan that documents the designated material storage area(s).
- Moisture management details that identify the moisture protection methods to be used at common building details and panel joints and edges.
- Drainage plan that identifies the appropriate drainage paths for controlling site water.

The requirements for moisture management plans may be incorporated in the mass timber product specifications, or provided as a sperate specification, as shown in Appendix B, to address all mass timber products in a project. Refer to Appendix B: Sample Specification, Section 01 43 39 "Moisture Management Plan" for an example of a project specification that outlines required deliverables that follow the moisture management process. A common requirement of a moisture management submittal package includes identifying moisture control measures that will be executed during the construction phase.

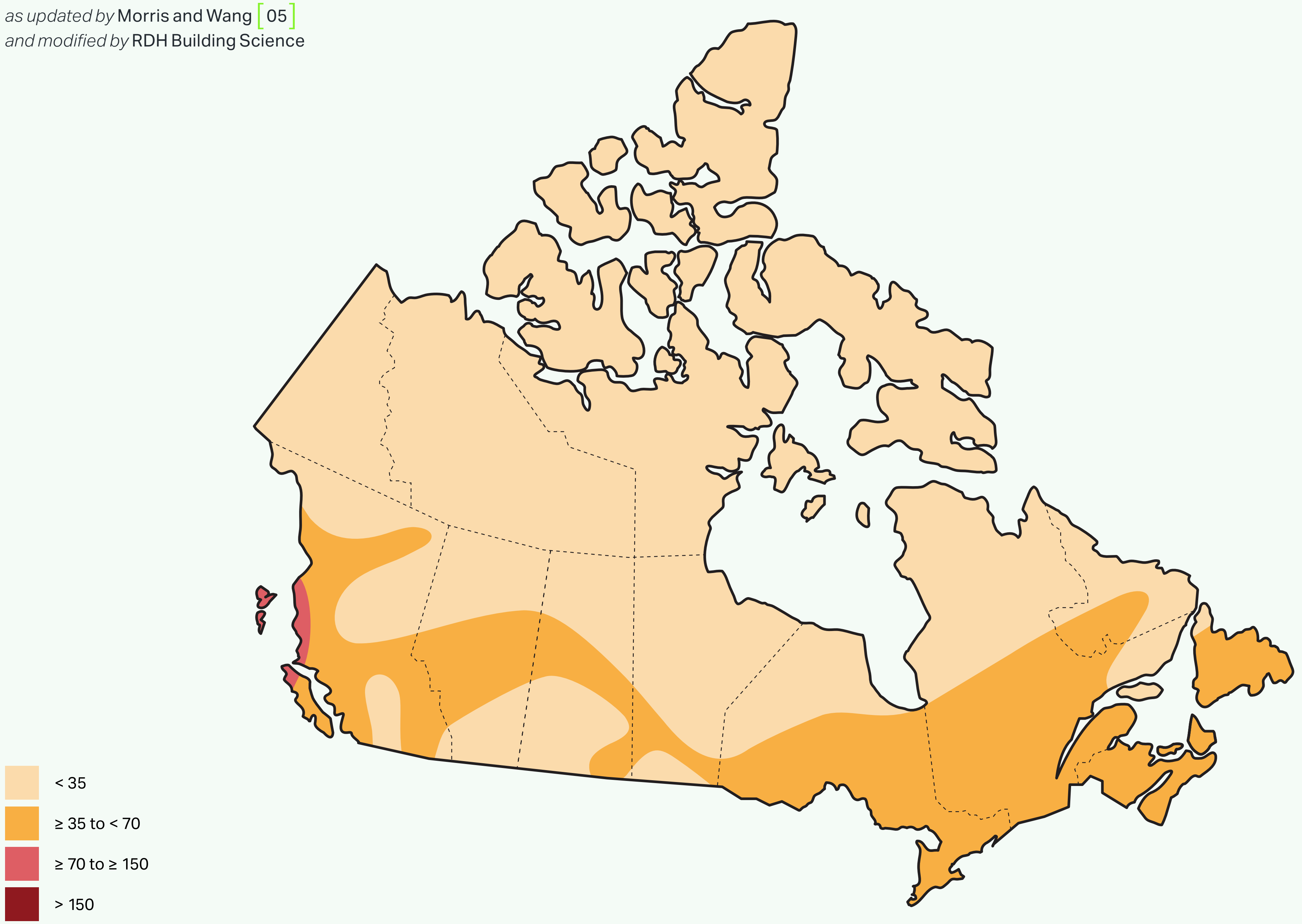
8.6.2 Horizontal assemblies moisture management systems

The need for a temporary moisture management systems (TMMS) will vary by project and is impacted by both seasonal temperatures and frequency of rain events. One approach to determine an effective TMMS is to use a climate index such as the Scheffer Climate Index Map [05]. Refer to **Figure 8.7** for the four categories of climate indices across Canada.

In general, temporary moisture management systems are recommended in areas with a climate index of 35 or greater, especially when construction is scheduled during wet weather seasons. Areas with a climate index less than 35 may also benefit from a temporary moisture management system, and should be considered as a risk control strategy, as even mild moisture exposure can cause swelling and staining. It may be tempting to use a less robust TMMS as an initial cost-saving measure; however, be careful to also consider the increased risk of exposing the NLT to moisture and the associated cost of retroactive moisture management and moisture mitigation.

Scheffer Climate Indices (SCI) may vary based on local climates and geographic features. Where specific conditions merit, calculate a project-specific SCI using recent weather data acquired from the closest available weather station. Refer to "A New Decay Hazard Map for North America Using the Scheffer Index" by Morris and Wang [05] for more information and city-specific indexes.

Figure 8.7
Scheffer Climate Index
as updated by Morris and Wang [05]
and modified by RDH Building Science



Roof assemblies may receive the greatest amount of moisture exposure during the construction phase; however, floors are also susceptible to wetting risks, such as shown in **Figure 8.8**, especially if construction schedule delays occur. The use of TMMS and additional moisture management strategies at both roof and floor assemblies can limit the risk of exposure to moisture during construction. New moisture management products are continuously being added to the market. Refer to Table 8.1 for categories of temporary moisture management systems for each climate index category.

TMMS for horizontal assemblies may include applied membranes, panel joint treatments, or both to control construction phase moisture ingress. Membrane and joint treatment products used in the system should be UV stable throughout the expected exposure period. Always consult with the roofing system warranty requirements if a temporary moisture management system will not be removed after its use.

Figure 8.8 Horizontal NLT floor panel subjected to snow
Photo courtesy of StructureCraft

Table 8.1 Horizontal temporary moisture management systems

	Visual reference	TMMS / joint treatment	Benefits	Challenges / limitations	Recommended climate index / season
High protection		**Field membrane:** Fully adhered, vapour-impermeable waterproof membrane on sheathing. **Joint treatment:** Fully adhered or welded membrane laps.	• High durability of membrane laps where torched or welded. • Factory applied field membrane prior to shipping minimizes errors and weather limitations of on-site application and allows for immediate installation of joint treatment (if skilled workers are available). • Field membrane may serve as part of permanent roof membrane or flooring underlay. • May be used for permanent air barrier and water control functions.	• Requires pre-coordination with subcontractor installing TMMS. • Can trap moisture within the NLT assembly and significantly reduce drying should water penetrate the membrane or travel under laps. • Prone to blistering if mass timber below is damp and membrane is exposed to solar radiation.	All climateindices / all seasons
Moderate protection		**Field membrane:** Precoated, moisture-resistant bonded water-repellent coating on sheathing. **Joint treatment:** Taped and/or sealed (e.g., flexible flashing membrane or tape).	• Precoated sheathing minimizes need for experienced membrane installers. • Sheathing and TMMS field membrane are combined into a single fabrication step. • Allows immediate installation of joint treatment following panel installation.	• Sheathing attachment penetrates through TMMS field membrane; taped/seal over fasteners. • May be susceptible to damage and/or adhesion failure due to trade activities. • May have limited exposure time; ponding water may result in water absorption and slow drying.	Climate index ≤ 70 / all seasons
Moderate protection		**Field membrane:** Fully adhered, vapour-permeable and ponding and moisture- resistant membrane on sheathing. **Joint treatment:** Taped and/ or sealed (e.g., flexible flashing membrane or tape).	• Factory applied field membrane prior to shipping minimizes errors and weather limitations of on-site application and allows for immediate installation of joint treatment (if skilled workers are available). • Field membrane may serve as part of permanent air barrier if made continuous. • Vapour permeable; does allow some drying of NLT through it; however, it can also allow some wetting.	• Lap joints/seams may require additional sealing beyond self-adhesive to mitigate water migration risks. • Requires pre-coordination with subcontractor installing TMMS. • May be susceptible to damage and/or adhesion failure due to trade activities. • May require skilled/experienced installer. • Not a vapour barrier. • Limited products available.	Climate index ≤ 70 / all seasons

Table 8.1 continued

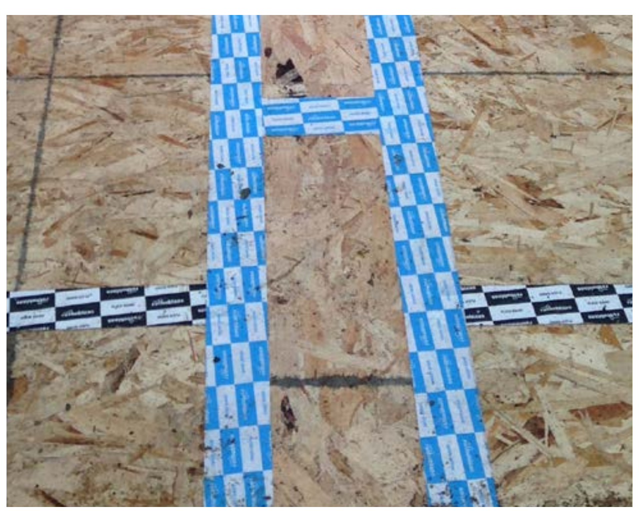
	Visual reference	TMMS / joint treatment	Benefits	Challenges / limitations	Recommended climate index / season
Moderate protection		**Field membrane:** Full adhered, vapour impermeable and moisture resistant membrane on sheathing. **Joint treatment:** Fully adhered laps.	• Higher durability at field and laps than permeable and semi-impermeable fully adhered membranes. • Factory applied field membrane prior to shipping minimizes errors and weather limitations of on-site application. • Field membrane often serves as part of permanent air barrier if made continuous.	• Moderate durability of membrane laps (less than waterproof membrane). • Prone to blistering if mass timber below is damp and membrane is exposed to solar radiation.	Climate index ≤ 70 / all seasons
Moderate protection		**Field membrane:** Full adhered, vapour-semi permeable and moisture resistant membrane on sheathing. **Joint treatment:** Fully adhered laps.	• Factory applied field membrane prior to shipping minimizes errors and weather limitations of on-site application and allows for immediate installation of joint treatment (if skilled workers are available) • Field membrane may serve as part of permanent air barrier if made continuous.	• Lap joints/seams may require additional sealing beyond self-adhesive to mitigate water migration risks. • Properties (e.g., water repellency, vapour permeability, life span) dependent on product, chemistry, and exposure. • Low vapour permeance (1 US perm); does allow limited drying through it; however, it can also allow some wetting. • May be susceptible to damage and/or adhesion failure due to trade activities. • Prone to membrane fishmouths and wrinkles including/ at lap joints which increase risk of water migration. • Not a vapour barrier.	Climate index ≤ 70 / all seasons
Low protection		**Field membrane:** None. Exposed plywood/ OSB sheathing. **Joint treatment:** Taped and/ or sealed (e.g., flexible flashing membrane or tape).	• Allows for immediate installation of joint treatment following panel installation. Skilled/experienced workers not required for joint treatment installation. • Additional applications of water sealer may further increase water resistivity of the sheathing. • Cost effective compared to options with field membrane.	• Site installed. • Some joint treatment products may not bond to damp or wet sheathing substrate. • Joint treatment may be susceptible to damage and/or adhesion failure due to trade activities.	Climate index ≤ 35 / all seasons Climate index ≤ 70 / dry seasons

Table 8.1 continued

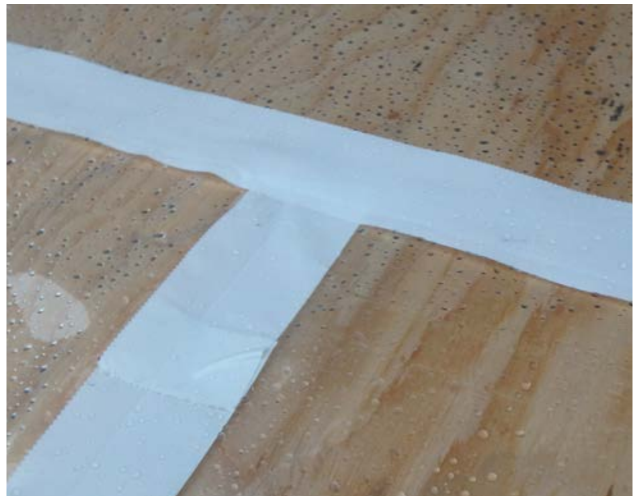
	Visual reference	TMMS / joint treatment	Benefits	Challenges / limitations	Recommended climate index / season
Very low protection		**Field membrane:** None. Exposed plywood/ OSB sheathing. **Joint treatment:** None. Exposed sheathing joints.	• No additional material cost. • No sequencing required. • Additional applications of water sealer may further increase water resistivity.	• System permits water migration between sheathing joints and into the NLT in wet weather conditions.	Climate index ≤ 35 / all seasons
Very low protection		**Field membrane:** None. Exposed NLT laminations. **Joint treatment:** Not applicable.	• Accommodates sheathing installation at a later date or following site installation of overframing. • No sequencing required. • No additional material cost.	• Option permits water migration between NLT in wet weather conditions.	Climate index ≤ 35 / all seasons
Isolated protection only		**Field membrane:** Loose laid sheet over sheathing. **Joint treatment:** Taped and/ or sealed (e.g., flexible flashing membrane or tape).	• Serves as short-term temporary protection for isolated areas.	• Low durability. Difficult to seal. • Typically slippery and dangerous to walk on. • Allows lateral moisture movement beneath membrane. • Not adhered to the substrate, so it requires fastening or weighing down. • Attachment points create a leakage path in TMMS unless holes are sealed or gasketed fasteners are used. • Susceptible to tears and removal due to wind uplift.	Isolated conditions (evaluate for project specific appropriateness)

Table 8.1 continued

	Visual reference	TMMS / joint treatment	Benefits	Challenges / limitations	Recommended climate index / season
Isolated protection only		**Field membrane:** Membrane under sheathing and over NLT laminations. **Joint treatment:** Varies	• Sheathing protects membrane from trade damage.	• TMMS is inaccessible for quality control review. • TMMS below sheathing is difficult to drain and dry; traps moisture within NLT. • Allows lateral moisture movement beneath membrane.	Not recommended. Avoid.

Below Algonquin College DARE District, Ottawa, ON, during construction
Architecture by Diamond Schmitt *Photo courtesy of* Diamond Schmitt

Below Algonquin College DARE District, Ottawa, ON
Architecture by Diamond Schmitt *Photo credit* Doublespace Photography *Photo courtesy of* Diamond Schmitt

8.6.3 Vertical assemblies moisture management systems

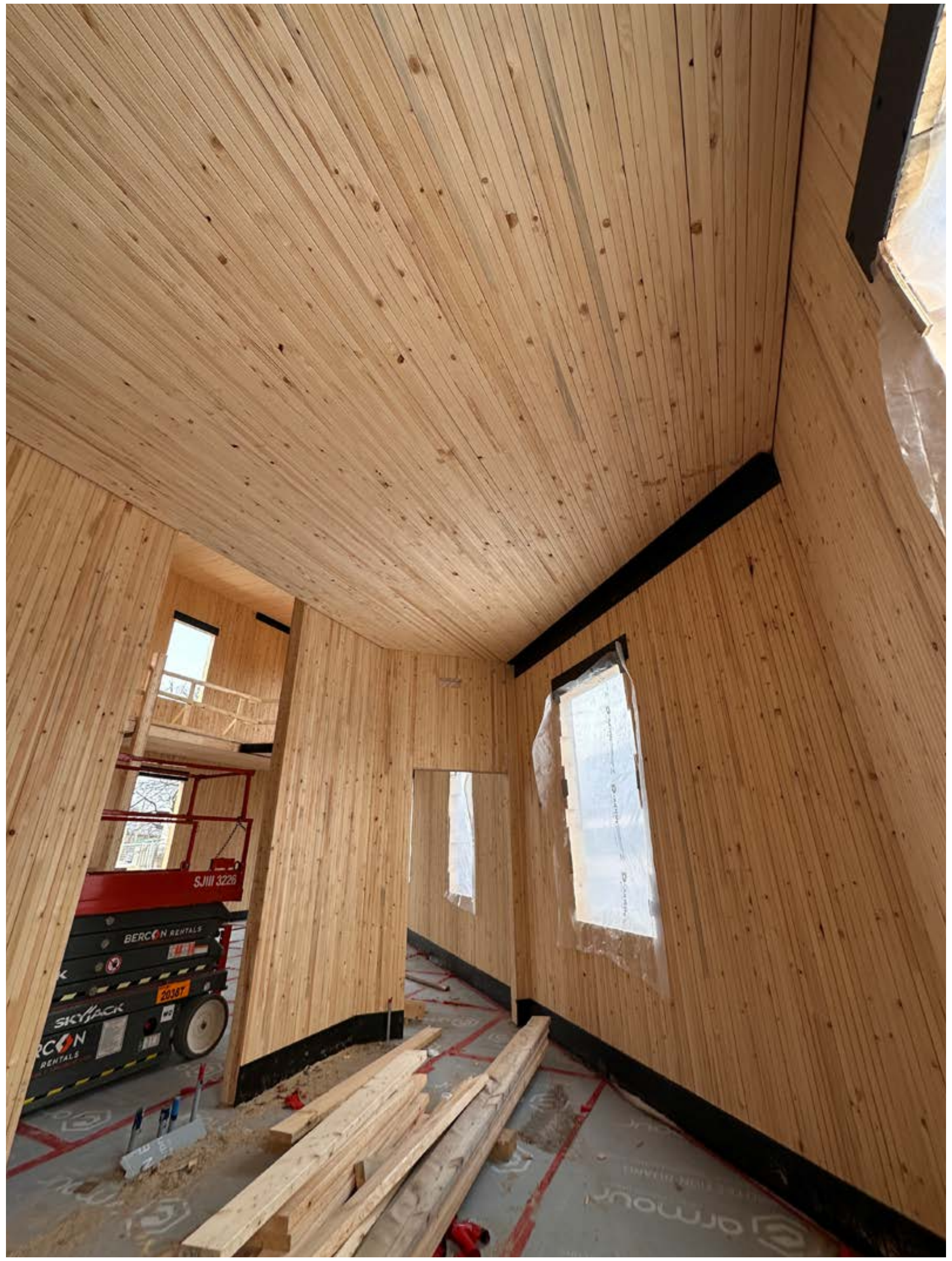
For walls, a vapour-permeable weather-resistant barrier (WRB) membrane is beneficial to allow NLT to dry while minimizing further water absorption. For all seasons and climate indexes protecting mass timber wall panels from wetting during the construction phase includes either factory- or site-installed application of the WRB membranes. If factory installation of WRB membranes is not feasible, then it is recommended that a WRB membrane is installed in parallel with, or shortly following, the erection of the NLT on-site. In cases where exterior materials with low vapour permeance are selected, the NLT panels should be dry (i.e., with a moisture content below 16%) prior to their installation.

The exposed edges (i.e., end grain) of the mass timber wall panel at joints, window and door rough openings, and penetrations, such as those shown in **Figure 8.9** and **Figure 8.10**, consist of horizontal, unsloped surfaces that are unable to readily shed water. These details are at the highest risk for moisture intrusion; therefore, these details have a higher moisture exposure level than field-of-wall areas and require appropriate and effective moisture protection methods during the construction phase to minimize wetting risks.

Even with these precautions, it is likely that mass timber panels will experience some wetting during transport or construction, and that they will be installed with built-in moisture in localized areas. Accordingly, the most durable wall design strategies will use vapour-permeable materials to allow excess moisture to escape the assembly, thereby minimizing damage and deterioration.

Figure 8.9 Exposed end grain edge of NLT panel
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood

Figure 8.10 Rough opening in NLT wall. The sill of the rough opening is susceptible to water ponding. *Photo courtesy of* Silvaspan



8.6.4 Additional considerations and strategies for moisture management systems

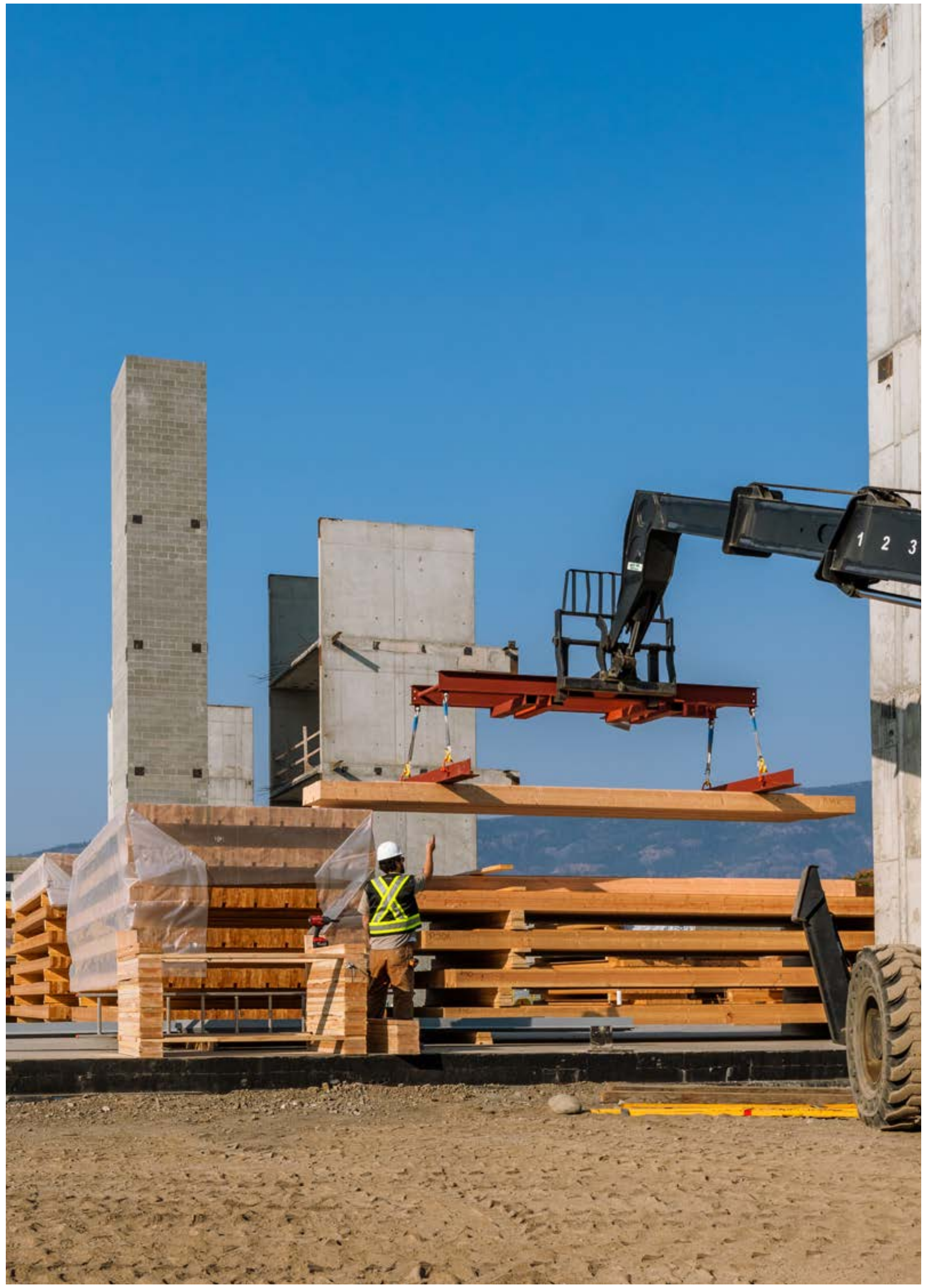
Successful moisture risk mitigation involves completing all steps of the moisture management process: Complete a risk assessment, develop a moisture management plan, and execute the plan during construction. The moisture management process begins early in the design phase and continues throughout the construction phase of the project. If moisture risk is considered early there is opportunity to consider a combination of proactive strategies and be prepared for construction conditions.

When selecting TMMS for horizontal assemblies and WRB at walls, consider the following:

- Compatibility with any interfacing membranes or assemblies and membrane, tape, and other materials sensitivity to UV exposure relative to the project schedule.
- Where the TMMS and WRB will also be used as the permanent air barrier system such as at roof and walls, and vapour control layer at roof, ensure the TMMS and/or WRB has the appropriate properties to function accordingly, and is repaired as needed prior to covering.
- For horizontal systems also consider the TMMS ability to accommodate construction activity without undue risk of workers slipping, and that the TMMS may impact the adhesion of a concrete topping slab.
- TMMS must be intact to be effective. Take care where fasteners penetrate through the TMMS at elements such as hoisting hardware, fall arrest anchors (refer to Chapter 9), scaffolding supports, or structural outriggers (refer to Chapter 4). Detail fastener penetrations through the TMMS and consider additional protection for high rainfall areas. Any temporary penetrations, removed fasteners, or damaged TMMS areas should be promptly repaired.

A range of other moisture control measures may be implemented to supplement or replace the chosen TMMS for NLT assemblies. Consider incorporating these into the design or moisture management plan, each are discussed in detail through the remainder of this chapter:

- Optimize schedules
- TMMS joint treatment
- TMMS end grain protection and treatment
- Water deflection/draining mechanisms
- Tenting
- Drying



Above The Exchange under construction, Kelowna, BC
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood

Optimize schedules

Minimizing the duration of the NLT and associated moisture management systems are exposed to wetting reduces the risk of wetting occurring. Consider implementing the following scheduling strategies if possible to minimize wetting risk:

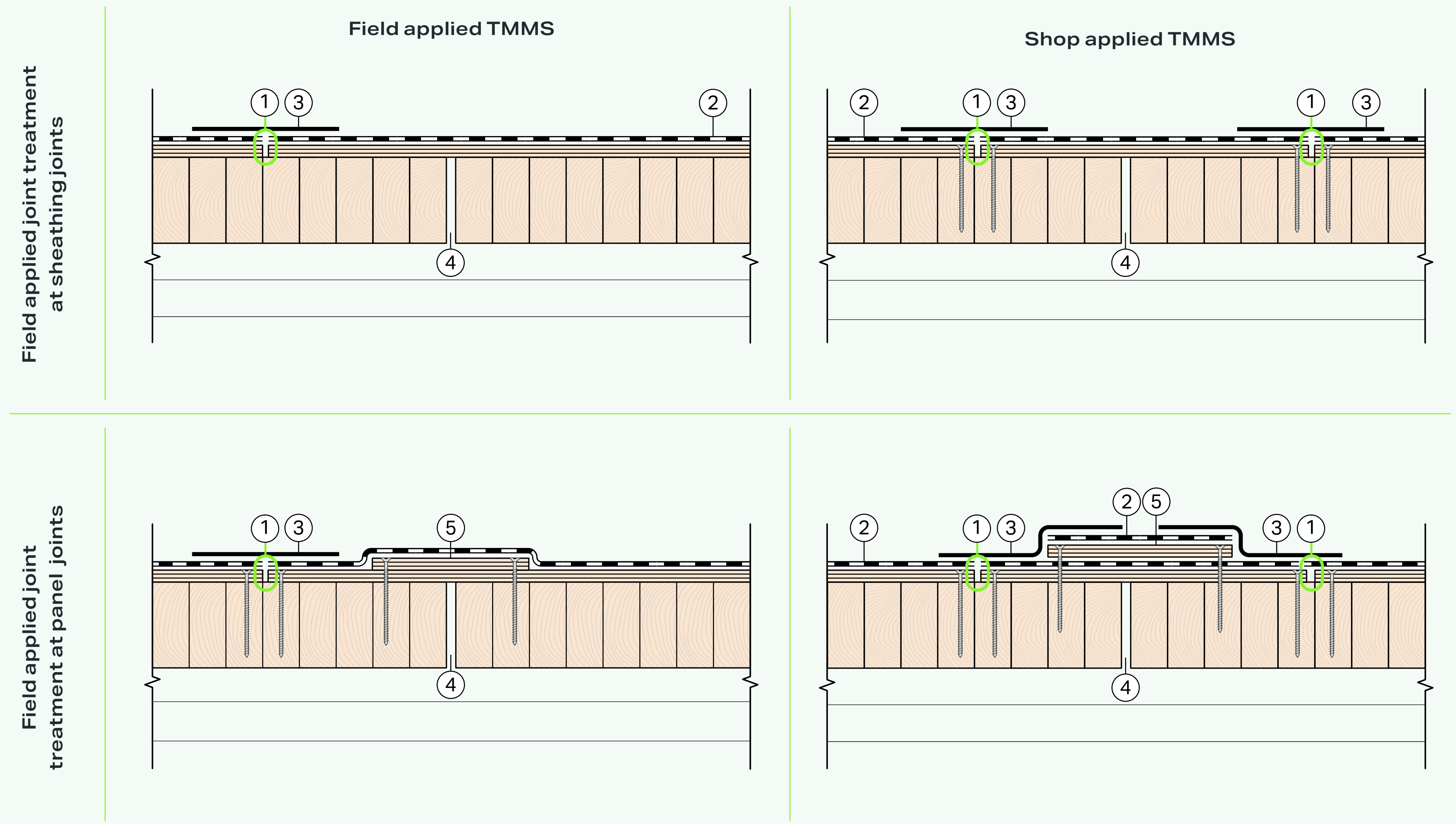
- Schedule NLT installation during dry seasons;
- Coordinate shipping for just-in-time delivery and installation of NLT panels;
- Increase the speed of erection including the installation of the roof and roofing membrane;
- Minimize schedule delays between constructions of adjacent floor levels;
- Minimize schedule delays between construction of structure and enclosure components.

TMMS joint treatment

Install sheathing, field membrane, and/or joint treatment (where used) at panel connections as soon as possible after installation. This connection is critical for protecting against moisture intrusion and providing a continuous TMMS. Example TMMS joint treatment concepts based on panel-to-panel sheathing details are shown in **Figure 8.11**. In all cases, the TMMS should extend continuously across the surface of the NLT. Regardless of TMMS type, always design the system to accommodate possible swelling during construction, as discussed in Chapter 4 and Appendix C.

Joints provide an easy pathway for water to migrate into the NLT. Detail the splines with the TMMS field membrane and/or joint treatment as soon as possible after placement, and before wet weather conditions occur.

Figure 8.11
Temporary moisture management systems joint treatment concepts



1. Structural sheathing break
2. TMMS membrane
3. TMMS joint treatments such as tape or membrane
4. Movement gap per structural engineer
5. Sheathing per fire engineer (if required)

TMMS end grain protection and treatment

End grain protection and/or treatment can greatly benefit moisture risk mitigation because NLT end grain absorbs water more quickly than the NLT surface. Common details and interfaces that may need treatment include joints as discussed earlier, assembly interfaces, column connections, penetrations, wall edges, structural attachments, and parapets as shown in **Figure 8.12**.

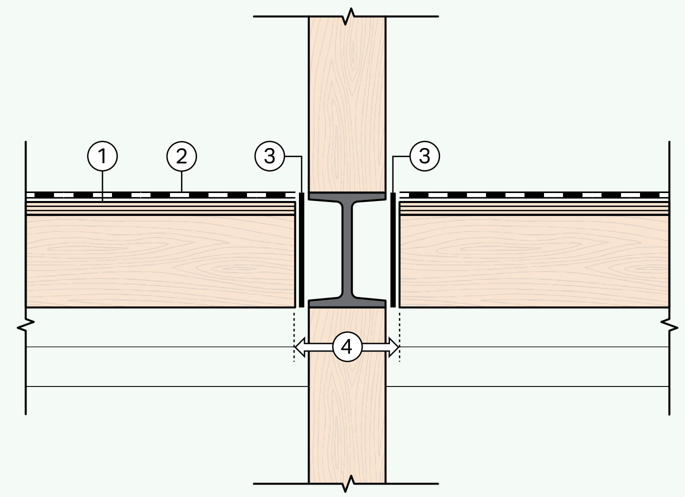
Various treatment strategies are available, but tapes and self-adhered membranes, or a combination of these materials, are most commonly used to protect against moisture and promote water shedding. Shop or factory applied protection is best practice to mitigate moisture risk. If factory applied protection is not utilized, ensure protection is installed as soon as possible after panel placement and penetrations occur, and before wet weather conditions occur.

Additional end grain protection strategies include:

- Detail rough openings and penetrations as soon after panel placement as possible, and before wet weather conditions occur.
- Separate the mass timber wall from concrete surfaces using a vapour-impermeable membrane.
- Elevate the mass timber walls a sufficient elevation above grade and provide additional protection of the wall base to prevent the mass timber from wicking water.
- Maximize panel size to decrease the number of site-installed TMMS joints where they are most susceptible to leakage.

Additional coordination with appropriate the structural and/or fire design professional may be needed where join treatment is required. Coordinate with the with the project architect to make sure any end grain protection is removable for any visible areas at project project completion.

Figure 8.12
Self-adhered membrane installed at a floor column connection to protect the edge grain from construction phase moisture



1. Structural sheathing
2. TMMS membrane
3. TMMS end grain treatments such as tape or membrane
4. NLT penetration gap or penetration eith exposed end grain

Water deflection/draining mechanisms

On all project sites where rain or snowmelt may occur, temporary drains sealed to the TMMS will divert water away from the NLT assemblies and supplement the TMMS. At the building perimeter, provide temporary protection to minimize water ingress through openings and penetrations such as hoarding or tarping. Close off perimeter wall cavities at the top. Water that is not deflected or drained may cause ponding on the horizontal NLT surfaces. Where ponding occurs, actively remove ponding water that may develop using vacuums, squeegees, and other water-removal tactics. Divert removed water to appropriate drainage paths. Additionally, ensure any other water deflection/diversion mechanisms avoid concentrating water at spline locations.

Tenting

For construction during the wet season in wet climates, or climates prone to cold and snow, consider a temporary tent until the building is enclosed as an alternative to a TMMS. Tents may be fixed or movable (refer to **Figures 8.13**). Tenting represents the lowest risk in terms of moisture impacts and can also facilitate wintertime construction; however, tents can be costly and may hinder some installation strategies.

Drying

If NLT moisture content exceeds recommended limits in spite of the TMMS applied, a strategy to dry the wood will be necessary. The overall depth of the NLT and the extent of water intrusion will determine the most effective strategy; deep assemblies require more aggressive tactics and more time to dry. Where large dimension wood panels require drying, it is also important to control the rate of drying to minimize checking.

Using natural ventilation to dry wet NLT is not effective; drying typically occurs slowly and relies on natural heating from sun exposure, and air flow from wind [06]. Active heating and dehumidifying are more effective but have limited benefit in cases where there is a membrane on top of the assembly.

In these instances, heating and dehumidifying can lower the moisture content of wood close to the underside of the NLT, but research suggests the membrane slows the overall rate of drying; heat may be ineffective at drying the plywood/OSB or moisture trapped just below it. Heating and dehumidifying is most effective in combination with ventilation. Accordingly, remove membranes and plywood/OSB whenever possible to allow drying of both the top and bottom sides of the NLT. Tenting, as described previously, can also help speed the process.

Figures 8.13 Fixed tenting installation *Photos courtesy of* Fast + Epp

Post-installation drying of mass timber components is identified as an emergency response resulting from wetting that exceeds the recommended moisture content limits (post-installation drying should not be considered a normal step in the construction of a mass timber building). When moisture content exceeds the recommended limits established during the project's moisture management planning, the drying strategy devised during the planning phase of the project is implemented.

Chapter 8.0 references

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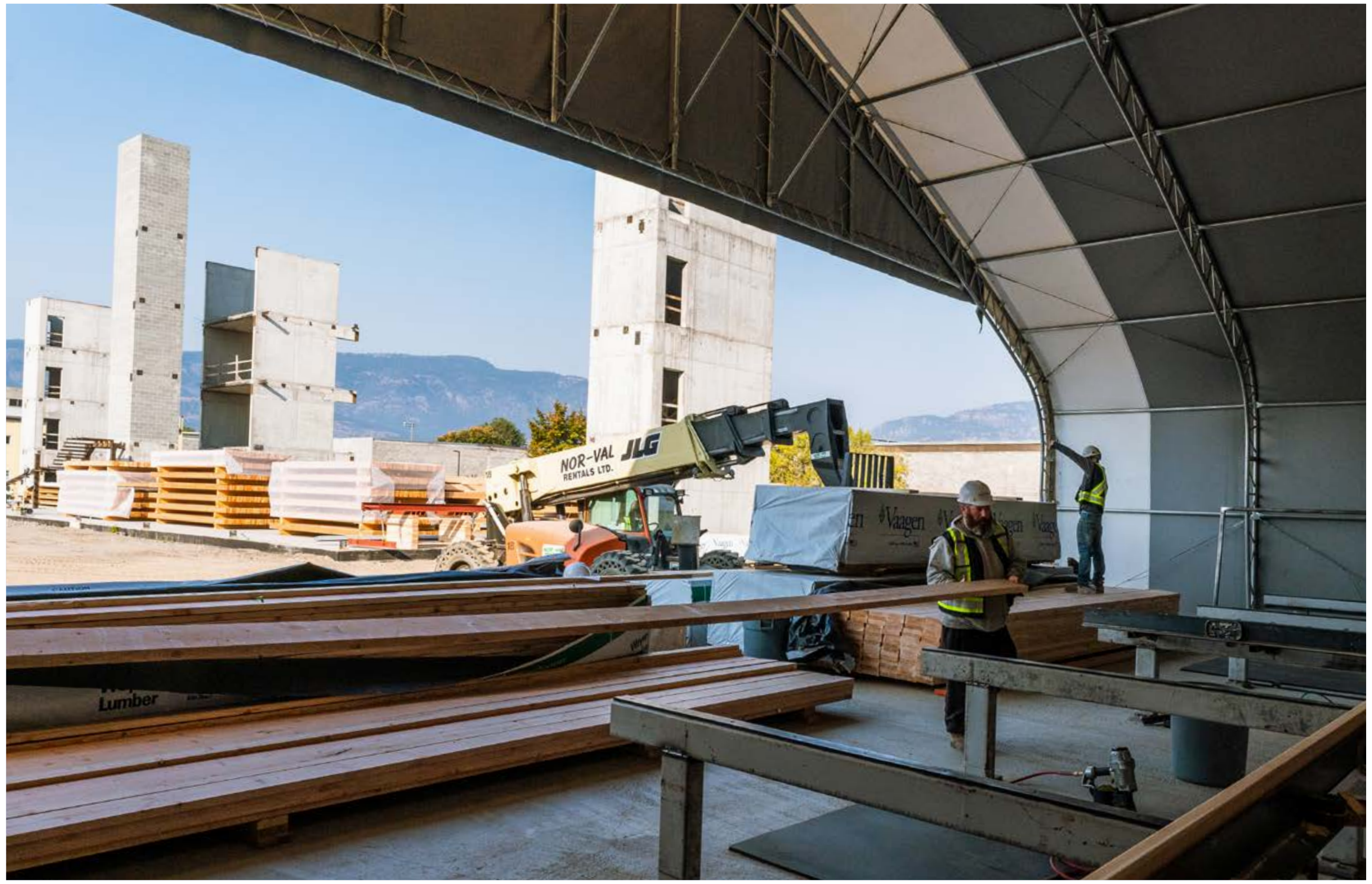
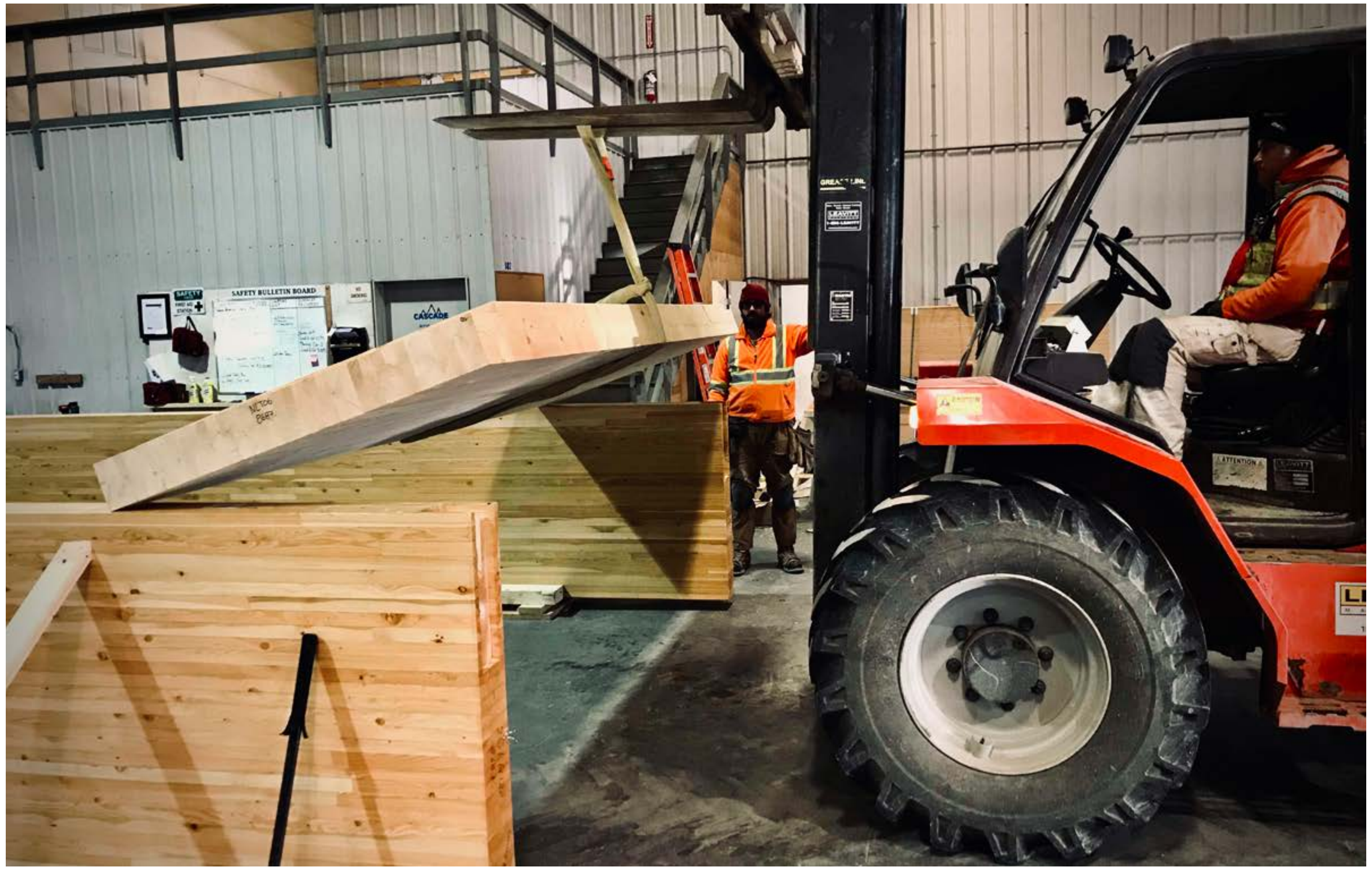
Below NLT fabrication set-up at The Exchange, Kelowna, BC
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood



Below NLT panel fabrication
Photo courtesy of Kinsol



9.0 Erection Engineering

9.0 Erection engineering

NLT projects usually require specialty erection engineering for panel lifting, fall arrest, temporary structural stability, and NLT wall shoring where applicable.

This engineering can be performed by the structural engineer but is more often carried out by the supplier or installer's temporary works engineer.

For larger structures, an engineered, stamped, and sealed set of erection drawings should be in place prior to the start of work on-site.

Below The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

Below The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

Below The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

9.1 Design loads

Successful systems for lifting and temporary stability are based on accurate design load calculations.

Consider the following:

- IBC and Work Safe requirements for temporary stability, construction loads per ASCE 37-14, and fall arrest loads.
- The impact of wind to increase forces in lifting systems. Maximum wind speeds for panel lifting should be specified by the erection engineer.
- Accurate panel weights, considering wood species and moisture content of the NLT panel.
- Appropriate Dynamic Amplification Factors related to the lifting mechanism being proposed (refer to **Table 9.1**).
- Accurate calculation of the panel's centre of gravity and any impact of asymmetric lifting.

Take care before specifying a specific load rating for any engineered lifting system. Once a rating is stated, others may assume it to be valid even under significantly different circumstances.

Table 9.1 Dynamic acceleration factors (F) [01]

Lifting device	Dynamic coefficient of acceleration (F)
Fixed crane	1.1 ~ 1.3
Mobile crane	1.3 ~ 1.4
Bridge crane	1.2 ~ 1.6
Lifting and moving on flat terrain	2.0 ~ 2.5
Lifting and moving on rough terrain	3.0 ~ 4.0 *and* +

Above The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

9.2 Panel lifting

Many systems for lifting NLT panels are available, ranging from simple lifting with slings to pre-engineered systems using screws. Lifting drawings sealed by a professional engineer are required for many of these systems.

Typical stamped lifting drawings can be re-used across projects if they are reviewed for applicability with a registered professional engineer prior to re-use.

Below The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

9.2.1 Engineering considerations

Lifting capacities depend on many project-specific factors including wood species, moisture content, panel shape or openings, and crane type. Specify and include the following information on panel lifting or erection drawings:

Weight: Loading and panel weights.

Lifting mechanism: Slings, spreader bars, and chain hoists can all be components of the rigging system which attaches to pick points on panels. Specifying allowable sling angles and required sling or chain capacities is critical to a safe lifting plan. Specify use of tag lines to safely guide the panel during lifting.

Lifting point connection details: Specify associated reinforcing screws if required.

Lifting point capacities and assumptions: Account for wood species, moisture content, panel build-up, type of lifting device, factor of safety, and assumed dynamic amplification factor related to the specific lifting device or crane being used.

Location of lifting points: Notches and non-rectangular panel shapes modify the position of the centre of gravity; in these cases, typical lifting point patterns must be rearranged to ensure panel stability during lifting. Some panels may require so-called strong backs or reinforcement atop the panel during lifting to avoid excessive deflection or damage to the panel until it is fully supported in its final installed condition.

Screw installation: Screws should never be installed with an impact drill. Do not remove or reinstall screws. Do not reuse holes.

Stability of support structure: The support structure must be adequately braced and connected prior to landing NLT panels, both to ensure sufficient load-bearing capacity and to maintain panel alignment once set.

Minimum connection from panel into support structure: Prior to walking on panels or attaching fall arrest anchor points, a minimum level of connectivity is required between the NLT panel and the support structure.

Temporary lateral restraint of walls: Temporary restraint of walls prior to the installation of floors, and their diaphragms above, allow for stability and adjustment of the walls to achieve plumbness requirements. In these cases, strong backs are commonly required for both lifting and lateral support of NLT walls. Note that the system is not stable until the walls and diaphragm are fully connected, and the diaphragm is connected to the vertical lateral elements (shear walls, braces, etc.).

9.2.2 Lifting mechanisms

Many different lifting mechanisms are possible, and a registered professional engineer should design an appropriate lifting mechanism for the project and panel configuration.

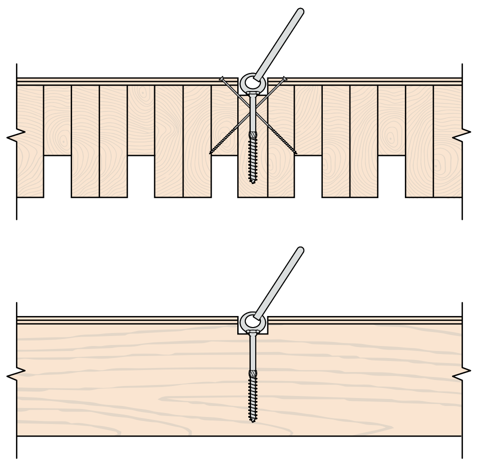
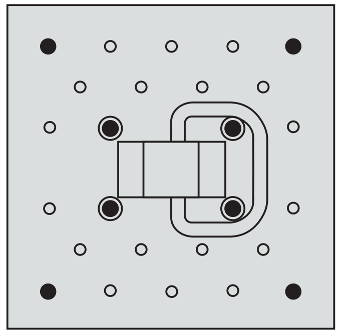
Refer to **Table 9.2** for some common approaches to lifting horizontal NLT panels for floors or roofs, many of which include high-strength self-tapping screws. Where these screws are used, place them centered on NLT laminations. Screws of larger diameter should be predrilled.

Use the right tools, correctly calibrated to prevent stripping of the wood during screw installation. Never use impact tools to avoid overdriving the screw, breaking the screw, or stripping the holes. Generally, these screws cannot be re-used; consult with the supplier to confirm.

NLT wall panels with vertically oriented laminations and a horizontal top plate require special lifting techniques. Consider the use of choked slings or screws fastened through the top plate, or D-ring plates fastened to the sides of the panel. It is important to consider load transfer between laminations, although where plywood/OSB is pre-installed on at least one side this is usually straightforward.

Right Straps
Photo courtesy of Seagate Structures Ltd.

Table 9.2 Lifting mechanism options

	Lifting mechanism	Use and load ranges	Considerations
Screwed-in quick release anchors		• Common system for mid-range panel weights. • Load is dependent on the withdrawal capacity of high- strength screws.	• Quick-connect system reduces cycle times. • Screws must be installed at correct angle and located centered on a lamination. • Local reinforcement of panel is required. • For higher loaded connection, provide timber blocking fastened to the top of the panel or a counterbore into the panel to ensure lifting screws are loaded in withdrawal only. • Screws penetrate pre-installed TMMS.
Straps		• Simple system common or narrow panels or tight spaces (ex: shops). • Load is governed by sling capacity and rigging configuration.	• Slings can be re-used. • Hook-up and release of panels is slow. • Typical max width is 4 ft. (use of a spreader bar can increase the sling angle). • Sling angles less than 60° increase lifting anchor force (impacts lift rating). • Difficult to remove slings, so panels must be landed apart and pulled together. • Potential for instability of the panel if slings slip. • No penetration through the TMMS (where applicable).
Screwed plates with lifting rings		• Governed by plate dimension and number of screws installed. • Used for higher load panels (or reduced number of pick points).	• D-ring plates and screws can be re-used. • Can be time consuming to install. • Consider impact to dunnage during shipping for pre-installed plates. • Multiple plates required for a project will impact the cost. • Provide either swivel lift ring or orient d-ring to pivot in same direction as chains/slings. • Large number of penetrations into the TMMS.

9.2.3 Pick points

Pick-point distribution for lifting is critical for any mass timber panel erection strategy.

Left Algonquin College DARE District, Ottawa, ON, during construction *Architecture by* Diamond Schmitt *Photo courtesy of* Diamond Schmitt

Floor and roof panels pick points

Distribute pick points such that the resulting lifting hook position lies over the panel center of gravity, minimizing eccentricities and any tendency for the panel to tip in one direction. For asymmetric panels, a stable arrangement of pick points can be determined by placing two, three, or four pick points on a radius drawn from the panel center of gravity. This radius should not be less than one-quarter of the overall panel length.

When picking more than two lifting points from a single hook, use appropriate compensation systems to ensure proper load distribution between all pick points, and carefully consider effective loads on each pick point.

Wall panel pick points

NLT and MLT are not composite elements, but mechanically fastened individual laminations. Accordingly, panels have significantly reduced weak axis strength and stiffness compared to CLT or even GLT, adding complexity to lifting walls panels. The reduced weak axis strength means that strong backs are likely required for lifting walls, particularly for wider panels. Strong backs are useful in facilitating the pick-points and accommodate lifting panels from a horizontal position (off the truck or from on-site storage) to vertical for installation. Strong backs must be designed to be both strong and stiff enough to resist weak axis bending and deflection; assume that no additional weak axis strength is provided by the panel. Strong backs should be the first step in installation, installed on unexposed sides of the wall. Practice extreme care when lifting walls panels that are not pre-sheathed, and ensure strong backs are fastened to a sufficiently large number of laminations.

Pick points on both faces of the panel provide a robust lifting mechanism where pick points are aligned with, or even connected directly to the strong-backs using screwed plates for wood strong backs or steel bolted/welded lifting devices for steel strong backs. Where architecturally feasible, lifting can also be completed with slings through-holes within the wall panels themselves. Alternately, lifting from the edge of the panel (i.e. face grain of the lamination) is also feasible where pick points can be aligned closely with the strong backs.

In all cases avoid connection of lifting devices into the end grain of NLT, M-NLT or any MLT product, even if deemed acceptable for GLT or CLT. NLT and MLT panels are not solid composite panels and have weaker axis strength. The individual laminations should not be supported from their end grain.

9.3 Fall arrest and horizonal life-lines

Temporary fall arrest systems atop horizontal NLT are an important part of any installation plan, in addition to any fall arrest anchors required for permanent conditions.

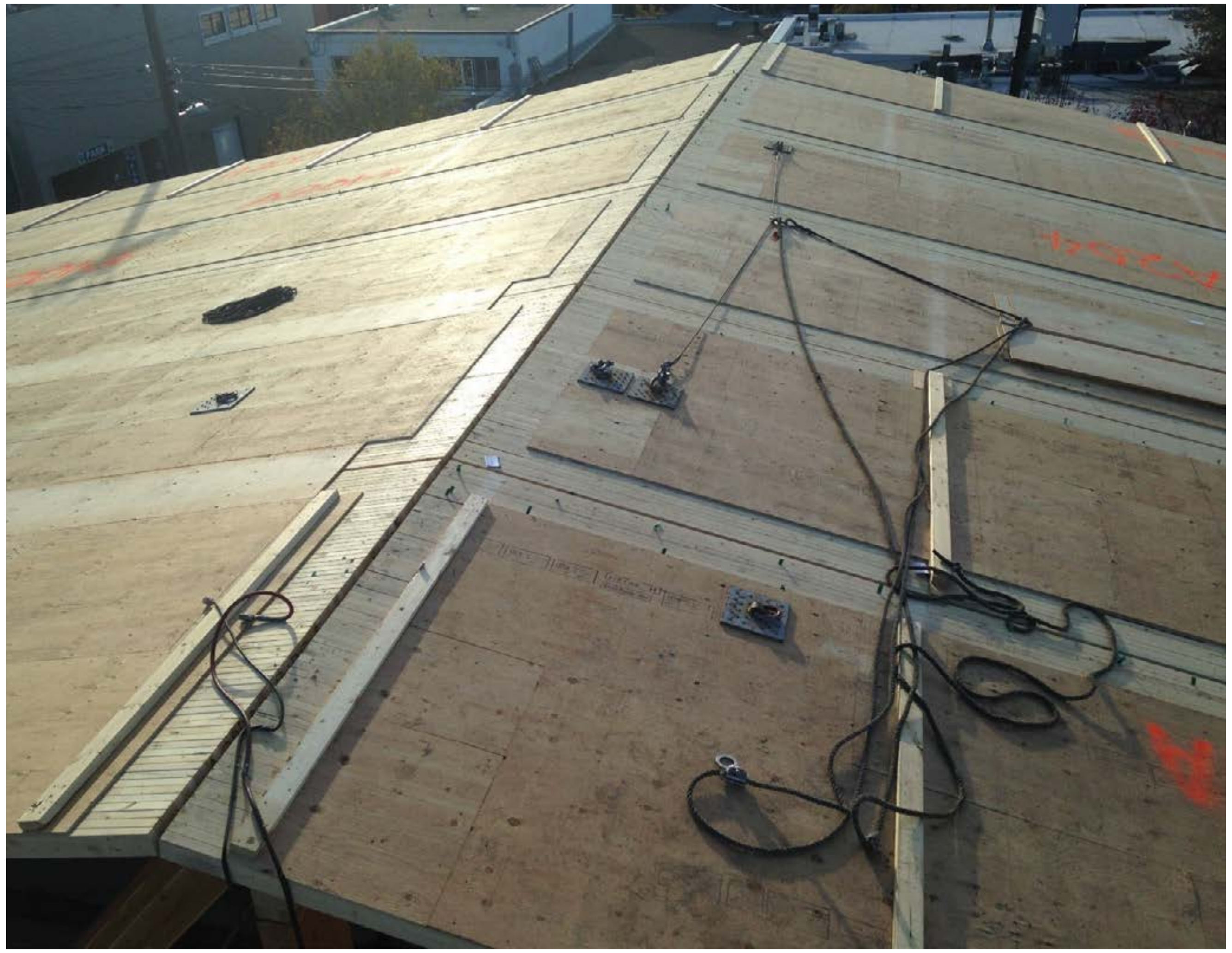


Figure 9.1 Point arrest and lifelines
Photo courtesy of StructureCraft

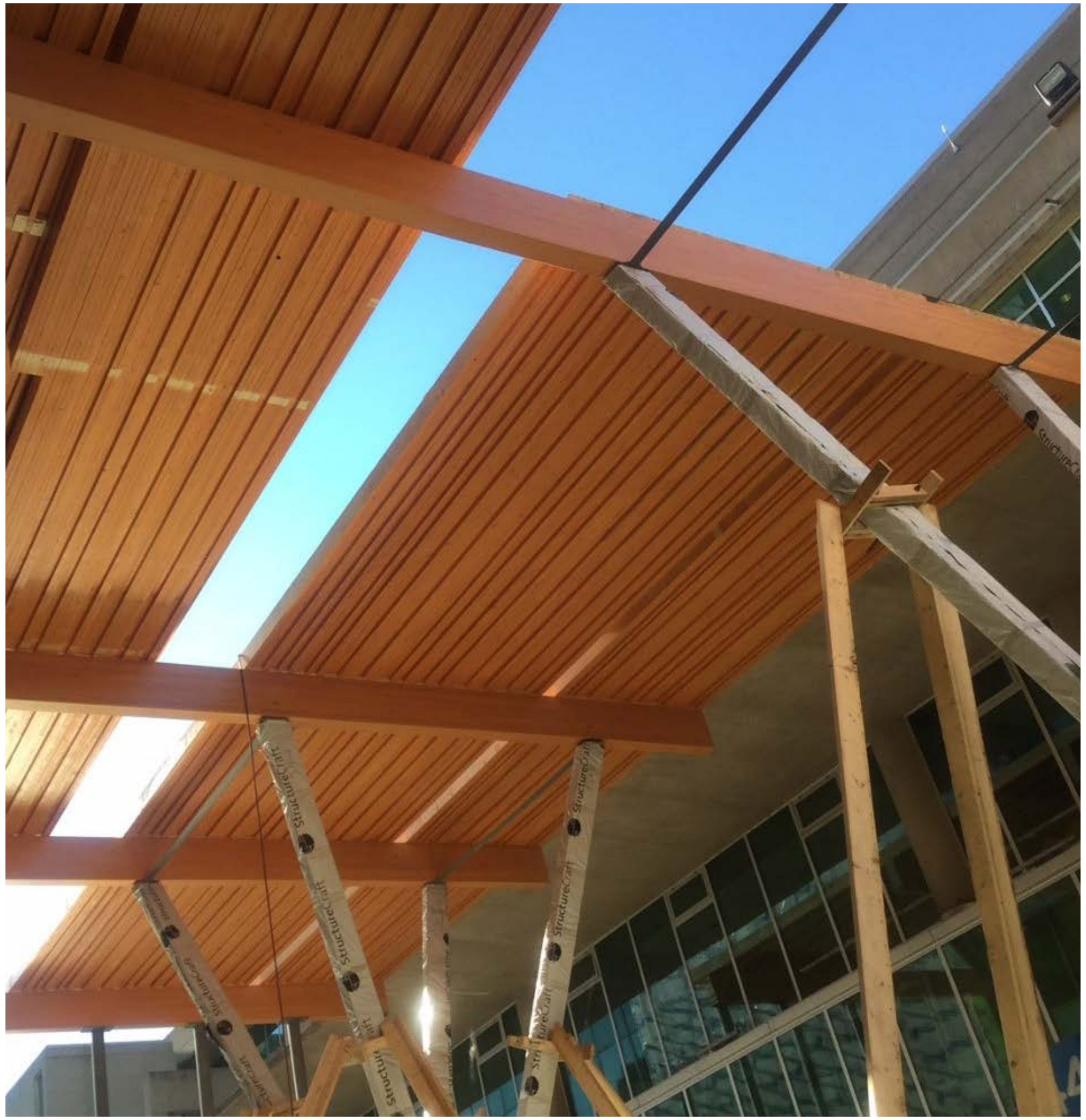
Both systems can be fastened directly to the NLT and provide sufficient capacity to meet OSHA requirements. They require specific engineering, which is usually provided by the installer's engineer. Give special consideration to load transfer requirements from the NLT to the supporting structure.

Panels that are covered with lumber wrap or adhesive membrane for weather protection also become very slippery when wet, posing an additional hazard during construction. For temporary fall arrest systems, D-plates can be fastened directly to the NLT and used for both point arrests and lifelines; refer to **Figure 9.1**. Not all lifting systems are designed for fall arrest. Fall arrest engineering should be done in addition to lift engineering.

Permanent fall arrest anchors typically impose larger loads on the structure than temporary systems, because minimum clearances above the finished roof increase the height of the anchors. Local reinforcement of the NLT may be required at anchor locations to distribute the load to enough laminations. If the anchor locations are coordinated early enough, reinforcing screws can be preinstalled in the NLT. In other cases, 45-degree screws attaching the anchor base plate to the NLT can function both as anchorage and as reinforcing. If fasteners for fall arrest anchors penetrate either the permanent or temporary waterproofing membrane, consider their impact on the integrity of the membrane.

9.4 Temporary stability

To properly align elements before and after NLT installation, temporary stability supports may be applied to the structure supporting NLT floor or roof panels as shown in **Figure 9.2**, or NLT wall panels.



9.4.1 Floor and roof panels temporary stability

NLT is heavier than light-wood frame construction and therefore less susceptible to wind uplift, but lateral loads such as horizontal fall arrest loads or seismic loads during construction must be considered. Install a minimum required number of fasteners between the NLT and its supports immediately to secure each panel in place.

If panels are stacked on the structure during installation, check the weight of the panel stacks against the design loads for the structure. Wall panels require restraint for temporary construction loading such as wind. Shores are common and may take several forms, from custom built-up 38 mm x 140 mm (2x6) braces with adjustable turnbuckles at either end, to pre-manufactured and adjustable metal shores.

9.4.2 Wall panels shoring

Shoring and lateral restraint for NLT wall panels is crucial until the panels are permanently connected to the diaphragm above. The diaphragm system needs to be tied back to either a temporary lateral restraint, to the final bracing or wall system to be considered completely restrained. As a result, shores can be in place for some time and should always have an erection engineer's approval before they are removed. Where additional walls are installed above without a completed lateral system, ensure the shoring has been designed to handle the increased construction loading.

Left | Figure 9.2
Temporary stability supports
Photo courtesy of StructureCraft

Connections for temporary shoring should follow the same recommendations as pick points. NLT wall panels need strong backs or frequent temporary restraint posts to spread the load between laminations between the shores given the very low weak axis strength and stiffness of the panels. The combination of shores and strong backs should be stiff enough to keep the entire width of the wall within erection tolerance for plumbness. Face mounted plates and anchor systems can be mounted to the wall, near strong backs where they are used, or directly to the strong backs themselves. Screws can be used where mounted to wood, but thru-bolts offer a reusable and robust connection where acceptable architecturally.

Chapter 9.0 references

[01] Karacabeyli, Erol, and Brad Douglas. 2013. CLT handbook: cross- laminated timber. Pointe-Claire, Québec: FPInnovations.

Above Brightwater C4 Building, Port Credit, ON, during construction
Architecture by Diamond Schmitt *Photo courtesy of* Silvaspan

Above The Exchange, Kelowna, BC, during construction
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

Glossary

A

Absorption
Gain of liquid moisture into the volume of a material.

Adsorption
Accumulation of moisture in the form of vapour into and the porous surfaces of a material.

Aesthetic grading
Additional grading done to select lumber with a higher quality appearance. This form of visual grading does not allow higher structural design values than typical visually graded lumber.

Anisotropic
Having different physical properties along different axes. For example, wood is stronger parallel to the grain than it is perpendicular to the grain.

Apparent Impact Isolation Class (AIIC)
A single number rating that indicates the ability of a floor/ceiling assembly to reduce impact sound. It is based on in-situ field measurements and includes sound flanking paths. Refer also to Impact Isolation Class (IIC).

Apparent Sound Transmission Class (ASTC)
A single number rating that indicates the ability of a partition (e.g. floor/ceiling or party wall) to block air-borne sound sources. It is based on in-situ field measurements and includes sound flanking paths. Refer also to Sound Transmission Class (STC).

Appearance grading
See **Aesthetic Grading**.

B

Bound water
Water held within the cell walls of wood.

Butt joint
End to end alignment of laminations within a course, generally without a direct connection between the lams (i.e. no toe-nails, glue, or connection plates).

C

Checking
See Lumber Checking.

Computer-aided design (CAD)
The use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design.

Computer numeric control (CNC) machine
The use of digitized data from a computer or computer-aided program, to control, automate, and monitor the movements of a machine such as a router, used to cut materials into specific forms defined by the data.

Course
Multiple laminations arranged end-to-end.

Cross-laminated timber (CLT)
A solid structural panel consisting of three, five, seven, or nine layers of sawn lumber oriented at right angles to one another, and then glued. (NOTE THIS IS CERTIFIED PRODUCT)

Curved-in-plan NLT
Planar NLT with a curve or profile in plan only, generally formed by cutting the edges of the panel.

Curved NLT
NLT curved in section, perpendicular to the laminations, generally created on a curved jig to follow the curve of a supporting perpendicular beam. This fabrication process does not produce a true curve but a faceted surface, with each facet being the width of one lam.

D

Desorption
Loss of moisture from a material.

Dimension lumber
Visually graded or mechanically graded sawn lumber cut into planks, typically called up as thickness-by-depth. Thicknesses are typically 2x (38 mm), 3x (64 mm), or 4x (89 mm) with depth typically falling from 89mm (4 in. nominal), 140 mm (6 in. nominal), 184 mm (8 in. nominal), 235 mm (10 in. nominal), or 286 mm (12 in. nominal). Refer to CSA O86 tables for design values.

Dowel-laminated timber (DLT)
A solid wood structural panel, created by placing dimension softwood lumber (nominal 2x, 4x, etc., thickness) on edge and friction-fastening laminations together with hardwood dowels. (NOTE THIS CAN BE A CERTIFIED PRODUCT PER CSA O125)

Dunnage
Scrap wood or disposable material placed below construction material to raise it off the ground, floor, or truck bed.

E

Engineered wood product
Elements made by binding or fixing strands, particles, fibres, or veneers or boards of wood together with a binder, such as glue or resin, to form composite materials. These materials can be structural or non-structural.

Equilibrium moisture content (EMC), %
A moisture content at which wood neither gains nor loses moisture to the surrounding air.

F

Fibre saturation point, %
The moisture content at which the cell walls of wood are saturated with water (bound water) and no water is held in the cell cavities by capillary forces. It usually is taken as 25% to 30% moisture content, based on weight when oven-dry.

Firestop
A fire protection system made of various components used to seal openings and joints in a wall or floor assembly.

Fire separation
A fire-resistant element that divides a building or space to prevent fire spread, such as a fire wall.

F

Flanking
The passage of sound around, over, or under the primary partition separating two spaces.

Flashover
The near-simultaneous ignition and sustained burning of most or all of the exposed combustible material in an enclosed area.

Flame-spread rating
A standardized rating system used to describe the surface burning characteristics of a building material. One common rating systems is the ASTM E-84.

Finger joined lumber
Lumber manufactured by bonding two pieces of lumber with ends machined to mated finger-like profiles.

Free water
Water that is not bound within the cell walls of wood.

Forest Stewardship Council (FSC) certified wood
Wood from forests evaluated by the Forest Stewardship Council to meet environmental and social standards (www.fsc.org).

G

Glued-laminated timber (GLT)
A solid wood structural element composed of individual sawn lumber laminations, specifically selected and positioned based on their performance characteristics and then bonded together with durable, moisture-resistant adhesives. The grain of all laminations runs parallel with the length of the member. (NOTE THIS IS A CERTIFIED PRODUCT)

Glulam
See **glued-laminated timber (GLT)**.

H

Heavy timber construction
A traditional type of combustible construction in which a degree of fire safety is attained by placing limitations on the sizes of wood structural members, the thickness and composition of wood floors and roofs, and by the avoidance of concealed spaces under floors and roofs.

Hi-line grade
An appearance grade of SPF lumber, often for export, and generally kiln- dried. It generally meets visual grading standards (white, bright, straight); however, a visual grading standard must also be specified. May also be known as home centre grade.

Hygroscopic
Tending to absorb or adsorb water from the air.

I

Impact Isolation Class (IIC)
A single number rating that indicates the ability of a floor/ceiling assembly to reduce the transmission of impact sound. It is based on laboratory measurements. See also Apparent Impact Isolation Class (AIIC).

J

J- grade lumber
The preferred appearance grade of wood in the Japanese market. This grade meets high visual grading standards (minimal defects, white, bright appearance) and is kiln-dried for dimensional stability. This is generally the most selective appearance grade of lumber.

Jig
A temporary structure or device that holds a piece of material and guides the tools operating on it.

K

Kerf
A slit made by a saw cut. The kerf width is equal to the saw blade width.

Kiln-dried (KD) lumber
Lumber dried in a wood-drying kiln to meet lower moisture content values, generally around 12%.

L

Lamination or lam
Individual dimension lumber component within NLT.

Laminated strand lumber (LSL)
A structural composite lumber made of wood strand elements with wood fibres primarily oriented along the longitudinal axis of the member. The strands are selected to meet specific strength requirements.

Laminated veneer lumber (LVL)
A structural composite lumber made of wood veneer sheets with wood fibres primarily oriented along the longitudinal axis of the member. The veneers are selected to meet specific strength requirement.

Layout
Placement, orientation, and location of prefabricated NLT panels in plan view.

Layup
Individual lamination pattern within NLT.

Leadership in Energy and Environmental Design (LEED)
A third-party-verified green building rating system managed by the US and Canada Green Building Councils which provides a method of measuring environmental benefit of buildings and communities (www.usgbc.org; www.cagbc.org).

Lumber checking
A separation of wood along the fibre direction that usually extends across the rings of annual growth, commonly resulting from stresses created in wood during seasoning/drying.

M

Mass timber
Engineered wood products of massive panel type such as cross-laminated timber (CLT), nail-laminated timber (NLT), glued-laminated timber (GLT), laminated strand lumber (LSL), laminated veneer lumber (LVL) and other large-dimensioned structural composite lumber (SCL).

Machine stress rated (MSR) lumber
Lumber graded using machine stress rating equipment instead of being visually graded. Each piece is non-destructively evaluated and assigned to a bending and modulus of elasticity class.

Mechanically laminated timber (MLT)
A solid wood structural elements consisting of dimension lumber on edge, mechanically fastener together, and certified to CSA O125.

Mechanical nail-laminated timber (M-NLT)
A type of MLT where the mechanical fasteners are nails or spikes driven through the face of lumber laminations.

Moisture content, %
The ratio of the total mass of water within the wood relative to the total mass of wood in its oven dried state. Living trees can have a moisture content between 30% and 200+%.

N

Nail-laminated timber (NLT)
A solid wood structural element consisting of dimension lumber on edge and fastened together with nails.

NLT–1
Nail-laminated timber where laminations are continuous and single span. No butt joints.

NLT–2
Nail-laminated timber where all laminations are continuous over multiple supports. No butt joints within panels. Panels abut at supports only.

NLT–3
Nail-laminated timber where laminations have controlled random pattern with butt joints at and between supports. Panels are continuous over four or more supports.

NLT–4
Nail-laminated timber where laminations have controlled random pattern with butt joints at and between supports. Panels are continuous over three supports.

Noise Reduction Coefficient (NRC)
A single number rating of the sound absorption properties of a material, derived by averaging Sabine absorption ranging from 0 to 1, where 0 represents no noise absorption (e.g. concrete) and 1 represents complete noise absorption (e.g. an open hole).

Nominal size
As applied to products such as dimension lumber, the approximate rough- sawn commercial size by which it is known and sold in the market. Actual rough-sawn sizes may vary from the nominal.

Reference to standards or grade rules is required to determine nominal/ actual finished size relationships:

- 38 mm (1-1/2 in.) actual finished width = 2 in. nominal
- 65 mm (2-1/2 in.) actual finished width = 3 in. nominal
- 89 mm (3-1/2 in.) actual finished width = 4 in. nominal
- 140 mm (5-1/2 in.) actual finished width = 6 in. nominal
- 184 mm (7-1/4 in.) actual finished width = 8 in. nominal
- 235 mm (9-1/4 in.) actual finished width = 10 in. nominal
- 286 mm (11-1/4 in.) actual finished width = 12 in. nominal

P

Penny size
A designation of nail size. For example 6D, 8D, 10D, or 12D. In this guide, nail type, penny size, diameter and length are specified for clarity.

Programme for the endorsement of forest certification (PEFC)
An international non-profit, non-governmental organization dedicated to promoting Sustainable Forest Management (SFM) through independent third-party certification. PEFC-certified wood may be required by projects pursuing certification under some green building rating systems (www.pefc.org).

S

Sawn lumber
Visually or mechanically graded wood sawn to typical construction sizes as described in CSA O86. The term applies to a variety of sizes and species as defined in CSA O86, Section 6.3.

Seasoned lumber
Lumber that has been either air-dried or kiln-dried to lower the moisture content not in excess of 19%.

Sound Transmission Class (STC)
A single number rating that indicates the ability of a partition (e.g. floor/ ceiling assembly or party wall) to block airborne sound. It is based on laboratory measurements that exclude flanking sound transmission. See also Apparent Sound Transmission Class (ASTC).

Spruce-Pine-Fir (SPF)
A specific wood species group as described in CSA O86.

Specific heat capacity
The amount of energy needed to increase one unit of mass by one unit in temperature. Expressed as J/kg·K (Btu/lb-°F).

Stickers
Narrow strips of scrap wood or disposable material placed between layers of construction material to provide a gap between layers.

Structural composite lumber (SCL)
A family of engineered wood products created by layering dried and graded wood veneers, strands or flakes with moisture resistant adhesive into blocks of material known as billets, which are subsequently re-sawn into specified sizes. The grain of each layer of veneer or flakes runs primarily in the same direction resulting in solid, highly predictable, and uniform engineered wood products.

Sustainable Forestry Initiative (SFI)
A non-profit organization that manages the SFI Forest Management and Certification Standard which may be required by some projects pursuing green building rating systems (www.sfiprogram.org).

T

Thermal conductivity
Quantity of heat flow through a material for a given unit temperature difference, expressed as W/m·K (Btu·in/h·ft^2·°F).

Thermal diffusivity
The thermal conductivity of a material divided by the product density and specific heat capacity.

Thermal resistance, RSI (R-Value)
Measure of a material, component or assembly's resistance to heat flow through it at a given temperature difference, expressed as m^2·K/W (ft^2·°F·hr/btu) and often denoted as per unit thickness of a material (RSI/mm and R-value/inch).

Temporary moisture management system (TMMS)
Applied membranes, panel joint treatments, or both used to control construction phase moisture.

V

Visually graded lumber
Lumber graded by visual evaluation in accordance with the grading rules of the applicable grading or inspection agency, and identified as No.1, No.2, or Select Structural.

Volatile Organic Compound (VOC) Content
Organic chemicals that have a high vapour pressure/ low evapouration point causing large numbers of molecules to evapourate or sublimate into the air at ordinary room temperature. Maximum VOC content for composite wood products may be specified by projects pursuing certification through green building rating systems such as LEED.

W

Warped NLT
NLT forming an undulating or bent surface out of plane, generally by staggering the NLT courses up or down from the adjacent courses to create curvature in section perpendicular to the laminations.

Z

Zero-strength layer
A calculation term which accounts for a reduction in strength of the heated wood beyond the char front.

Appendices

A

NLT Appearance Chart

Table A1 NLT appearance chart showing three grades
Photo credit KK Law *Photo courtesy of* NaturallyWood

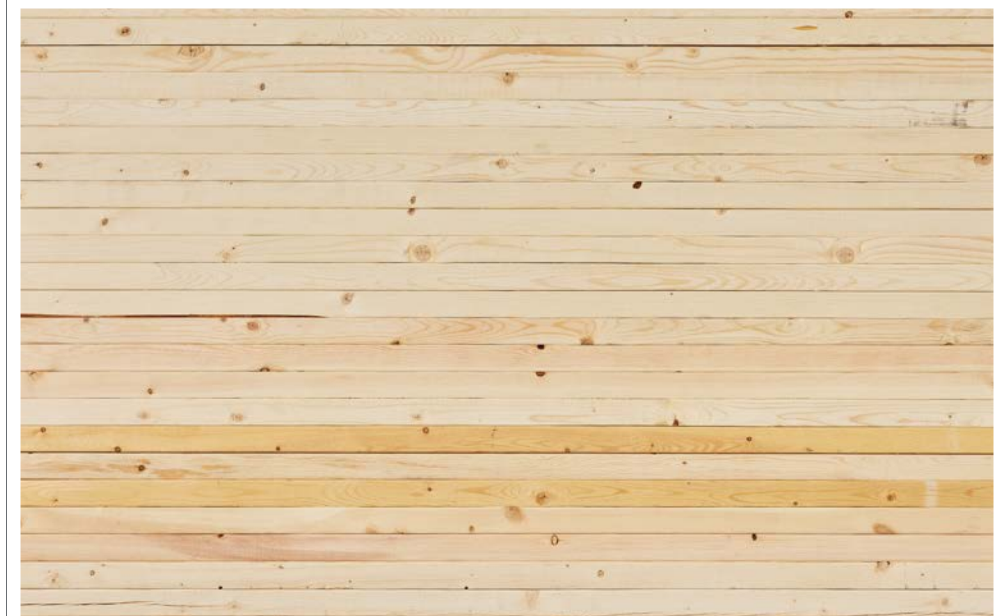
	Industrial	Architectural	Premium architectural
Panels			
	• Significant wane and knots • Variable colouration • Loose vertical tolerance on placement of laminations	• Minimal wane and some knots • Variable colouration • Tight vertical tolerance on placement of laminations	• No wane no knot holes • Uniform colouration • Tight vertical tolerance on placement of laminations **NLT fabricated according to CSA O86 is required to meet min. tolerance*
Raw materials			
	Knots, wane and inconsistent colour	Minimal wane, some knot holes	No wane, no knot holes

Table A2 NLT appearance chart showing typical defects
Photo credit KK Law *Photo courtesy of* NaturallyWood

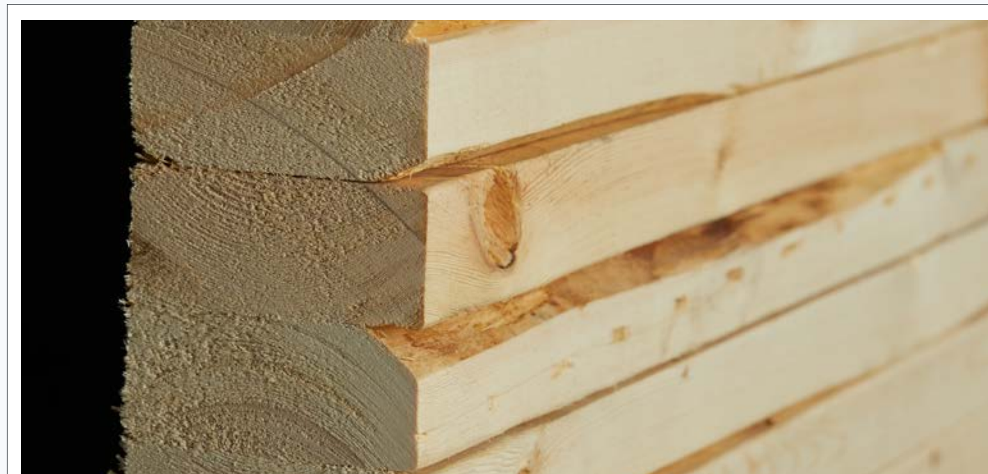
Colour variation	Staining	Pine beetle staining
		
UV damage	**Knot and knot holes**	**Dents**
		
Wane	**Checking**	**Grade stamps / markings**
		

Table A3 NLT appearance chart - species comparison
Photo credit KK Law *Photo courtesy of* NaturallyWood

	Industrial grade	Architectural grade	Premium architectural grade
Spruce-Pine-Fir (SPF)			
	SPF is light yellow in colour. Consistent colouration is generally achievable, but completely avoiding knots is unlikely regardless of grade.		
Hemlock (Hem-Fir)			
	Hemlock is slightly darker yellow with more variation in colour than SFP. Knots are wider spaced making it possible to avoid more knots with careful selection. The industrial grade panel shown here may appear to be higher quality than other industrial grade hemlock due to availability at the time of sourcing.		
Douglas Fir (D.Fir)			
	Douglas Fir varies most in colour, and has a darker, red tone. Knots are larger and variable; with careful selection most knots can be avoided.		

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

	Industrial grade
Spruce-Pine-Fir (SPF)	
	SPF is light yellow in colour. Consistent colouration is generally achievable, but completely avoiding knots is unlikely regardless of grade.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

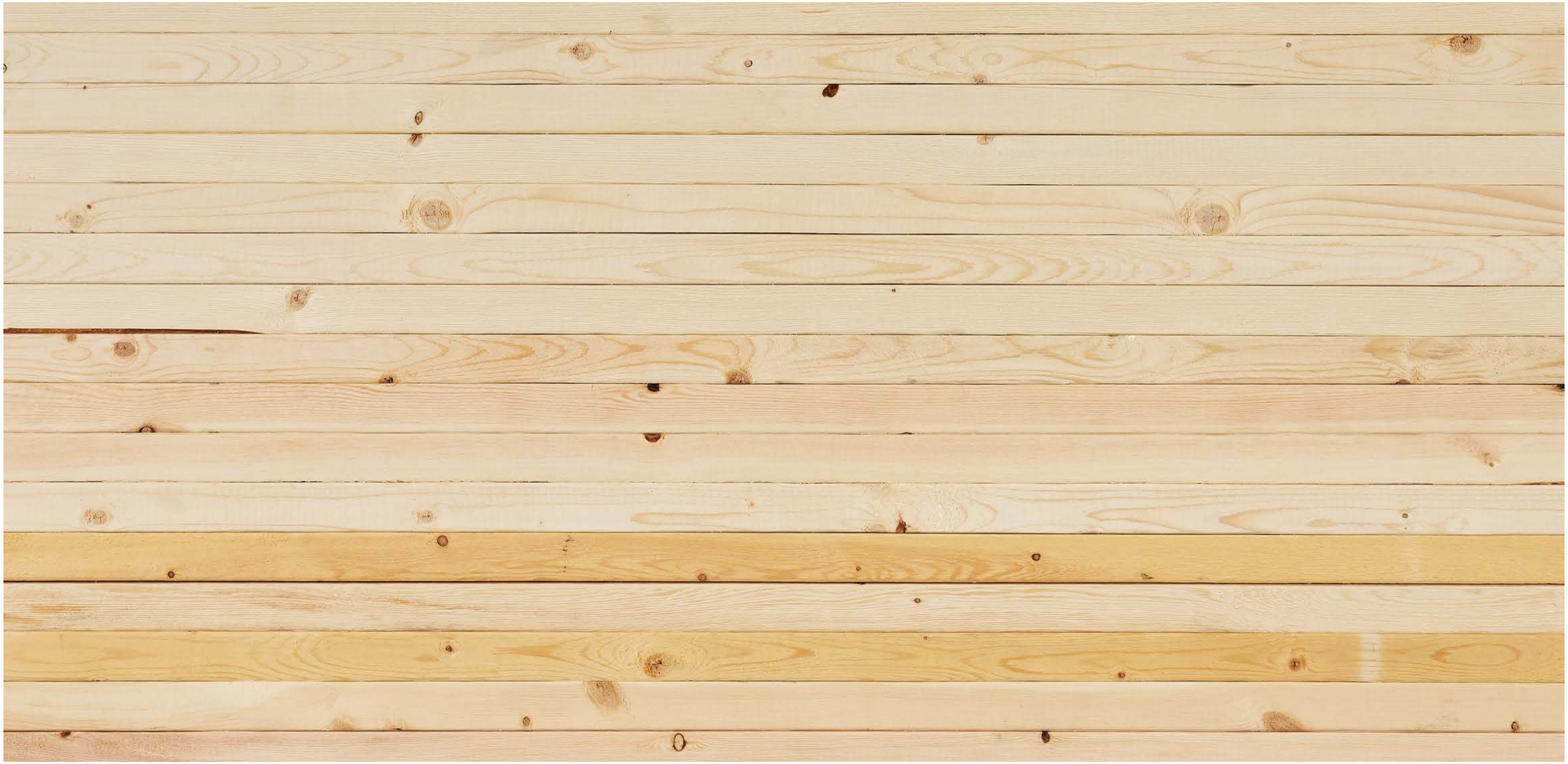
	Architectural grade
Spruce-Pine-Fir (SPF)	
	SPF is light yellow in colour. Consistent colouration is generally achievable, but completely avoiding knots is unlikely regardless of grade.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

	Premium architectural grade
Spruce-Pine-Fir (SPF)	
	SPF is light yellow in colour. Consistent colouration is generally achievable, but completely avoiding knots is unlikely regardless of grade.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

Industrial grade

Hemlock (Hem-Fir)

Hemlock is slightly darker yellow with more variation in colour than SFP. Knots are wider spaced making it possible to avoid more knots with careful selection.
The industrial grade panel shown here may appear to be higher quality than other industrial grade hemlock due to availability at the time of sourcing.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

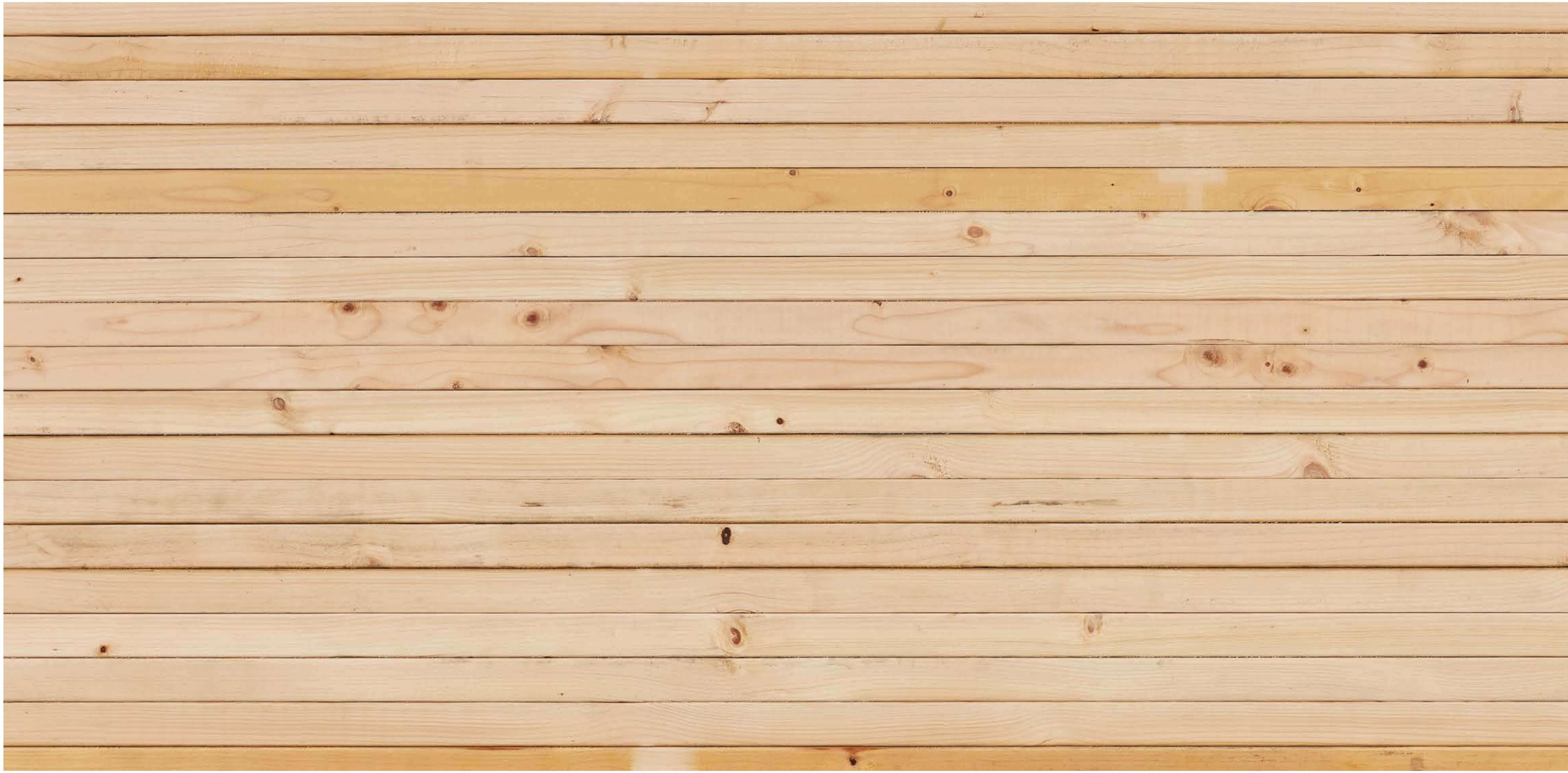
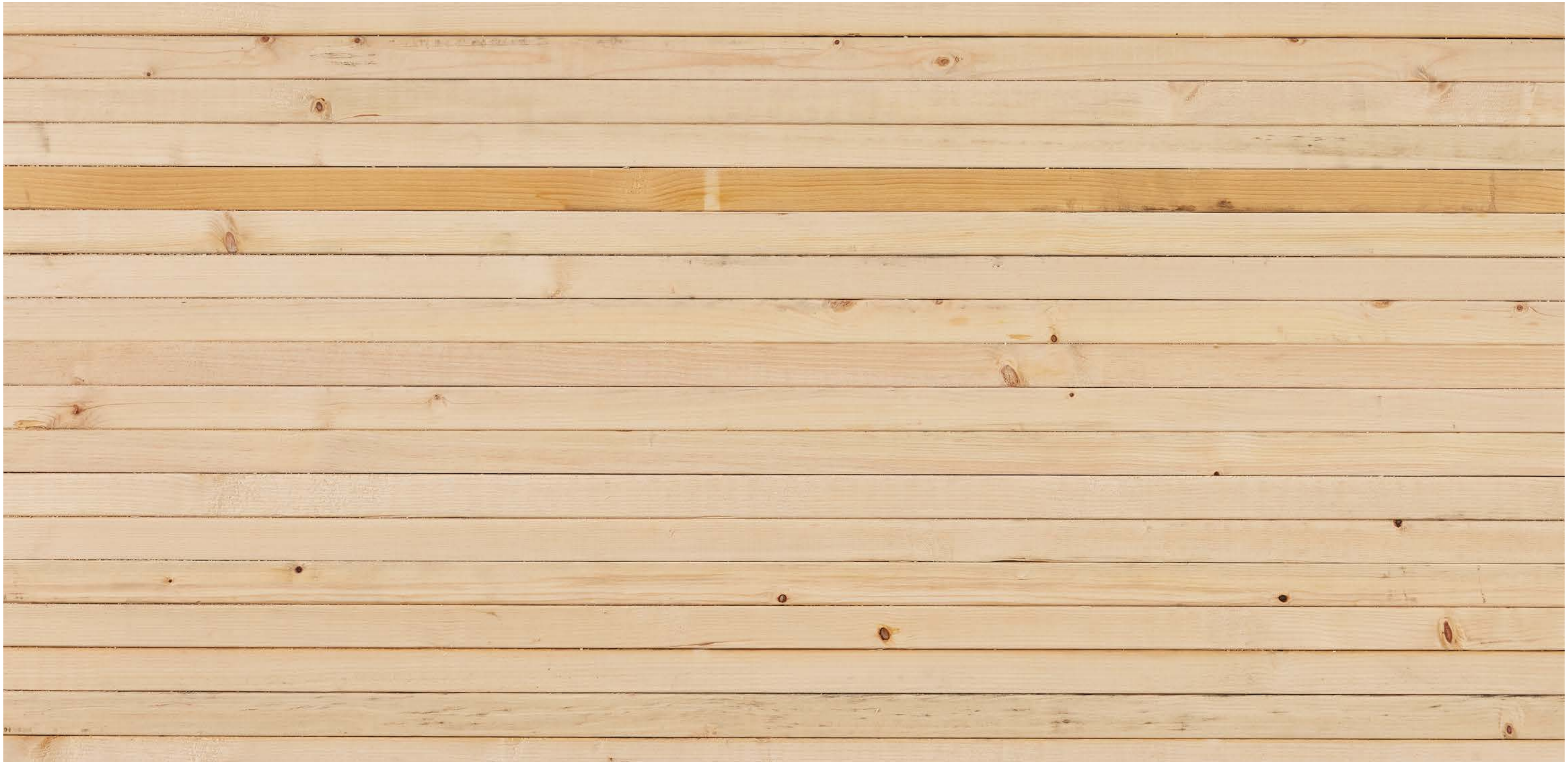
	Architectural grade
Hemlock (Hem-Fir)	
	Hemlock is slightly darker yellow with more variation in colour than SFP. Knots are wider spaced making it possible to avoid more knots with careful selection. The industrial grade panel shown here may appear to be higher quality than other industrial grade hemlock due to availability at the time of sourcing.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

Premium architectural grade

Hemlock (Hem-Fir)

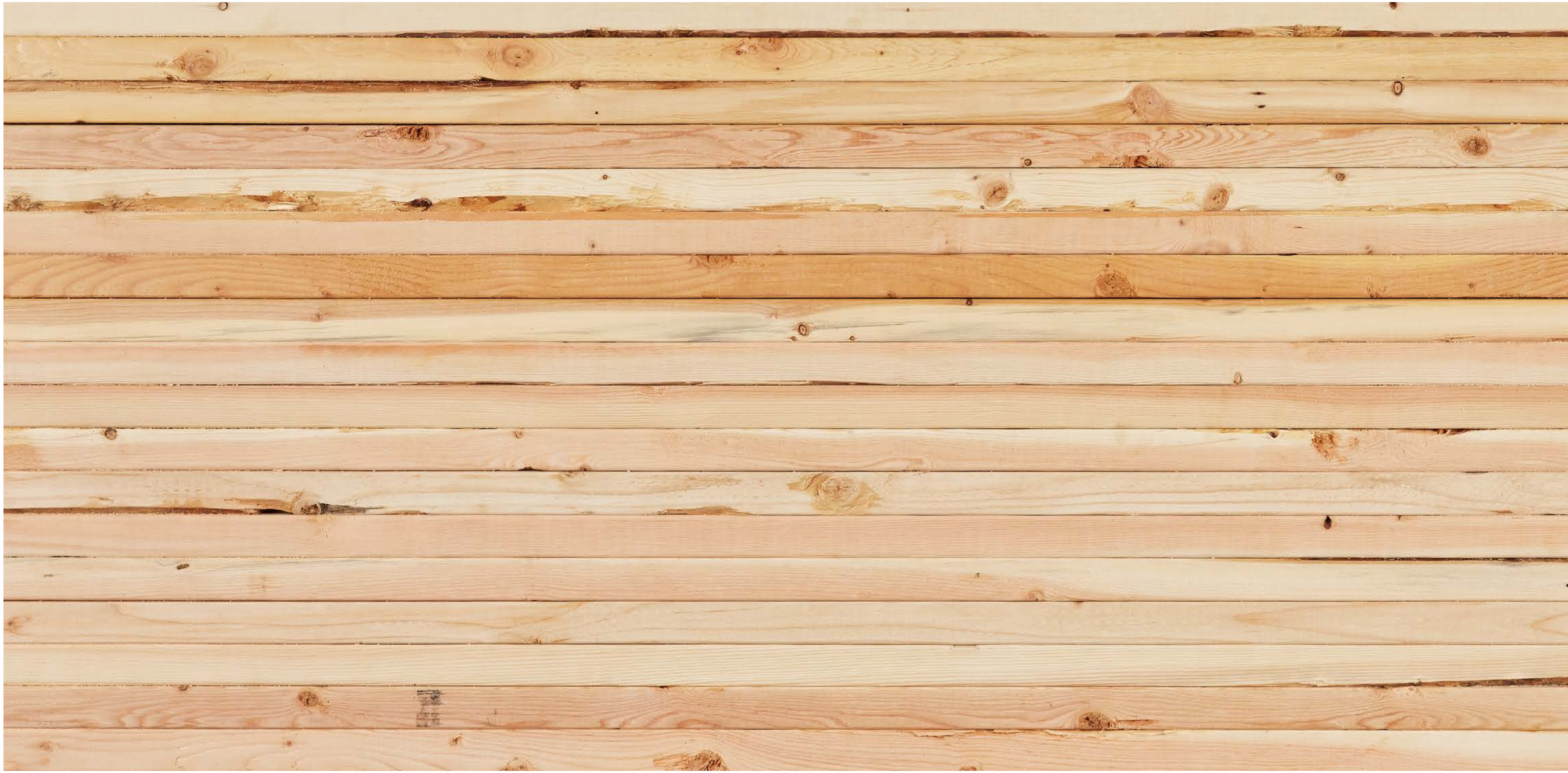


Hemlock is slightly darker yellow with more variation in colour than SFP. Knots are wider spaced making it possible to avoid more knots with careful selection.
The industrial grade panel shown here may appear to be higher quality than other industrial grade hemlock due to availability at the time of sourcing.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

Industrial grade

Douglas Fir (D.Fir)

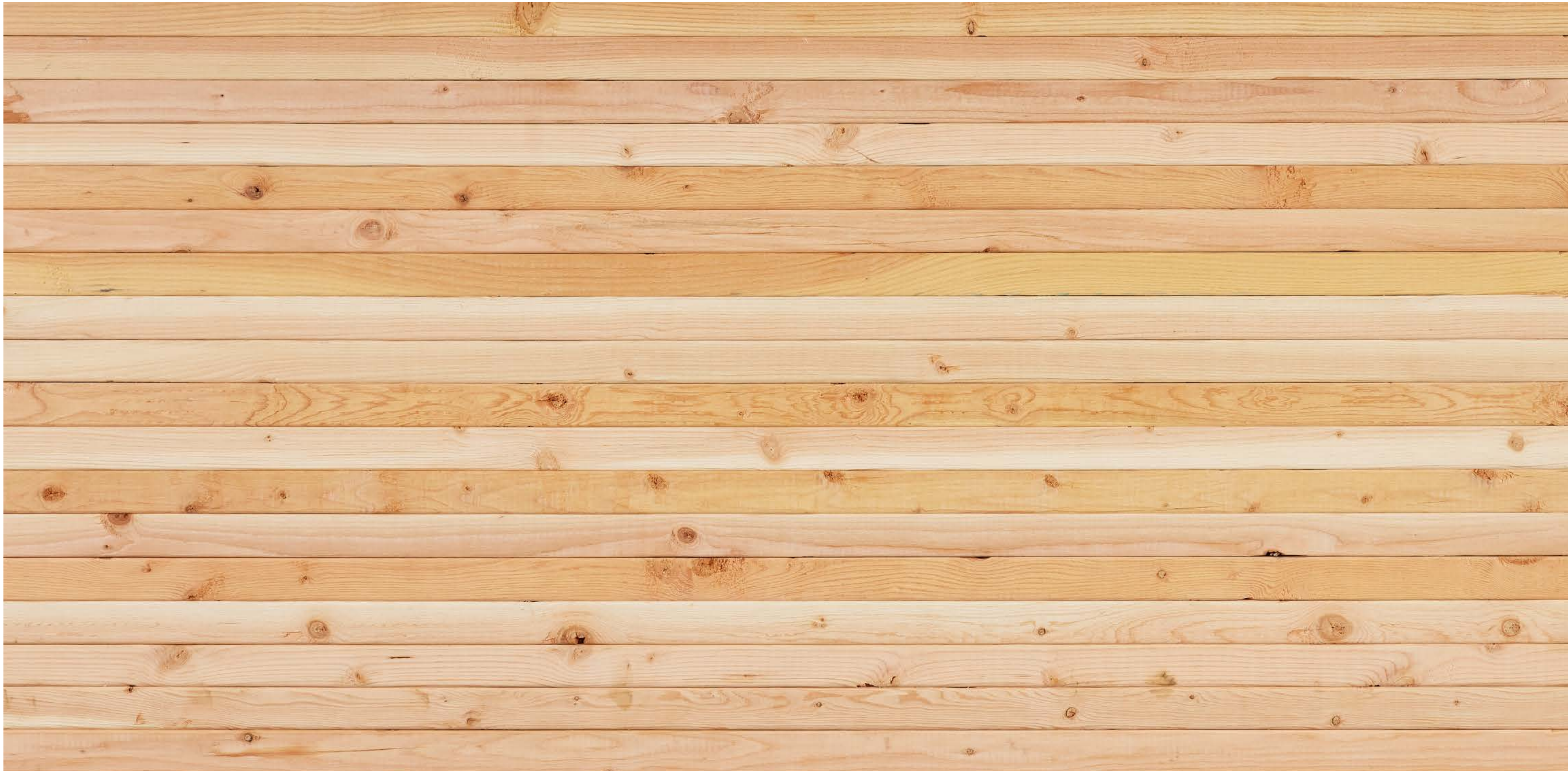


Douglas Fir varies most in colour, and has a darker, red tone. Knots are larger and variable; with careful selection most knots can be avoided.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

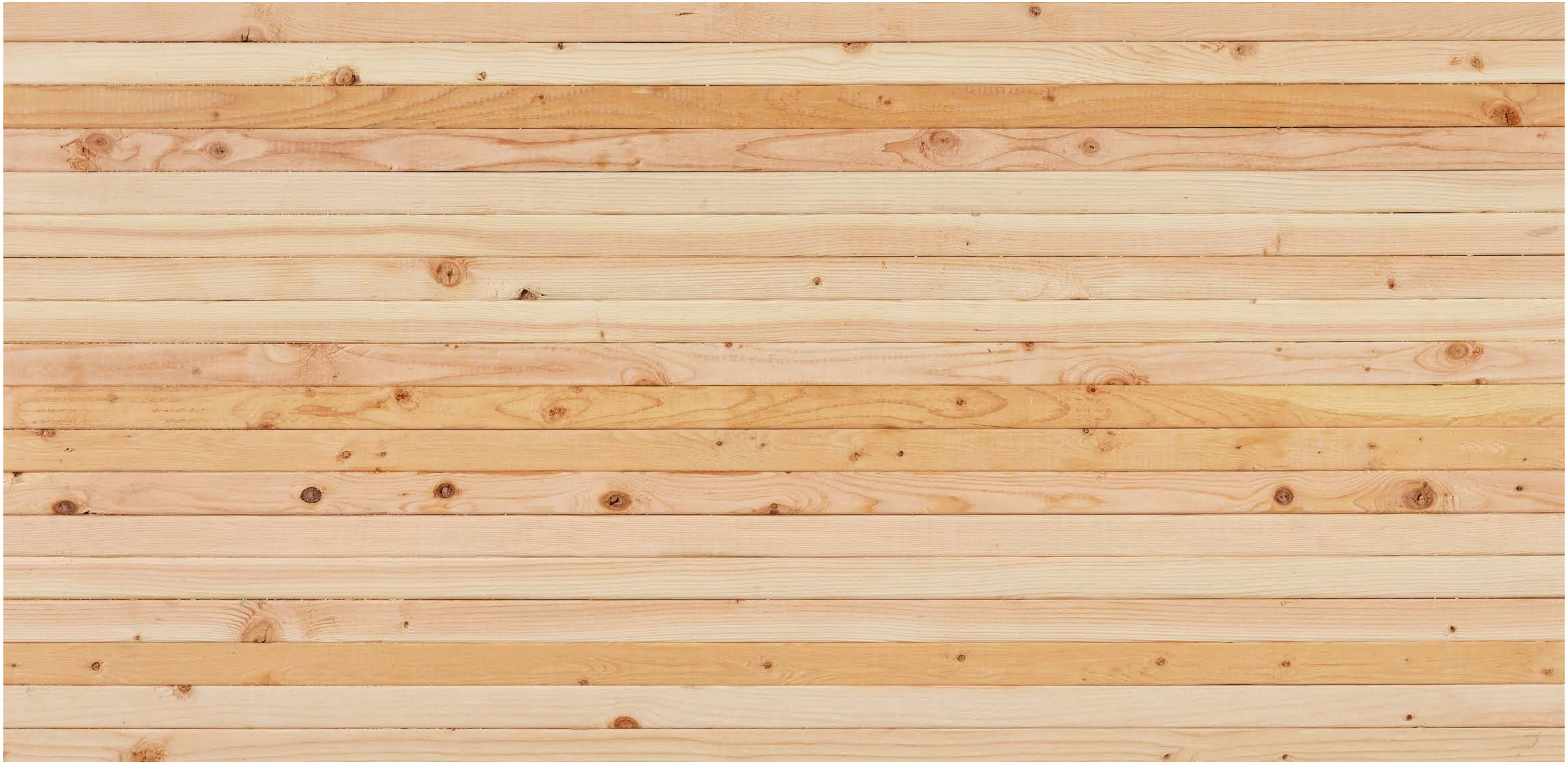
Architectural grade

Douglas Fir (D.Fir)



Douglas Fir varies most in colour, and has a darker, red tone. Knots are larger and variable; with careful selection most knots can be avoided.

Table A3 NLT appearance chart - species comparison - close ups
Photo credit KK Law *Photo courtesy of* NaturallyWood

	Premium architectural grade
Douglas Fir (D.Fir)	
	Douglas Fir varies most in colour, and has a darker, red tone. Knots are larger and variable; with careful selection most knots can be avoided.

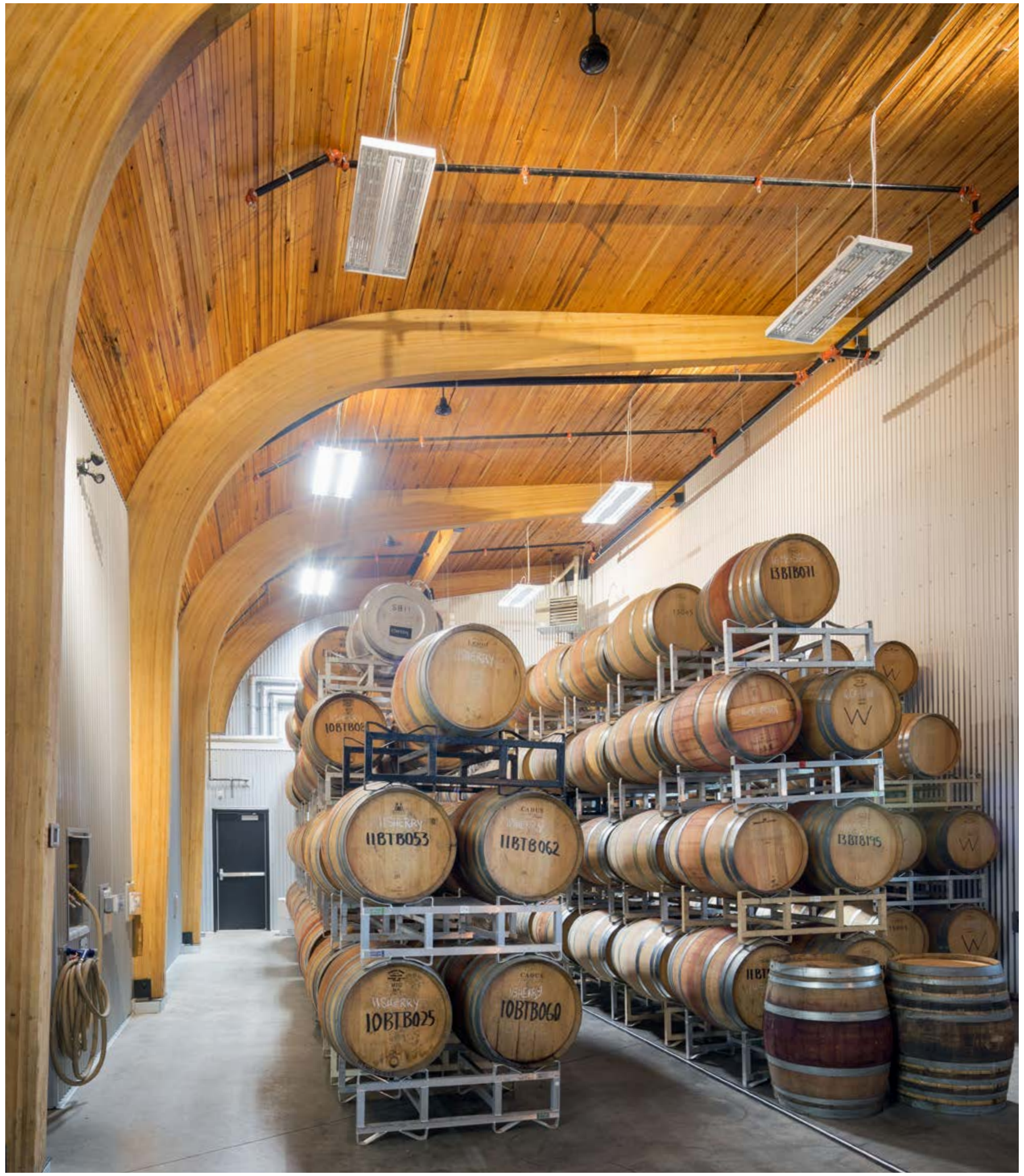
NLT panel grade visual references in built projects

Below Example of vertical tolerance, industrial grade
Photo credit Jason Harding *Photo courtesy of* NaturallyWood

Below Example of vertical tolerance, architectural grade
Photo credit Bryce Byrnes *Photo courtesy of* NaturallyWood

NLT panel grade visual references in built projects

Below Industrial grade NLT shown at Time Winery, Kelowna, BC
Photo credit Dan Schwalm *Photo courtesy of* HDR



Below Architectural grade NLT shown at UBC Bookstore, Vancouver, BC
Photo credit Ema Peter *Photo courtesy of* Fast + Epp

NLT panel grade visual references in built projects

Below Premium architectural grade shown at Ādisōke Public Library, Ottawa, ON
Architecture by Diamond Schmitt *Photo courtesy of* Fast + Epp

Below Premium architectural grade shown at Ādisōke Public Library, Ottawa, ON
Architecture by Diamond Schmitt *Photo courtesy of* Fast + Epp

B

Sample Specification

Part 1 General

1.1 Related Documents

1.1.1 Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.

1.2 Summary

1.2.1 Section includes nail-laminated timber (NLT) floor and roof construction, prefabricated in panels or built in place.

1.2.2 Related Sections:

- 1.2.2.1 Section 01 35 18 "Sustainable Design Requirements" for LEED requirements.
- 1.2.2.2 Section 05 12 00 "Structural Steel Framing" for custom-fabricated steel connection brackets.
- 1.2.2.3 Section 06 10 00 "Rough Carpentry" for dimension lumber framing.
- 1.2.2.4 Section 06 16 00 "Sheathing" for floor and roof sheathing.
- 1.2.2.5 Section 09 91 13 "Exterior Painting" and Section 09 91 23 "Interior Painting" for painting and coating requirements.

LEED requirements.

1.2.3 References:

- 1.2.3.1 ASTM A153/A153M-16a Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.
- 1.2.3.2 ASTM A307-14e1 Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60,000 PSI Tensile Strength.
- 1.2.3.3 ASTM A563-15 Standard Specification for Carbon and Alloy Steel Nuts.
- 1.2.3.4 ASTM F1667-18 Standard Specification for Driven Fasteners: Nails, Spikes, and Staples.
- 1.2.3.5 CSA O86-24 Engineering Design in Wood.
- 1.2.3.6 CSA O141-05(R2014) Softwood Lumber.
- 1.2.3.7 CSA O125-23 Mechanically Laminated Timber.

Review and include only for M-NLT.

Sample specification index

Sample Specification Index

1.2.3.8 ICC-ES ESR-1539 Power-Driven Staples and Nails.
1.2.3.9 NLGA (National Lumber Grades Authority) Standard Grading Rules for Canadian Lumber, 2014 Edition.
1.2.3.10 National Building Code of Canada 2020 (including Part 9).
1.2.3.11 For Projects overseen by a Construction Manager or Design-Build Contractor in lieu of a General Contractor, references to “Contractor” shall apply to the relevant Subcontractor(s).

1.3 Definitions

1.3.1 NLT: A solid wood structural element created by placing dimension lumber on edge and fastening the individual laminations together with nails.

1.4 Performance Requirements

1.4.1 Engage a qualified professional engineer, licensed at the place where the Project is located, to design connections specified on the Drawings.

1.4.2 Structural Performance: Design connections to withstand forces specified on the Drawings, within limits and under conditions indicated.

1.4.3 Design Standard: Comply with CSA O86.

This section is optional only for M-NLT where certified products with specified strengths may be used. Remove for NLT projects.

1.5 Action Submittals

1.5.1 Product Data: For each type of factory-fabricated product.
1.5.1.1 Include data on lumber, fasteners, layup, and cross-section, fabrication, and protection.
1.5.1.2 For connectors, include installation instructions.

Delete for M-NLT (assumed to be factory-fabricated).

1.5.2 Shop Drawings: Showing fabrication and erection of NLT.
1.5.2.1 Submit erection drawings.
1.5.2.1.1 Indicate panel locations and elevations. Label each panel with a piece number or other unique mark.

1.5.2.1.2 Include details connections to supports and between panels.
1.5.2.1.3 Indicate all shop- and field-applied sheathing and finishes.
1.5.2.1.4 Do not reproduce structural Drawings for use as erection drawings.

1.5.2.2 Submit piece drawings for each panel.
1.5.2.2.1 Show full dimensions of each panel.
1.5.2.2.2 Indicate species, grade, appearance classification, and shop-applied finishes.
1.5.2.2.3 Show dimensions of typical individual laminations.
1.5.2.2.4 Show lamination joint patterns.
1.5.2.2.5 Show nail sizes and nailing patterns.
1.5.2.2.6 Include details of cuts, openings, and holes.

1.5.3 Delegated Design Submittal: For connections indicated to comply with performance requirements. Include sealed shop drawings and design calculations prepared by a qualified professional engineer.

This section is optional only for M-NLT where certified products with specified strengths may be used. Remove for NLT projects.

1.5.4 Contractor shall provide a moisture management plan (refer to **Section 01 43 39**) that outlines the steps to be taken during construction to ensure adequate moisture (humidity, condensation, precipitation, ground water, snow, snow-melt, ice, frost, or water from other sources) protection of wood structures protection of wood structures. The plan shall at minimum include the following:
1.5.4.1 Identification of specified materials that may be at risk from moisture damage, and identify robust and appropriate Moisture Control Measures compatible with site conditions and constraints.
1.5.4.2 Construction schedule, highlighting timber delivery and installation sequencing.
1.5.4.3 Plans for on-site storage of timber elements.
1.5.4.4 Moisture content monitoring and moisture protection measures from delivery to enclosure of building.

For larger projects or projects with specific concerns or needs, consider including a separate **moisture management plan specification** section such as the sample provided on pages 205 to 208.

Sample Specification Index

1.5.4.5 Temporary drainage plans during construction.
1.5.4.6 Remediation measures if damage to timber occurs.
1.5.4.7 Remediation approach for drying of timber should accidental moisture exposure occur.

1.6 Informational Submittals

1.6.1 Material Certificates: Issued by an approved grading agency.
1.6.1.1 For dimension lumber specified to comply with minimum allowable unit stresses, indicate species, grade, and design values for each use.
1.6.1.2 For exposed items, omit grade stamp and provide certificates as to species, grade, stress grade, seasoning, moisture content, and other evidence as required to show compliance with the Specifications.

1.6.2 Evaluation Reports: For the following, from CCMC or ICC-ES:
1.6.2.1 Power-driven fasteners.
1.6.2.2 Post-installed anchors.
1.6.2.3 Metal framing anchors.

1.6.3 Qualification Data: For manufacturer and installer

Include only for M-NLT.

1.6.4 The fabricator and erector shall submit a QA/QC log of items such as but not limited to:
1.6.4.1 Environmental conditions at all stages, such as during fabrication, storage, transportation, erection and ideally until building is completely finished.
1.6.4.2 Actual length, thickness and width of the panels. Length, width, thickness and diagonal measurement are to be noted on top surface of panels.
1.6.4.3 Actual layup patterns QA/QC procedure
1.6.4.4 Records for finger joint testing and dimensions.
1.6.4.5 Site deliveries, including verified load manifests with notes of damaged or missing materials and elements.
1.6.4.6 Material and element install with sign off for QC on hardware/fastener installation.

Sample Specification Index

1.6.4.7 Equipment used, such as but not limited to torque drills (with torque clutch) for screw installation through steel plates.
1.6.4.8 Any changes or modifications.
1.6.4.9 The inclusion of representative pictures within the log is required.
1.6.4.10 Regular moisture content readings of the NLT panels during construction. Logs to be made readily available to consultant upon request. Submit monthly reports of field inspections to the Architect.

1.7 Quality Assurance

1.7.1 Manufacturer Qualifications: Company specializing in manufacturing the Products specified in this Section with minimum three years of experience, and certified in accordance with CSA O125.

Include only for M-NLT. Not that the amount of required experience should be considered as the NLT experience grows.

1.7.2 Installer Qualifications: Company specializing in performing the Work of this Section with minimum three years of experience and approved by the manufacturer.

1.7.3 The Professional Engineer sealing the fabricator's shop drawings is also responsible for all field review of his or her Work. The Engineer shall provide signed and sealed letters of assurance to the Consultant confirming the Work has been completed in accordance with the final reviewed shop drawings and all structural requirements.

1.7.4 Grading Agencies: Certified by NLGA.

Include only for NLT case. M-NLT requires this are part of the CSA O125 standard.

1.7.5 Build mock-ups to demonstrate aesthetic effects and set quality standards for materials and execution.
1.7.5.1 Where NLT panels are prefabricated, build one full panel.
1.7.5.2 Where NLT is built in place, install a minimum area of one meter by one meter.

Delete this section for M-NLT case.

1.7.5.3 Mockup must illustrate typical wood appearance, coating, and finish.

1.7.5.4 Keep mockup available to view as the standard of Work for remaining fabrication.

1.7.5.5 Approved mock-ups may become part of the completed Work if undisturbed at the time of Substantial Completion.

1.7.5.6 Build prefabricated panels in a shop environment for quality control. Shop fit panels during fabrication. Review with Consultant prior to proceeding further.

Remove this for M-NLT. Inherent in standard.

1.8 Delivery, Storage, And Handling

1.8.1 Protect NLT from staining and damage at all times during fabrication, transportation, and installation.
For prefabricated panels Individually wrap panels using plastic-coated paper covering with water-resistant seams.

1.8.1.1 Keep wrapping on panels until temporary moisture management plan is implemented.
If wrapping is kept in place, slit underside to prevent accumulation of moisture inside the wrapping.

1.8.1.2 Do not deface panels when slitting wrap.

1.8.2 Store all materials and assembled panels under cover with proper drainage. Provide for air circulation around panels and under coverings.

1.8.3 Take particular care to protect exposed end grain.

1.8.4 Handle and temporarily support NLT to prevent surface damage, compression, and other effects that might interfere with indicated finish.

1.8.5 Take all necessary precautions to keep NLT dry and protected from UV radiation during and after installation.

1.8.6 Perform regular field inspections of the materials, construction, and moisture control measures to ensure compliance with the Moisture Management Plan and the Contract Documents. Submit monthly reports of field inspections to the Architect.

Sample Specification Index

Sample Specification Index

Part 2 Products

2.1 Nail-Laminated Timber

2.1.1 Provide NLT that complies with CSA O125.

2.1.1.1 Factory mark each NLT panel with the stamp of an approved agency in accordance with CSA O125. Place mark on surfaces that are not exposed in the completed Work.

2.1.1.2 Provide NLT made from a single species unless noted otherwise.

2.1.1.3 Provide NLT made with fasteners complying with CSA O125.

2.1.2 Grade: As indicated on the Drawings.

2.1.3 Appearance Classification: Industrial for concealed panels; Architectural elsewhere, unless noted otherwise.

Include this section for M-NLT only.

2.2 Dimension Lumber

2.2.1 Grading Rules: NLGA. All softwood lumber shall conform to CSA O141 and CSA O86.

2.2.1.1 Factory mark each piece of lumber with grade stamp of grading agency unless noted otherwise.

2.2.1.2 Do not grade stamp lumber exposed to view. Deliver to site with certificates as to species, grades, stress grades, seasoning, moisture content, and other evidence as required to show compliance with the Specifications.

2.2.2 Wood Members: SPF #1/#2 unless noted otherwise on the Drawings.

2.2.3 Maximum Moisture Content: 19% at time of fabrication.

2.2.4 Finger jointed Lumber: Conforming to NLGA SPS1 and CSA O86.

2.2.5 Dress lumber, S4S, unless noted otherwise.

Include this section for NLT only. Inherent in M-NLT standard.

2.3 Fasteners

2.3.1 Provide fasteners of size and type indicated that comply with requirements specified in this article for material and manufacture. Provide fasteners with hot-dip zinc coating complying with ASTM A153 or of Type 304 stainless steel.

2.3.2 Nails, Spikes, and Staples: ASTM F1667.

2.3.3 Power-Driven Fasteners: Fasteners with a CCMC or ICC-ES evaluation report acceptable to authorities having jurisdiction.

2.3.4 Through Bolts and Anchor Bolts: ASTM A307, Grade A; with ASTM A563 hex nuts and, where indicated, flat washers, hot dip galvanized to ASTM A153.

2.3.5 Screws, Tight-Fit Pins and Bolts, Through-Bolts, Glued-In Rods, and Specialty Connectors: As specified on the Drawings.

2.3.6 Metal Straps and Ties: Galvanized Simpson Strong-Tie straps or approved equal where required.

2.3.7 Structural Steel Connectors: As specified in Section 05 12 00.
- 2.3.7.1 All steel and connectors shall be hot dip galvanized unless noted otherwise.
- 2.3.7.2 Fabricate steel hardware and connections with joints neatly fitted, welded, and ground smooth.
- 2.3.7.3 Test fit in shop.

2.3.8 Post-Installed Anchors: Fastener systems with a CCMC or ICC-ES evaluation report acceptable to authorities having jurisdiction.

2.4 Miscellaneous Materials

2.4.1 Moisture Barrier: Any of the following:
- 2.4.1.1 Light gauge metal.
- 2.4.1.2 Asphalt-impregnated building paper.
- 2.4.1.3 Closed-cell foam gasket material, 6 mm thick.
- 2.4.1.4 Saturated felt roll roofing.

2.4.1.5 Polyethylene, 6 mil thick.

2.4.2 Wood Sealer: As specified in Section 09 91 13 and Section 09 91 23.
2.4.2.1 Sealer shall be compatible with indicated finish.
2.4.2.2 End sealer shall be effective in retarding the transmission of moisture at cross-grain cuts.

2.4.3 Proprietary Products:
2.4.3.1 Proprietary products shown on the Drawings have been selected and specified based on the manufacturer's representation.
2.4.3.2 The Consultant shall not become guarantor of the product.
2.4.3.3 Install proprietary products in strict conformance with the manufacturer's recommendations.
2.4.3.4 Contractor is responsible for proper workmanship during installation.

2.5 Fabrication

2.5.1 Select lumber to ensure straightness and architectural-quality appearance.
2.5.1.1 No wane, knot holes, grade stamps, or stains are permitted to be visible in the completed structure.
2.5.1.2 Where pine beetle kill wood is specified, hand select all members to ensure beetle staining is visible. Ensure staining is spatially distributed throughout panels; avoid clusters of stained boards.
2.5.1.3 Assume a minimum of 20% - 30% lumber rejection rate to achieve acceptable appearance with #2-grade material. Higher grade material (e.g. J-grade or MSR lumber) will reduce the rejection rate and may be substituted for #2-grade material at Contractor's option.

This section for M-NLT only. Remove for NLT case.

2.5.2 Provide laminations per layup type and cross-section type as indicated on the Drawings
2.5.2.1 For staggered pattern, stagger and nail together as indicated by the fabrication standard.

Sample Specification Index

Sample Specification Index

2.5.2.2 For aligned joint pattern, place timbers with joints centered over support members below. No joints are to be visible from below. Nail together as indicated by the standard

2.5.3 After end cutting each panel to final length, apply a double coat of end sealer to ends and other cross-cut surfaces.

2.5.4 Mark panels for identification during erection.
- 2.5.4.1 Ensure marks will be concealed in final assembly for panels exposed to view.
- 2.5.4.2 Clearly mark top surface.

2.5.5 See Section 09 91 13 and Section 09 91 23 for shop finish requirements.

This section for M-NLT only. Remove for NLT case.

2.6 Fabrication

2.6.1 Hand select members to ensure straightness and architectural-quality appearance.
- 2.6.1.1 No wane, knot holes, grade stamps, or stains are permitted to be visible in the completed structure.
- 2.6.1.2 Where pine beetle kill wood is specified, hand select all members to ensure beetle staining is visible. Ensure staining is spatially distributed throughout panels; avoid clusters of stained boards.
- 2.6.1.3 Assume a minimum of 30% - 40% lumber rejection rate to achieve acceptable appearance with #2-grade material. Higher grade material (e.g. J-grade or MSR lumber) will reduce the rejection rate and may be substituted for #2-grade material at Contractor's option.

2.6.2 Place soffits of timbers so the least number of checks and knots will be visible in the completed structure.

This section for NLT only. Remove for M-NLT case.

2.6.3 Provide sill gasket material, caulking, or non-rigid vapour barrier sealant between laminations where NLT crosses the building enclosure.

2.6.4 Placement tolerance for timber soffits is plus or minus 2 mm.

2.6.5 Arrange timbers in staggered pattern or aligned joint pattern as indicated on the Drawings.
- 2.6.5.1 For staggered pattern, stagger and nail together as indicated on the Drawings.
- 2.6.5.2 For aligned joint pattern, place timbers with joints centered over support members below. No joints are to be visible from below. Nail together as indicated on the Drawings.

2.6.6 Use galvanized common steel wire nails unless noted otherwise.
- 2.6.6.1 Make tight connections between members.
- 2.6.6.2 Install fasteners without splitting wood.
- 2.6.6.3 Drive nails snug but do not countersink nail heads unless noted otherwise.

This section for NLT only. Remove for M-NLT case.

2.6.7 Substitution of common nails with power-driven nails of the same length and diameter is acceptable. Substitution of power-driven nails of smaller diameter is permitted only with the Consultant's approval.
- 2.6.7.1 Set nail gun pressure so that nail heads do not crush wood surface.
- 2.6.7.2 Nail head penetration shall not exceed 2 mm.

2.6.8 Mark panels for identification during erection.
- 2.6.8.1 Ensure marks will be concealed in final assembly for panels exposed to view.
- 2.6.8.2 Clearly mark top surface.

Sample Specification Index

Part 3 Execution

3.1 Examination

3.1.1 Examine supporting construction in areas to receive NLT, with Installer present, for compliance with requirements, installation tolerances, and other conditions affecting performance of the Work.

3.1.2 Proceed with installation only after unsatisfactory conditions have been corrected.

3.2 Installation, General

3.2.1 Provide temporary shores, guys, braces, and other supports during erection to keep NLT secure and in alignment against wind loads, seismic loads, temporary construction loads, and loads equal in intensity to design loads.

3.2.1.1 Any failure to make proper and adequate provisions for stresses during erection shall be solely the responsibility of the Installer.

3.2.2.2 Fasteners required for erection purposes are the responsibility of the Contractor and are to be included in the bid.

3.2.2 Fit NLT panels closely and accurately to required levels and lines without trimming, cutting, or other modifications, unless approved in writing by the Consultant.

Remove for NLT case.

3.2.3 Securely attach NLT to supports as indicated on the Drawings.

3.2.4 Install connectors as indicated. Install bolts with same orientation within each connection and in similar connections.

3.2.5 Provide moisture barrier at all locations where NLT abuts concrete or masonry construction.

Sample Specification Index

3.2.6 Provide gaps as required for construction tolerances and swelling.

3.2.6.1 Details and locations shall be discussed with and approved by the Consultant in writing prior to construction.

3.2.6.2 Gaps on the interior of the building are to be filled after the building is fully enclosed and temperature-controlled, unless approved in writing by the Architect and Consultant or indicated otherwise by the Drawings.

3.2.7 Ensure moisture content of NLT is at or below 19% before installation of concrete toppings and other impermeable components. Ensure manufacturer requirements for membranes are met where more stringent that specified here.

3.2.8 Provide field finish of NLT as specified in Section 09 91 13 and Section 09 91 23.

3.2.9 Repair damaged surfaces and finishes after completing erection. Replace damaged NLT if repairs are not approved by Architect.

3.2.10 Site cutting or boring of NLT, other than shown on shop drawings, is not permitted without written consent of Consultant.

3.2.11 After erection, touch up galvanized and primed steel surfaces.

3.3 Installation, Prefabricated NLT Panels

3.3.1 Fit NLT panels closely and accurately to required levels and lines without trimming, cutting, or other modifications, unless approved in writing by the Consultant.

3.3.2 Handle and temporarily support NLT panels to prevent surface damage, compression, and other effects that might interfere with indicated finish.

Remove for M-NLT case.

3.4 Installation, NLT Built In Place

3.4.1 Hand select members to ensure straightness and architectural-quality appearance.

- 3.4.1.1 No wane, knot holes, grade stamps, or stains are permitted to be visible in the completed structure.
- 3.4.1.2 Where pine beetle kill wood is specified, hand select all members to ensure beetle staining is visible.
- 3.4.1.3 Assume a minimum of 30% - 40% lumber rejection rate to achieve acceptable appearance with #2-grade material. Higher grade material (e.g. J-grade or MSR lumber) will reduce the rejection rate and may be substituted for #2-grade material at Contractor's option.

3.4.2 Place soffits of timbers so the least number of checks and knots will be visible in the completed structure.

3.4.3 Provide sill gasket material, caulking, or non-rigid vapour barrier sealant between laminations where NLT crosses the building enclosure.

Remove for M-NLT case.

3.4.5 Arrange timbers in staggered pattern or aligned joint pattern as indicated on the Drawings.

- 3.4.5.1 For staggered pattern, stagger and nail together as indicated on the Drawings.
- 3.4.5.2 For aligned joint pattern, place timbers with joints centered over support members below. No joints are to be visible from below. Nail together as indicated on the Drawings.

3.4.6 Use galvanized common steel wire nails unless noted otherwise.

- 3.4.6.1 Make tight connections between members.
- 3.4.6.2 Install fasteners without splitting wood.
- 3.4.6.3 Drive nails snug but do not countersink nail heads unless noted otherwise.

3.4.7 Substitution of common nails with power-driven nails of the same length and diameter is acceptable. Substitution of power-driven nails of smaller diameter is permitted only with the Consultant's approval.
  - 3.4.7.1 Set nail gun pressure so that nail heads do not crush wood surface.
  - 3.4.7.2 Nail head penetration shall not exceed 2 mm.

Remove for M-NLT case.

3.5 Erection Tolerances

3.5.1 Connections used may require tighter tolerances than specified below. Supplier and installer are responsible to coordinate during the shop drawing process.

3.5.2 For rectangular areas, the corner-to-corner diagonal measurements should not deviate from each other by more than 13mm or 0.25% of the length of the shortest side of the rectangle, whichever is greater.

3.5.3 Walls:
  - 3.5.3.1 Plumbness: 0.25% of wall height (1:400) maximum deviation from plumb measured at any point along the wall.
  - 3.5.3.2 Position: plus or minus 10 mm from theoretical at base.

3.5.4 Floors and Roofs:
  - 3.5.4.1 Overall Surface Levelness (Floors and Flat Roofs): 6 mm in 3 meters maximum.
  - 3.5.4.2 Elevation: plus or minus 10mm from theoretical.

3.5.5 Joints: 10mm maximum gap between panels unless noted otherwise. Maximum 4 mm gap between laminations within a panel unless noted otherwise.

Remove gap between laminations for M-NLT case. Inherent in standard.

End of section

Sample Specification Index

Section 01 43 42
Moisture management plan

Part 1 General

1.01 Section includes

A. Requirements for moisture management plan for mass timber.

B. Coordinate plan with the work of other related sections.

1.02 Reference standards

A. If applicable, comply with requirements of the authorities having jurisdiction over the location of the project.

1.03 Definitions

A. Moisture Management Plan: A written plan for the temporary protection of specified materials from moisture during transportation, storage, and construction.

B. Moisture Control Measures: A method for the protection of a specified material from moisture, including but not limited to tenting, wrapping, application of temporary or permanent water- resistant coatings or membranes, use of just-in-time delivery methods or adaptive scheduling and sequencing of the work, and active measures to remove accumulated moisture in a timely fashion.

C. Moisture: Humidity, condensation, precipitation, ground water, snow, snow-melt, ice, frost or water from other sources with which a specified material may come into contact.

1.04 Submittals

A. Develop and submit complete Moisture Management Plan prior to product shipment or prior to any Work, whichever occurs sooner.

1. Submit to Architect for Owners review and approval.

B. Contact Information:

1. Provide contact details for a representative of the Contractor who will be responsible for the Moisture Management Plan and its implementation.

C. If Contractor does not have staff qualified to prepare a Moisture Management Plan, engage a qualified building enclosure specialist registered in the location of the project with a minimum of 5-years experience to prepare a plan on the Contractor's behalf.
   1. Approved Building Enclosure Firms:
      a. RDH Building Science Inc.; www.rdh.com.
      b. Morrison Hershfield; www.morrisonhershfield.com.
      c. Pre-approved alternative.

1.05 Quality assurance

A. See Preconstruction Conference requirements in Mass Timber Section 06 ______.
B. Perform regular field inspections of the materials, construction and moisture control measures to ensure compliance with the Moisture Management Plan and the Contract Documents.
C. Submit monthly reports of field inspections to the Architect.

1.06 Moisture management plan

A. Owner requires that this project implement strict moisture management controls to protect the mass timber elements.
B. Prepare Moisture Management Plan. Reference Moisture Risk Strategies Document listed in Section 00 31 00, Available Project Information.
C. In addition to the recommendations in the Moisture Risk Strategies document, include the following in the Plan:
   1. Provide descriptions for Moisture Control Measures identified.
   2. Schedule of Materials:
      a. Identify specified materials that may be at risk from moisture damage.
      b. For each material identified, include in the Plan the following:
         i) Risk of exposure to moisture during fabrication, transportation, storage, and construction.
         ii) Risk of structural or functional damage.
         iii) Risk of visible damage, distortion, discoloration, staining, or moulding.

3. Moisture Control Measures - Identify and provide the following in the Plan:
   a. Identify robust and appropriate Moisture Control Measures compatible with site conditions and constraints.
4. Site Monitoring - Outline in the Plan:
   a. Protocols for monitoring and evaluation of adopted Moisture Control Measures throughout the duration of the Work, including inspection and testing of moisture content of wood products and other materials where appropriate.
   b. Protocols for identifying and correcting deficiencies in adopted measures.
5. Provide a template for monthly written reports.
6. Contact Information:
   a. Provide contact details for a representative of the Contractor who will be responsible for the Moisture Management Plan and its implementation.

D. Maintain and make available a copy of the Moisture Management Plan at the job site.
E. Perform testing and inspections as necessary to comply with the Moisture Management Plan.

Part 2 Products - not used

Part 3 Execution

3.01 Moisture management plan implementation

A. Conduct Work and comply with Moisture Management Plan for the duration of the Project.
B. Manager: Designate an on-site person or persons responsible for instructing workers and overseeing and documenting results of Moisture Management Plan.
C. Distribute copies of the Moisture Management Plan to job site foreman, each subcontractor, Owner and Architect.
D. Arrange for periodic field visits by third-party building enclosure firm/commissioning agent.

E. Provide on-site instruction of appropriate moisture control measures to be performed by all parties at the appropriate stages of the project.
   1. Provide chart to all professionals performing work on the site to aid decision-making for selection and implementation of moisture control measures in relation to environmental conditions.

F. Meetings: Discuss moisture control measures, goals and issues at pre-construction meeting and regular job-site meetings. Record these discussions in regular job-site meeting reports.

End of section

C

Swelling & shrinkage of wood

Appendix C
Swelling & shrinkage of wood

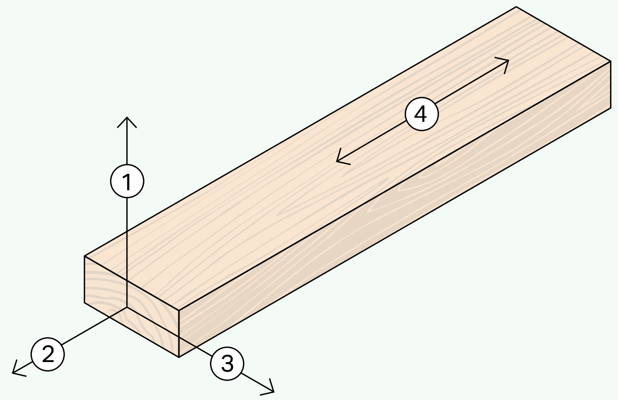
Wood is a natural material, therefore its properties vary with the direction of the wood grain. As shown in **Figure C1**, three directions of grain are identified: radial, longitudinal, and tangential.

Although there are no prescribed manufacturer standards for NLT, typical softwood species used to construct NLT include Douglas Fir (DF) and Spruce-Pine-Fir (SPF). Different species have different physical properties, including density and water vapour permeability.

As a natural hygroscopic material, wood experiences sorption and desorption; its moisture content will change with exposure to both liquid water and water vapour within the surrounding environment. Changes in moisture content at or below fiber saturation point affect wood dimensions and structural properties. With regard to water vapour, the equilibrium moisture content (EMC) of wood will change with the temperature and relative humidity of the surrounding environment. The relationship of EMC and relative humidity at a given temperature is expressed as a sorption isotherm as shown in **Figure C2**.

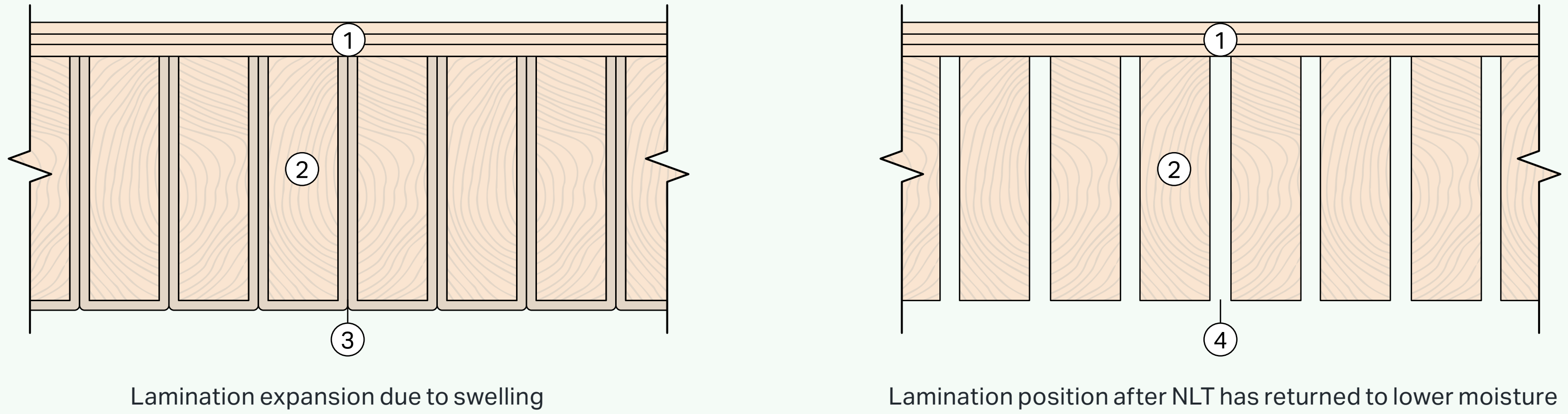
Wood will change dimensionally with changes in moisture content most in the tangential direction, half as much in the radial direction, and a minimal amount (0.1% to 0.2%) in the longitudinal direction (United States Departement of Agriculture Forest Service, 2010). As longitudinal shrinkage/swelling is so small, it is generally ignored in the design and construction of NLT panels. Expected values of swelling can be calculated by estimating the material's installation moisture content and the maximum expected moisture content during a heavy rain event. Typically these values range from 12% to approximately 28% respectively. Values of shrinkage can be calculated by estimating the material's installation moisture content and the building's equilibrium moisture content. Typically, equilibrium values range from 8% to 12%.

Figure C1 The three principal axes of wood grain



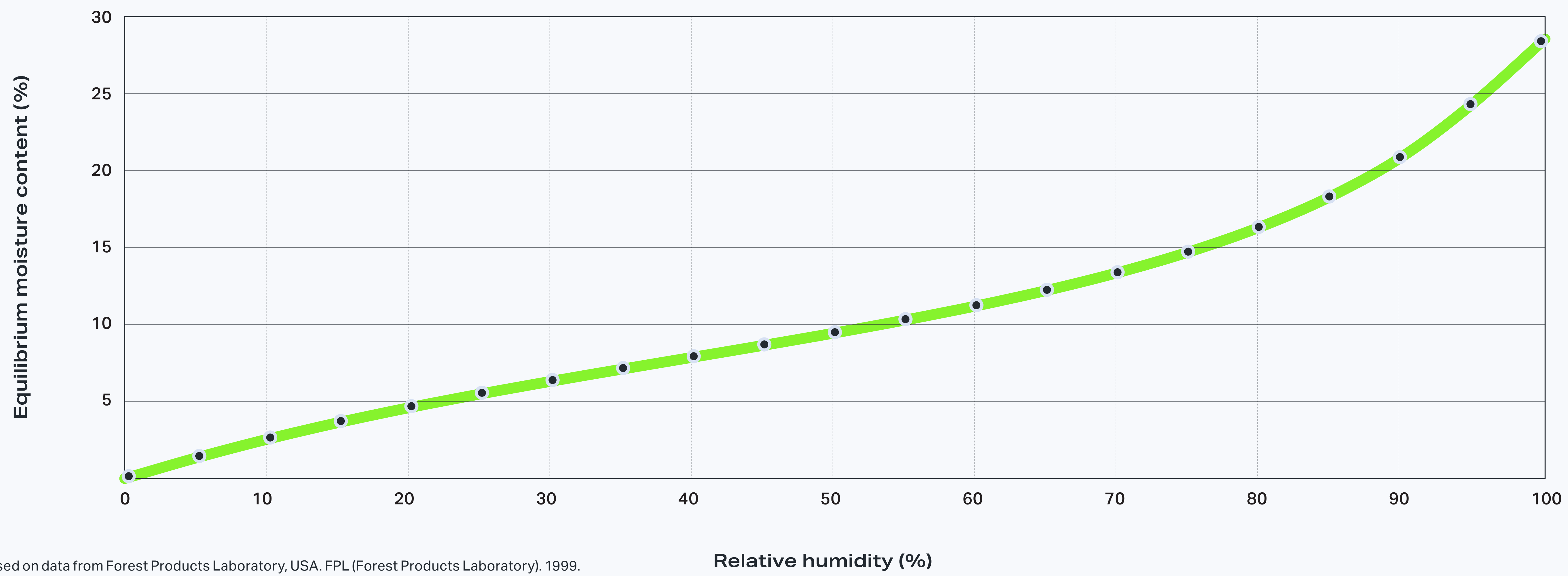
1. Radial
2. Longitudinal
3. Tangential
4. Fiber direction

Figure C2 Swelling and shrinkage in individual laminations (scale exaggerated to show general effect)



When NLT gets wet, the wood fibers will fill with water and begin to swell. When NLT dries out and finds stable humidity and temperature levels, the individual laminations will shrink in cross-section. When detailing NLT, consider both swelling during the construction phase and shrinkage during the first few years of building service life. This cycle can result in small gaps between the NLT laminations as shown in **Figure C3**.

Figure C3 Wood moisture sorption isotherm at 20°C



Based on data from Forest Products Laboratory, USA. FPL (Forest Products Laboratory). 1999. Wood Handbook-Wood as an Engineering Material. Gen. Tech. Rep. FPL-GTR-113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory

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