

NAIL- LAMINATED TIMBER

CANADIAN DESIGN
& CONSTRUCTION
GUIDE v1.1





Binational Softwood Lumber Council



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Investment®**

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Above Lansdowne Station, Richmond, BC. Architecture: Perkins+Will. (Photo credit: Martin Tessler)

Glossary

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 Field Impact Isolation Class (FIIC) and 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 airborne sound such as speech frequencies. It is based on in-situ field measurements and includes sound flanking paths. Refer also to Field Sound Transmission Class (FSTC) and Sound Transmission Class (STC).

Appearance Grading

See Aesthetic Grading.

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).

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.

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.

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.

Dunnage

Scrap wood or disposable material placed below construction material to raise it off the ground, floor, or truck bed.

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.

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.

Field Impact Isolation Class (FIIC)

A single number rating that is an indication of a partition's (e.g. floor/ceiling assembly) ability to block impact sound. It is based on field measurements where sound flanking has been eliminated. See also Apparent Sound Transmission Class (ASTC) and Sound Transmission Class (STC).

Field Sound Transmission Class (FSTC)

A single number rating that indicates the ability of a partition (e.g. floor/ceiling assembly or party wall) to block sound, such as speech frequencies. It is based on field measurements where airborne sound flanking has been eliminated. See also Apparent Impact Isolation Class (AIIC) and Field Impact Isolation Class (FIIC).

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.

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 system 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).

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.

Glulam

See Glued-Laminated Timber (GLT).

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.

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) and Field Impact Isolation Class (FIIC).

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.

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%.

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.

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.

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+%.

Nail-Laminated Timber (NLT)

A solid wood structural element consisting of dimension lumber on edge and fastened together with nails.

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.

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

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).

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, such as speech frequencies. It is based on laboratory measurements. See also Field Sound Transmission Class (FSTC) and 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).

Thermal Conductivity

Quantity of heat flow through a material for a given unit temperature difference, expressed as $W/m \cdot K$ ($Btu \cdot in/h \cdot ft^2 \cdot ^\circ F$).

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 $m^2 \cdot K/W$ ($ft^2 \cdot ^\circ F \cdot hr/btu$) 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.

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 evaporation point causing large numbers of molecules to evaporate or sublime 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.

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.

Zero-Strength Layer

A calculation term which accounts for a reduction in strength of the heated wood beyond the char front.



Above *Samuel Brighthouse Elementary School. Richmond, BC. Architecture: Perkins+Will. (Photo credit: Nic Lebourg)*

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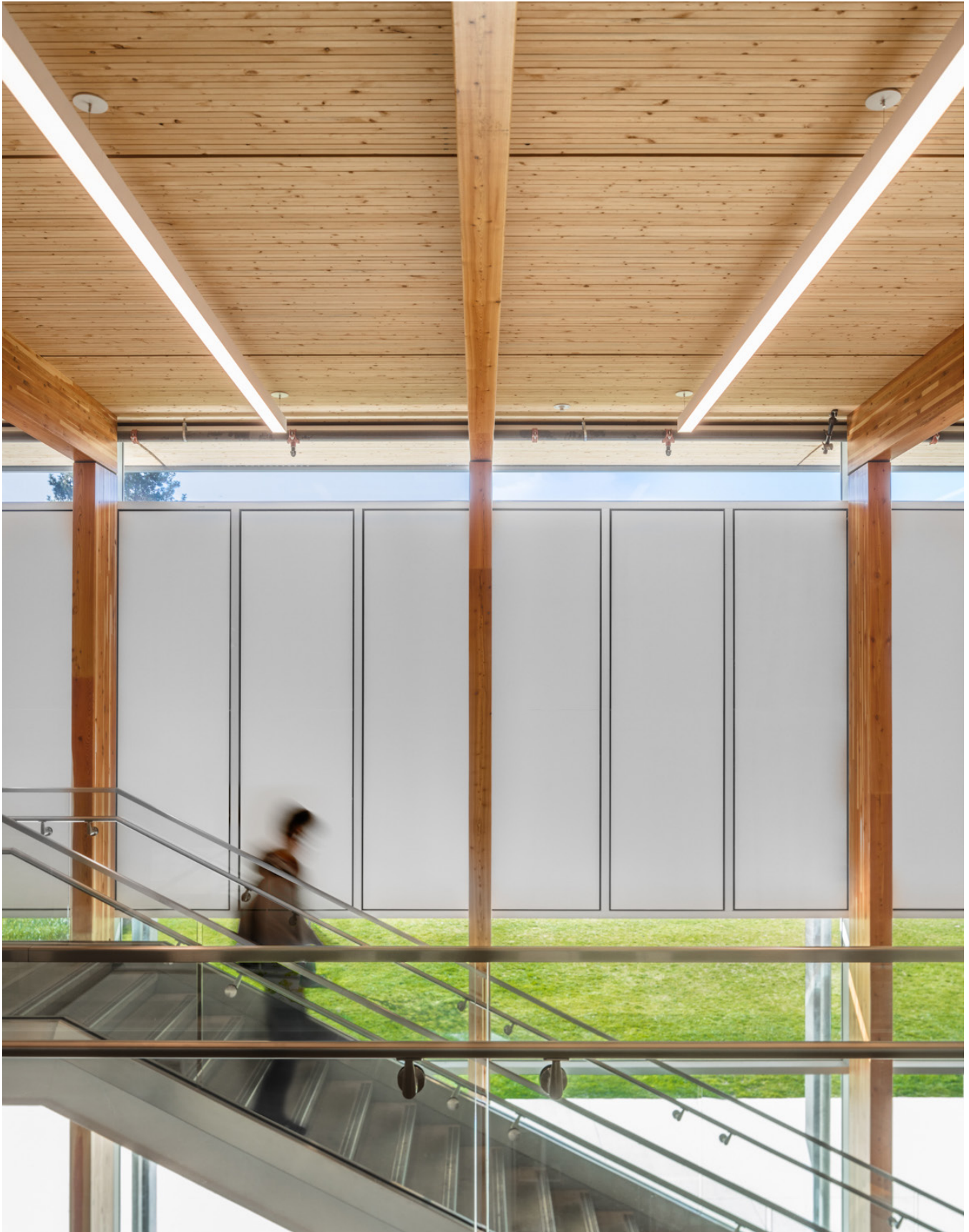
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Above Orchard Commons, Vancouver, BC. Architecture: Perkins+Will. (Photo credit: Michael Elkan)



Above UBC Bookstore, Vancouver, BC. Architecture: Office of McFarland Biggar Architects + Designers (Photo credit: Ema Peter)

1 Introduction

Part of the family of mass timber panel products, Nail-laminated Timber (NLT) is 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 can provide in-plane shear capacity, allowing the product to be used as a shear wall or diaphragm.

Nail-laminated Timber (NLT) is an old method of construction with a range of modern opportunity to create compelling architecture. Used in many historic applications, it is enjoying renewed interest as we rediscover the many benefits of mass timber and advance wood technology and manufacturing. Lightweight, low-carbon, and very compatible with high-performance buildings, innovation with NLT is inspiring new opportunities for large and small-scale buildings and infrastructure across sectors and around the world.

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. While this wide range of products affords many options for specific design applications, each has different design 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.

While products like GLT and CLT have modern publications and resources aimed at assisting designers and builders with specification, detailing, and installation, NLT resources are dated and focus on prescriptive rather than engineered applications.

This Design and Construction Guide (the Guide) provides the Canadian design and construction industry with immediate support and guidance to ensure safe, predictable, and economical use of NLT. It is intended to offer practical strategies, advice, and guidance, transferring knowledge and lessons learned from those with experience.

This Guide focuses on design and construction considerations for floor and roof systems pertaining to current Canadian construction practice and standards. While NLT is being used for vertical elements for walls, stair shafts, and elevator shafts, this Guide provides the greatest depth of direction for common horizontal applications. 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 2015 (NBC) [1]
- CSA O86-14 Engineering Design in Wood [2]

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

References

- [1] Canadian Commission on Building and Fire Codes, and National Research Council of Canada. 2015. *National building code of Canada, 2015*. Ottawa, Ont: National Research Council Canada.
- [2] Canadian Standards Association. 2014. *Engineering design in wood*.



Above *Centre for Interactive Research on Sustainability, Vancouver, B.C.. Architecture: Perkins+Will. (Photo credit: Martin Tessler)*



Above T3, Minneapolis, MN. *Architecture: Michael Green Architecture. (Photo credit: Ema Peter)*

2 Architecture

2.1 Conceptual Considerations

2.1.1 Form

Nail-laminated timber (NLT) allows the creation of a monolithic “slab” of wood from off-the-shelf dimension lumber, supporting a broad range of architectural opportunities. Historically, NLT was primarily used for the construction of warehouses and other large buildings (refer to Figures 2.1 and 2.2). While flat floors and roofs remain the most common NLT building elements, more expressive and dynamic forms are being explored.



In This Chapter

- 2.1 *Conceptual Considerations*
- 2.2 *Planning Considerations*
- 2.3 *Detail Considerations*
- 2.4 *Mechanical, Electrical, and Plumbing Considerations*
- 2.5 *Acoustic Considerations*
- 2.6 *Durability Considerations*



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. vancouverurbanninery.com)



Figure 2.2: Renovated Space at Vancouver Urban Winery. The building dates from the 1920s, used originally as a steel manufacturing foundry. (Photo courtesy of Vancouver Urban Winery. vancouverurbanwinery.com)



Figure 2.3: NLT Stair Core (Photo courtesy of WoodWORKS! BC and Performance Construction)

The examples here are intended to inspire and illustrate the breadth of possibilities as they pertain to NLT. Although NLT floors and roofs can be covered by finishes, they are often left exposed as a key design element. NLT is most commonly exposed at the ceiling, where it is protected from wear and the elements.

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 2.3).

Creating simple curves from NLT is relatively easy. The roof of Aberdeen Station, shown in Figure 2.4, is composed of gently curving steel channels which support the lumber, creating a modular, prefabricated panel that was craned into place. The channels were bolted to the adjacent panel channels.



Figure 2.4: *Aberdeen Station, Richmond, BC. Architecture: Perkins+Will.*
 (Photo credit above: courtesy of Perkins+Will; Photo credit below: Martin Tessler)



Figure 2.5: *Samuel Brighthouse Elementary School. Richmond, BC. Architecture: Perkins+Will. (Photo credit: Nic Lebourg)*



Figure 2.6A: Brentwood Station, Burnaby, BC. Architecture: Perkins+Will. (Photo credit: Nic Lehoux)

The atrium at Samuel Brighthouse Elementary School, shown in Figure 2.5, advances the same concept with integrated steel struts and tension cables, turning the NLT into a truss system to create a whimsically undulating roof.

Compound curves are also possible. The NLT at Brentwood station is curved perpendicular to the laminations, and used a combination of curved NLT, curved-in-plan. Figure 2.6A shows the NLT curved to follow the shape of the glued-laminated beams, and Figure 2.6B 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.

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 shown in Figure 2.7.



Figure 2.6B: Brentwood Station, Burnaby, BC. Architecture: Perkins+Will. (Photo credit: Nic Lehoux)



Figure 2.7: Tsingtao Pearl Visitor Centre, Qingdao, China. Architecture: Boblin Cywinski Jackson. (Photo credit: Nic Lehoux)



Figure 2.8: CNC Milled Compound Curve Prototype. (Photo courtesy of Perkins+Will)

Compound curvature NLT with tight radii in the direction parallel to laminations requires the use of short lumber segments and results in noticeably faceted surfaces. Computer Numerical Control (CNC) milling of the faceted surface can be used to achieve a smooth surface. This is a labour and material-intensive process typically reserved for specialty applications. Refer to Figure 2.8 for prototype examples.

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 the designer 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 Standard O86-14 Engineering Design in Wood. 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.

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.

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 2.9. 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 not all fabricators will have the ability to plane NLT smooth. Refer to Chapter 6 for more on fabrication.

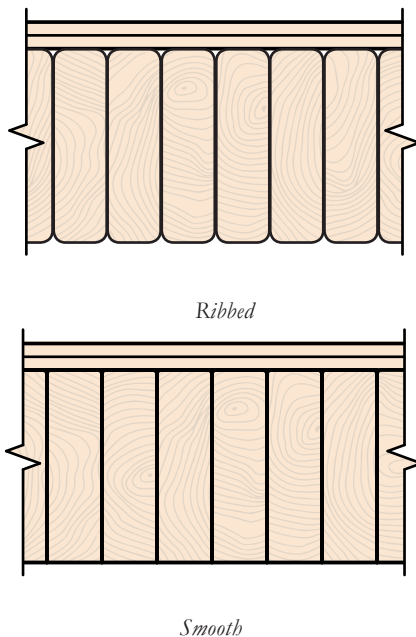


Figure 2.9: Ribbed and Smooth Surfaces on NLT from Un-planed and Planed Laminations

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 2.5.1). While the number of unique cross sections is theoretically infinite, most NLT is fabricated as illustrated in Figures 2.10, 2.11, and 2.12. 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.

Set expectations for panel 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 6 for more on fabrication.

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 6 for more on fabrication and 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 2.13 or a mockup. Detailed considerations on fabrication and installation are provided in Chapter 6 and Chapter 7. Refer to Appendix B for a sample specification including requirements for finish and mock-up requirements.



Figure 2.10: *Uniform Depth Cross-Section.*

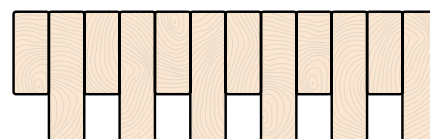


Figure 2.11: *1:1 Alternating Staggered Depth Cross-Section.*

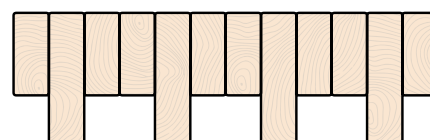


Figure 2.12: *2:1 Alternating Staggered Depth Cross-Section.*



Figure 2.13: *NLT Visual Reference. (Photo courtesy of StructureCraft Builders Inc.)*

TABLE 2.1 TYPICAL NLT FLOOR SPANS

| NLT DEPTH | TYPICAL SPAN RANGE |
|----------------------------|--------------------------------|
| 89 mm (4 in. nominal) | up to 3.7m (12 ft.) |
| 140 mm (6 in. nominal) | 3m to 5.2m (10 to 17 ft.) |
| 184 mm (8 in. nominal) | 4.3m to 6.4m (14 to 21 ft.) |
| 235 mm (10 in. nominal) | 5.2m to 7.3m (17 to 24 ft.) |
| 286 mm (12 in. nominal) | 6.1m to 7.9m (20 to 26 ft.) |

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

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 office 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. Refer to Chapter 3 for more information.

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 4.4.1 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.

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 envelope create additional design and detailing considerations; refer to Sections 4.4.3 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.



Figure 2.14: Office Partition Walls in Mountain Equipment Co-Op Head Office. Vancouver, BC. (Photo courtesy of Fast+Epp)

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, similar to a steel curtain wall system. Detailing in these situations are typically very similar despite the material.

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 2.14 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.



Figure 2.15: *Example of Continuous Soffit from Interior to Exterior. Samuel Brighthouse Elementary School. Richmond, BC. Architecture: Perkins+Will. (Photo credit: Nic Lebourg)*

Due to the difficulty in sealing linear elements to the underside of NLT, it is good practice to keep NLT from penetrating the building envelope. If a continuous soffit is desired from interior to exterior, similar to the example shown in Figure 2.15, devise a detail that accommodates continuity of air, vapour, and weather barriers. Refer to Figures 4.20 and 5.3 for example section details.

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 2.16 and 2.17. This approach creates a concealed space. Refer to Section 3.4.3 for details on protecting concealed spaces.

Vertical distribution of services through NLT must be coordinated with the structural engineer 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 4.4.2 for detailed 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 so as 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 after the fact. All pipes, conduit, cables, and so forth must be accounted for and accurately located during fabrication.

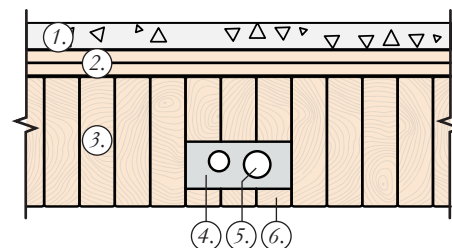


Figure 2.16: Service Chase in NLT.

Key

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 2.17: NLT Panel Before and After Capping the Service Chase. (Photos courtesy of StructureCraft Builders Inc.)

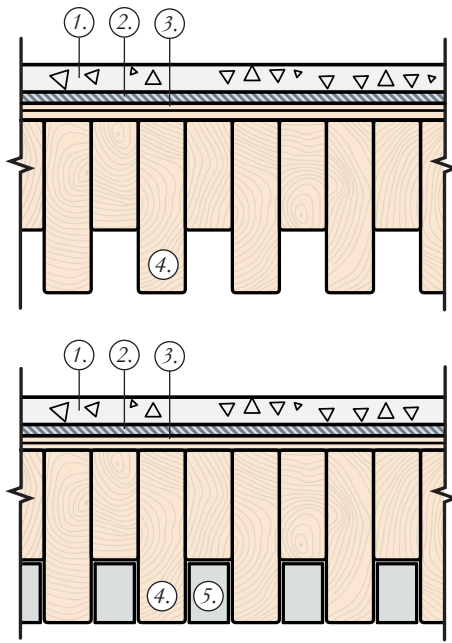


Figure 2.18: Alternating 38 mm × 89 mm (2×4) and 38 mm × 140 mm (2×6) Lumber With and Without Sound Absorbing Material

Key

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

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, hospitals, office buildings, and multi-family dwellings. Acoustics and noise control is one of the most common complaints in finished and occupied buildings.

The National Building Code of Canada (NBC) and relevant provincial codes, establishes minimum Sound Transmission Class (STC) targets for airborne sound isolation between multi-family residential units—STC 50. The NBC does not set requirements for impact noise, or Impact Isolation Class (IIC), but rather suggests a good practice target of IIC 55. Further, neither the NBC nor provincial codes provide guidelines for room finishes. While room finishes can affect the quality of life for occupants, finishes do not directly affect the sound isolation performance of walls or floor/ceilings with respect to their STC rating, nor do they affect the façade details in terms of outside-to-inside sound reduction (OITC). The selection of the appropriate OITC rating relative to acceptable interior noise levels in an occupied space is generally set by local noise bylaws.

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 floor/ceiling system and how sound reflects from the NLT surface when the underside is exposed in the room below.

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 [1] 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/OSB and/or a concrete topping over NLT may address sound leakage by limiting the passage of airborne sound. Addressing sound leakage paths is a prime consideration of the basic design. Once the potential for leakage through the panel itself has been addressed, the overall issue of sound flanking (that is, sound that bypasses the building structure) is dealt with in ways similar to those used for other structural materials and systems.

There are a number of recent building examples that use CLT and timber structural systems as the basis of design. The Wood Innovation Design Centre in Prince George, BC is a six-storey office and classroom building that uses exposed CLT to help achieve both the STC and room acoustics targets as well as good impact isolation for floor/ceiling systems with wood studs used for partitions. The 18-storey Brock Commons student residence project at the University of British Columbia applies a hybrid system of encapsulated CLT for the floor/ceiling system and metal studs for party walls.

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 similar to 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 assists with control of overall noise levels in a space, aids in speech intelligibility for both the spoken word and for sound systems, and provides a more 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 2.18). To improve sound absorption of the NLT system, introduce a material with reasonably good acoustic properties into the openings. This approach assumes that the ‘sound leakage’ of the basic construction has already been addressed. Refer to Figure 2.18 showing NLT made of alternating 38 mm x 89 mm (2x4) and 38 mm x 140 mm (2x6) dimension lumber with a strip of sound-absorbing material glued 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.). The exposed acoustic medium should be at least 70% of the surface area of the ceiling for a reasonably good acoustic environment. This can be achieved by greater spacing of the 38 mm x 140 mm (2x6) lumber.

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.

TABLE 2.2 IMPRESSIONS OF IMPACT/FOOTSTEP NOISES AS HEARD IN ROOMS DIRECTLY BELOW PARTY FLOORS WITH VARIOUS IIC RATINGS

| PARTY FLOOR IIC | IMPRESSIONS OF IMPACT/FOOTSTEP NOISE HEARD |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Less than 45 | Normal walking clearly audible below, chair movements, dropped objects audible. Unsuitable for multi-family units or where moderate isolation is required within same dwelling unit. |
| 45 to 55 | Normal walking (in hard shoes) still clearly audible, may be adequate between spaces within same dwelling unit, not suitable for most multi-family buildings. |
| 55 to 60 | Normal walking noise still clearly audible when background noise levels are fairly low; may be adequate for multi-family buildings in less critical situations. |
| 60 to 70 | Normal walking audible only during very low background noise situations, adequate for most multi-family buildings. |
| 70 to 80 | Normal walking generally inaudible, usually adequate for even the most sensitive (high quality, low background noise) situations. |
| 80 or higher | Virtually no audible impact noise transmitted from walking, small dropped objects etc. |

2.5.2 Inter-Space Sound Control

Transfer of sound between adjacent spaces takes two forms. The first is the transfer of airborne 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 Sound Transmission Class (STC). STC is determined by laboratory testing, according to specific ASTM requirements. The second form is the transfer of impact sound. Impact sound is most typically generated by footfall, but can also be generated from the movement of furniture, or dropping heavy objects. The ability of a floor/ceiling assembly to prevent the transfer of impact sound is described by a single number rating system called Impact Isolation Class (IIC), also determined by laboratory testing. 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 Table 2.2 for reference only.

Canadian national and provincial codes include requirements for minimum STC ratings¹ but only guidance for best practice for IIC². Further, the 2015 National Building Code sets design targets using the Apparent Sound Transmission Class (ASTC) rather than the previously referenced Sound Transmission Class, STC. It is expected that the forthcoming provincial codes will adopt the ASTC requirement. There are currently no proposed changes to the requirements for IIC. Refer to the following section on Impact Sound for more information.

¹ Minimum STC rating is 50 between occupied spaces in dwelling units, and 55 adjacent to elevator shafts.

² Best practice IIC minimum is 55.

Airborne Sound

To mitigate airborne sound in NLT construction consider how sound travels through the floor/ceiling assembly to a space below, as well as horizontally to an adjacent occupied space.

Reducing airborne sound through the floor/ceiling assembly is accomplished by addressing both the mass of the NLT and the homogeneous nature of its surface. Similar to other mass timber panel products, NLT does not have enough mass to mitigate airborne sound on its own to meet Building Code requirements. Materials must be added to the top and/or underside of the NLT structure to compensate for the lack of mass. To address the homogenous surface, refer to Section 2.5 and Figure 2.18. As a result of minor swelling and shrinkage, gaps may develop between the NLT laminations that penetrate the full depth of the NLT. Any gap through which air can pass is also a path for airborne sound, and can result in sound leakage. Accordingly, bare NLT without continuous plywood/OSB sheathing, or concrete topping will not provide effective attenuation to airborne sound.

Airborne sound can travel horizontally along any surface including NLT; the grooves on the surface of NLT unlike a smooth flooring finish provide potential sound leakage paths at the party wall/floor interface. Accordingly, designers should carefully consider interface details when using NLT. For example, where a wall running perpendicular to the laminations meets the underside or top-side of the NLT, an acoustic sealant must be applied between the NLT and the plates of the abutting wall to fill the gaps.³ If a concrete topping is used to increase the sound rating via the floor/ceiling system, the sound leakage through NLT gaps should be addressed automatically at the floor/wall interface at least.

Impact Sound

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 (both of which meet Building Code requirements for airborne sound) can effectively block the sound of voices from the suite above, but the sound of someone walking in hard-soled shoes or of chair movement will be clearly audible in the occupied space below. Complaints of impact noise are the most common in any occupied multi-family residential building.

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

TABLE 2.3 STC AND IIC TESTING DATA COMPLETED FOR NLT FLOORS

| FLOOR ASSEMBLY (TOP TO BOTTOM) | | STC | IIC |
|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|
| 1 | 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT panel (baseline measurement) | 34 | 32 |
| 2 | Bare CLT panel (5-ply, 175 mm [6-7/8 in.] thick) | 39 | 25 |
| 3 | 102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT | 51 | 44 |
| 4 | Carpet + 102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT | 51 | 58 |
| 5 | 102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF25 acoustical mat + 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT | 54 | 50 |
| 6 | 102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF50 acoustical mat + 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT | 56 | 52 |
| 7 | 38 mm (1-1/2 in.) Gypcrete 2000 + Maxxon Acousti-Mat II acoustical mat + 13 mm (1/2 in.) plywood + 2x6 NLT | - | - |
| 8 | 38 mm (1-1/2 in.) Gypcrete 2000 + Maxxon Acousti-Mat 3 acoustical mat + 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT | - | - |
| 9 | 102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT + RC + 16 mm (5/8 in.) Type C Gypsum | 55 | 49 |
| 10 | 102 mm (4 in.) normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 13 mm (1/2 in.) plywood + 38 mm x 140 mm (2x6) NLT + Pliteq GenieClip RST Clip + R8 Fibreglass batts + 16 mm (5/8 in.) Type C Gypsum | 60 | 59 |

Addressing impact sound is typically the governing factor for the floor/ceiling assembly, and like most structural floor systems, floor finish material can have a significant effect on an NLT floor assembly's IIC rating. In order to optimize the reduction of impact noise, additional material is typically applied on top of the NLT, below it, or both.

As previously noted, many local building codes have yet to adopt IIC ratings as part of their requirements, but the minimum acceptable target according to the International Building Code (IBC) is IIC 50. Floors in residential buildings with IIC ratings less than 50 often result in complaints related to impact noise. While it is not a requirement to provide a floor with a minimum IIC 50 rating, it is strongly recommended. Some residential developments implement more stringent ratings (IIC 55 or higher) in an effort to satisfy residents. In fact, the BC Building Code suggests a minimum of IIC 55 as good practice. Further, while IIC 55-58 is a common target range for upgraded performance, a range of at least IIC 65-70 is required for overall user satisfaction.

The IIC rating required to provide generally acceptable impact noise insulation depends on a range of factors, such as quality of building, expectations of occupants and background noise environment. Table 2.3 provides some guidance in selecting appropriate IIC targets for various design conditions.

Field Testing

Careful control of flanking paths is important for all construction and material types. Field-tested ratings⁴ are typically five points lower than those achieved in laboratories (STC and IIC) due to the effect of sound flanking in-situ.

Table 2.2 provides STC and IIC test results for NLT floors. Included in the table for comparison is the acoustic performance of bare NLT with plywood 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. In order 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 a number of CLT acoustic assemblies listed in the CLT Handbook [1] as well as others available from acoustical mat manufacturers; some provide STC/IIC values and some provide FSTC/FIIC 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, FSTC/FIIC, or ASTC/AIIC values. In addition, there are proprietary software programs that can predict 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.

2.6 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, without 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. 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

⁴ Field tested ratings are FSTC or FIIC where 'F' means 'Field'; where ASTC and AIIC are used, 'A' means 'Apparent'

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 a significant risk of staining, mould, decay, and excessive dimensional changes. 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. Enclosure elements must be designed to avoid trapped water and moisture build up, both during construction and in service. Refer to Chapter 5 for more on Enclosure. Construction phase moisture must be managed through a moisture protection plan established in consultation with the design team. Unplanned moisture exposure during the construction phase can delay project schedules and negatively impact the quality of the work. Refer to Section 7.6 for more on construction phase moisture protection.

REFERENCES

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



Above Chilliwack Secondary School, Chilliwack, BC. Architecture: Dialog. (Photo courtesy of StructureCraft Builders, Inc.)



Above Mountain Equipment Co-op Head Office, Vancouver, BC. Architecture: Proscenium Architecture+Interiors. (Photo credit: Ed White Photographics)

3 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 2015 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 Division B Part 3 of the NBC include provisions for the use of NLT in buildings permitted to be of combustible construction 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 1940, described as “solid sawn lumber planks set on edge and well spiked together.” The current NBC includes minimum allowable sizes when combustible construction with a fire-resistance rating up to 45 minutes is permitted in Division B Part 3 and provides historic generic acceptable solutions for fire-resistance ratings up to 1.5 hours. 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.

3.1 Fire Safety in Timber Buildings

The primary objectives for the construction requirements under Division B Articles 3.2.2.20 to 3.2.2.88 of the NBC, as noted in Article 3.2.2.1, are to limit the probability of fire spread, and to limit the risk of, or prevent, collapse caused by the effects of fire.

The intent of these construction requirements is to provide safety to building occupants, safety to property, and safety to fire fighters and emergency responders. 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 3.2.2.88.



In This Chapter

- 3.1 Fire Safety in Timber Buildings*
- 3.2 Fire Performance of Combustible Construction*
- 3.3 Fire Design*
- 3.4 Additional Considerations*

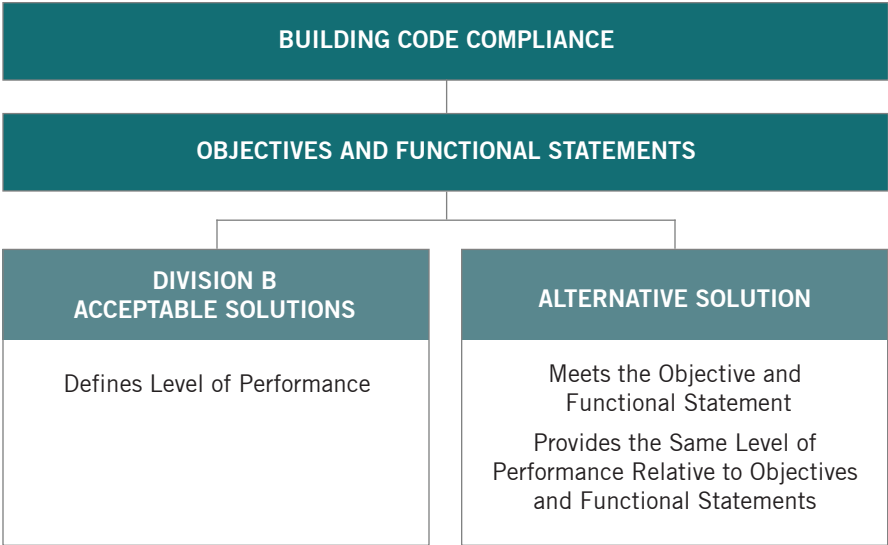


Figure 3.1: *Building Code Performance Requirements Compliance Path*

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

- Compliance with prescriptive requirements of Division B (“acceptable solution”);
- Simple building code alternative solutions per Division A;
- More complex alternative solutions, in particular, performance-based design, typically addressed by approval at the provincial level and/or a requirement for a third-party review.

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 wood-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. It is permitted where a fire-resistance rating of not more than 45 minutes is required and for selected uses in buildings otherwise required to be of

noncombustible construction. The minimum heavy timber dimensions required to provide the 45-minute fire-resistance rating are outlined in Division B Part 3, Article 3.1.4.7. Where combustible construction is permitted and a fire-resistance rating exceeding 45 minutes is required, Division B Appendix D-2.4 may be used to determine the required dimensions of NLT.

The NBC's Division A Sentence 1.2.1.1 (1) allows design flexibility beyond prescriptive requirements through alternative solutions as described under Section 2.3 of Division C. These alternative solutions must demonstrate to the authority having jurisdiction (AHJ), typically at the municipal level, that the fire safety objectives of the code will be achieved. Alternative methods to comply with the acceptable solutions of the NBC could range in scope from addressing specific details, such as minor combustible elements beyond that permitted by the acceptable solutions 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 more on performance-based design. The NBC 2015 acceptable solutions in Division B prescribe maximum allowable building areas and heights for combustible construction ranging from two storeys for care occupancies to six storeys for residential and business occupancies. Refer to Section 3.3.1 for more.

There are minimal provincial variations relative to the use of NLT. British Columbia (BC), Alberta, and Quebec adopted six-storey combustible construction provisions in advance of the publication of the NBC 2015. 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. Some provinces have specific processes for unique or special buildings. For example, the recently constructed Brock Commons, an 18-storey building of 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.

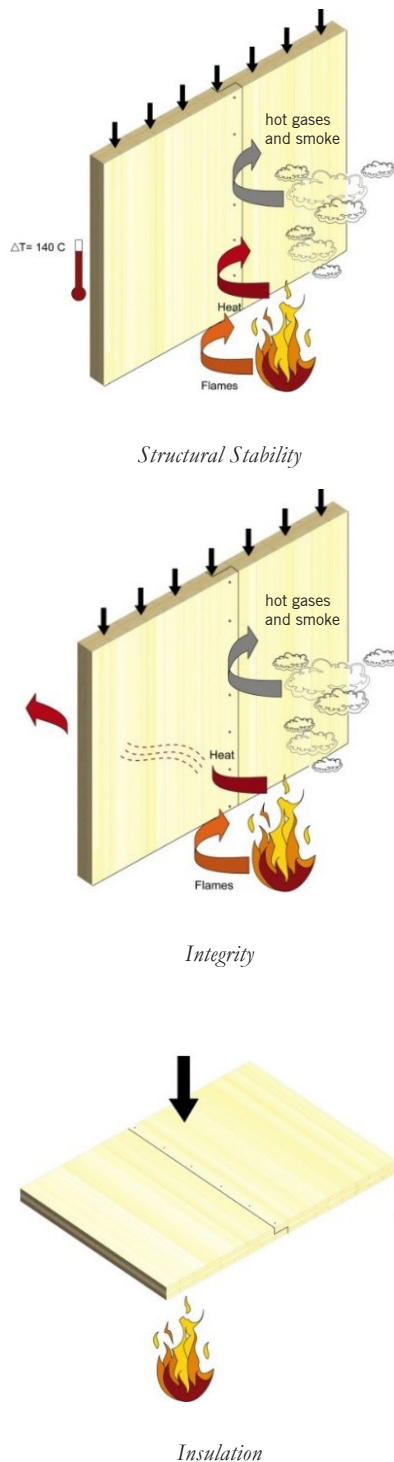


Figure 3.2: Functions of Fire Resistance [1]

3.2 Fire Performance of Combustible Construction

There are generally 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. Wood-frame construction is 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 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 similar to heavy timber construction except that member sizes are typically larger than the minimum sizes prescribed for heavy timber construction in the NBC, and mass timber includes engineered wood products (other than glued-laminated timber) not currently addressed by 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 1.5 hours contemplated by the current NBC acceptable solutions.

3.2.1 Fire-Resistance Ratings

Fire-resistance ratings are based on the following criteria, illustrated in Figure 3.2:

Structural stability: resistance of the assembly or member to structural collapse or exceedance of deformation limits.

Integrity: ability of the assembly to limit the spread of hot gases or fire to the unexposed side.

Insulation: ability of the assembly to limit the rise of temperature on the unexposed side.

The applicable criterion 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,

TABLE 3.1 MINIMUM THICKNESS OF SOLID WOOD WALLS, ROOFS, AND FLOORS (MM)
(ADAPTED FROM TABLE 2.4 OF THE NBC)

| TYPE OF CONSTRUCTION | FIRE-RESISTANCE RATING | | | |
|-------------------------------------------------------------------------------------------|------------------------|------------|--------|----------|
| | 30 MINUTES | 45 MINUTES | 1 HOUR | 1.5 HOUR |
| Solid wood floor with building paper and finish flooring on top | 89 | 114 | 165 | 235 |
| Solid wood, splined or tongued and grooved with building paper and finish flooring on top | 64 | 76 | - | - |
| Solid wood walls of load bearing vertical plank | 89 | 114 | 140 | 184 |
| Solid wood walls of non-load bearing horizontal plank | 89 | 89 | 89 | 140 |

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 of determining a fire-resistance rating above 45 minutes for NLT:

NBC assemblies: Division B, Appendix D-2.4 of the NBC 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 the Guide for reference as Table 3.1. NLT panels, by virtue of its fabrication as solid wood members spiked together, meets the definition of a solid panel. These designs have been in the code 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 code. The generic solutions provided in Appendix D-2.4 are acceptable solutions under the code.

Calculated fire-resistance: NLT systems can be designed to meet the minimum fire-resistance ratings based on char analysis and structural calculations. CSA O86, “Engineering Design in Wood” is the structural design standard referenced in the NBC. Annex B of this standard provides a methodology for establishing structural fire-resistance ratings although a specific methodology for NLT is not yet included. Currently, calculation methodologies such as Annex B of CSA O86 are considered alternative solutions under the code—except in Quebec, which recognizes Annex B as an acceptable solution.

Tested assemblies: There are currently very limited data on tested NLT assemblies. However, testing in this area is being contemplated. Once testing is completed, this guide will be updated and results made available by the Canadian Wood Council and/or Forestry Innovation Investment. Reports demonstrating an assembly or structural member has been tested in accordance with CAN/ULC-S101 is an acceptable solution under the code.

Notes:

- (1) See 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.

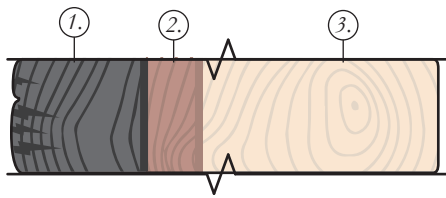


Figure 3.3: One-Dimensional Char Profile [2]

Key

1. Char Layer
2. Pyrolysis Zone
3. Normal Wood



Figure 3.4: Wood Charring (Photo courtesy of Holmes Fire)

3.2.2 Char

Charring of wood occurs when it is exposed to temperatures ranging from approximately 280°C to 300°C [2]. Extensive testing has allowed char rates of wood to be reliably predicted under 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 includes 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 of its structural strength.

NLT that meets the minimum sizes prescribed in Division B, Article 3.1.4.7 have inherent fire resistance due to their thickness and are recognized as elements of “heavy timber construction” in the NBC. Such members are permitted by the code 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.

Where the fire-resistance rating is required to be greater than 45 minutes, char calculations may be used to determine the structural stability of elements exposed to the CAN/ULC-S101 standard fire. 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 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 suggests where hot gases pass between the NLT laminations, bi-directional char may occur [3]; 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 be one-dimensional. The flow of hot air through the assembly is negligible, keeping char limited to one direction on the exposed bottom surface.

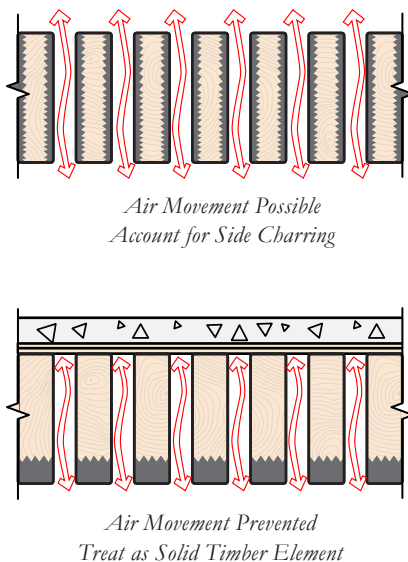


Figure 3.5: Air Movement Through NLT

In order 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. Further testing is required in this area to determine 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. A top membrane resolves this for floor assemblies; however, for walls, shafts or stair fire separations, possible smoke movement must be considered.

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 [4]; mm/min:

$$\text{Char rate} = \text{char depth [mm]} / \text{time [min]}$$

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 3.6 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 based 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

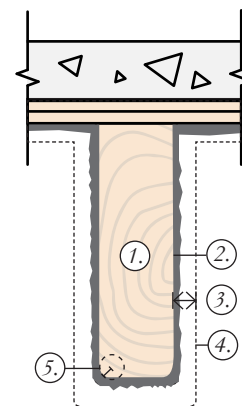


Figure 3.6: Representative Example of Effective Depth

Key

1. Residual Section
2. Calculated Charring Line
3. Calculated Depth of Charring
4. Profile of Original Section
5. Radius of Arris Rounding

or ambient wood below is assumed to maintain full strength and is used to evaluate structural stability and fire-resistance rating. As previously noted, test data on the char rates of NLT are limited; determining fire-resistance ratings of NLT may require close review by a fire safety engineer and structural engineer on a case-by-case basis.

Annex B of CSA O86 provides design charring rates for various wood products exposed directly to the CAN/ULC-S101 standard fire temperature conditions. These char rates apply only where the residual cross-section has dimensions greater than 70 mm (2.75 in.) when exposed to fire on two parallel sides. Specific details for NLT have not yet been incorporated in CSA O86; however, it is expected that future editions will include these. The methodology under ‘Timber Plank Decking’ may be used but is likely to prove onerous in comparison to the values provided in Appendix D-2.4 of the code.

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 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 Subsections 3.1.5 and 3.1.13 of Division B for interior finish requirements. The interior finish requirements noted in the NBC Subsection 3.1.13 of Division B apply to both combustible and noncombustible construction.

TABLE 3.2 MAXIMUM BUILDING HEIGHT PERMITTED FOR COMBUSTIBLE CONSTRUCTION BY OCCUPANCY TYPE

| OCCUPANCY TYPE | GROUP AND DIVISION | MAXIMUM BUILDING HEIGHT PERMITTED FOR COMBUSTIBLE CONSTRUCTION |
|--------------------------------|--------------------|----------------------------------------------------------------|
| Assembly | A1 | 1 storey (Heavy Timber) |
| | A2 | 2 storeys |
| | A3 | 1 storey |
| | A4 | 1 storey |
| Detention | B1 | - |
| Treatment | B2 | 2 storey |
| Care | B3 | 3 storey |
| Residential | C | 6 storey - includes A2 & E on lower floors |
| Business and Personal Services | D | 6 storey - includes A2 & E on lower floors |
| Mercantile | E | 3 storey |
| High Hazard Industrial | F1 | 3 storey |
| Medium Hazard Industrial | F2 | 4 storey |
| Low Hazard Industrial | F3 | 4 storey |

Division B Appendix D-3 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. 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, combustible construction is permitted for buildings up to six storeys in building height (depending on occupancy type). 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 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.

Per the acceptable solutions of the NBC, 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 less. The NBC does not require the protection of connections in this case.
- 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 structural elements may be determined as described in this Guide in Section 3.2.1, using Appendix D-2.4 of the NBC, standard fire-resistance tests, char calculations, or other design methods.
- 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.
- Solid lumber partitions (i.e. non-loadbearing walls) in buildings required to be of non-combustible 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).

3.3.2 Building Code Alternative Solutions

Although any design not specified in Division B of the Code is by definition an ‘alternative solution,’ in practice, alternative solutions fall into two categories: simple alternative solutions that are relatively easy to apply, and more complex performance-based designs.

Where NLT conforms to the prescriptive requirements of the NBC, the approval process is usually simple. Generally, most AHJs are familiar with wood design and heavy timber construction as prescribed by the acceptable solutions of the Code.

Designers are increasingly using NLT in modern buildings beyond prescriptive limits. Division C Section 2.3 of the NBC provides a mechanism for code approval through the use of alternative solutions. 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 in Division B as an acceptable solution still achieves at least the minimum level of performance required by Division B. 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.

The alternative solution approach involves working with an AHJ to identify a non-compliant condition, develop an alternative solution, demonstrate the minimum level of performance required by the code is achieved, and ultimately gain approval. Depending on the level of complexity of the alternative solution, the AHJ may request a third-party review.

Simple Alternative Solutions

For simple alternative solutions, where a condition not directly prescribed by Division B is proposed, consider enhancing or adding fire safety measures to balance the risks. Note that 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 that may not be otherwise required (i.e. an enhanced sprinkler);
- Enhanced fire resistance for structural elements;
- Enhanced compartmentalization within the building;
- Installation of non-combustible vertical exit enclosures; and
- 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 and non-combustible 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.

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;
- Roofs of two-storey portions of higher buildings required to be noncombustible construction; and
- NLT construction in small areas of buildings required to be of noncombustible construction.

3.3.3 Performance-Based Alternative Solutions

The NBC is an objective-based code, and AHJs expect that alternative solutions demonstrate that the minimum level of performance required by the code in the areas described by the objective and functional statements are met. This process typically requires that the level of performance provided by the alternative solution 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 demonstration design objectives not necessarily addressed in the code. The approval process for such an alternative solution may vary between provinces; for example, in BC, there is an option to for approval through Site-Specific Regulation approved by Ministerial Order.

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, methodology, and performance criteria. This process may involve analysis from first principles of fire design, 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.

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 [2];
- Appendix D of the NBC;
- SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings [5];
- ICC Performance-Based Code [6];
- International Fire Engineering Guidelines [7];
- National Performance Based Design Guide [8].

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 (typically 40 mm of cover for a 1-hour fire rating, as described in CSA O86), 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 3.7 and 3.8 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 [2]; refer to Figures 3.9 and 3.10.

Where NLT is used to conform to 45-minute combustible construction requirements and it conforms to the definitions of heavy timber construction, the code recognizes that protection of steel connections is not warranted.

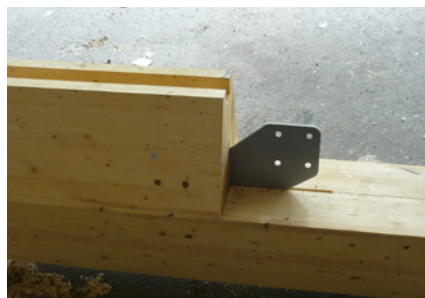


Figure 3.7: *Internal Steel Plate Connection Buried Within Wood Member (Photo courtesy of FPIInnovations)*



Figure 3.8: *Internal Plate and Concealed Fasteners (Photo courtesy of FPIInnovations)*



Figure 3.9: *Structural Connection with Column Cap at The Landing Building, Vancouver, BC (Photo courtesy of GHL Consultants Ltd.)*



Figure 3.10: *Structural Connection with Column cap at the Leckie Building, Vancouver, BC (Photo courtesy of FPIInnovations)*

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.

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 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.”

For exposed wood in general, fire testing has shown the importance of insulating the wood from metal penetrations, as the hot metal can cause unpredictable charring and allow passage of hot gasses and smoke [9]. There are limited tested or listed firestop systems for NLT; however, designs tested for CLT can reasonably be expected to perform similarly in NLT. Experience with testing of penetrations in CLT has shown that metal pipes or fittings in contact with timber cause charring, and metal 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 [1] 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 firestopping materials typically cannot be located on the underside of a timber floor. 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 with dropped ceilings, furred walls, or raised floors. Subsection 3.1.11 of the NBC addresses the protection of concealed spaces through the use of fire blocks to limit the size of any concealed space. 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 also 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 and is typically the responsibility of the general contractor. However, for complex alternative solutions and performance-based designs that include an extensive use of wood beyond typical applications, it is worth integrating as part initial design considerations.

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” [10];
- Technical Guide for Design and Construction of Tall Wood Buildings in Canada [2];
- Fire Safety During Construction for Five and Six Storey Wood Buildings in Ontario: A Best Practice Guideline [11];
- “Construction Site Fire Safety: A Guide for Construction of Large Buildings” – by Centre for Public Safety and Criminal Justice Research, University of the Fraser Valley, 2015 (<http://cjr.ufv.ca/construction-site-fire-safety/>) [12]; and,
- Municipal bulletins on construction fire safety.

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- [9] GHL Consultants. “Firestopping Test Witness Report for Nordic Structures”. GHL File NEW-4830.01 26 September 2016
- [10] National Fire Protection Association. 2013. *NFPA 241: standard for safeguarding construction, alteration, and demolition operations*.
- [11] “Fire Safety During Construction for Five and Six Storey Wood Buildings in Ontario: A Best Practice Guideline.” May 2016. Accessed October 04, 2017. <http://www.mah.gov.on.ca/Page14861.aspx>.
- [12] University of the Fraser Valley. “Construction Site Fire Safety.” Centre for Public Safety and Criminal Justice Research. May 28, 2015. Accessed October 04, 2017. <http://cjr.ufv.ca/construction-site-fire-safety/>.



Above Mountain Equipment Co-op Head Office. Vancouver, BC. Architecture: Proscenium Architecture+Interiors. (Photo credit: Ed White Photographics)



Above *East Village Presentation Centre, Calgary AB. Architecture: James KM Cheng Architects (Photo courtesy of StructureCraft Builders Inc.)*

4 Structure

Nail-laminated timber (NLT) is a system that spans in one direction to resist out-of-plane loading. 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 size of dimension lumber. Floors and roofs are typically sheathed on the top side with plywood or OSB to carry in-plane shear caused by lateral loads. The strength and serviceability of NLT 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 deflections and vibrations often govern the design of NLT floors. Designing for fire-resistance may also be a governing factor.

The guidance in this chapter is intended to cover design issues specific to NLT. The reader is assumed to have a general working knowledge of wood properties as well as design procedures according to CSA O86, the Canadian standard for Engineering Design in Wood. CSA O86 clause references in this chapter refer to the 2014 edition.

4.1 Gravity Design Procedures

To design for gravity loads, treat NLT as a built-up beam as shown in Figure 4.1. Follow the provisions in CSA O86, using general design requirements in Clause 5 and equations for sawn lumber in Clause 6. Where NLT contains butt-jointed laminations, additional modification factors are required beyond those given in CSA O86 to account for reductions in strength and stiffness.

Exposure condition, either in service or in construction, can significantly impact both the strength and the long-term deflections of NLT. It also affects durability, as discussed in Chapter 5. Vibrations can govern the design and should be checked when NLT is used for floors or occupied roofs.



In This Chapter

- 4.1 Gravity Design Procedures
- 4.2 Lateral Load Design Procedures
- 4.3 Connections
- 4.4 Additional Design Considerations
- 4.5 Specifications

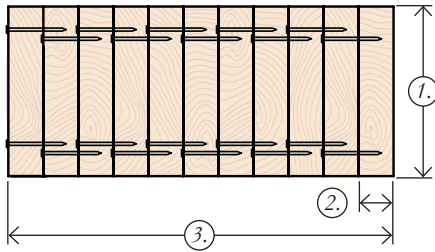


Figure 4.1: NLT Cross-Section

Key

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

Where NLT 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 4.15.

CSA O86 Modification Factors

Use modification factors for the design of NLT from CSA O86 Clause 6. Factors that require clarification for NLT in lieu of individual sawn lumber joists are discussed in this section. Apply the remaining modification factors directly per CSA O86 provisions.

System Factor, K_H

NLT meets the requirements for Case 1 by definition; most NLT assemblies also qualify as Case 2, provided the minimum requirements for sheathing given in CSA O86 Clause 6.4.4.2 are met. Apply the appropriate Case 1 or Case 2 K_H factor given in CSA O86 Table 6.4.4. Only one system factor can be used; do not apply the system factor for built-up beams.

Size Factor, K_z

Develop the size factor based on the individual lamination thickness (b_{lam}), analogous to the typical design approach for built-up sawn lumber members.

Lateral Stability Factor, K_L

Use a lateral stability factor of 1.0 except in rare cases where edge conditions or large openings may create narrow sections of NLT with only a few laminations.

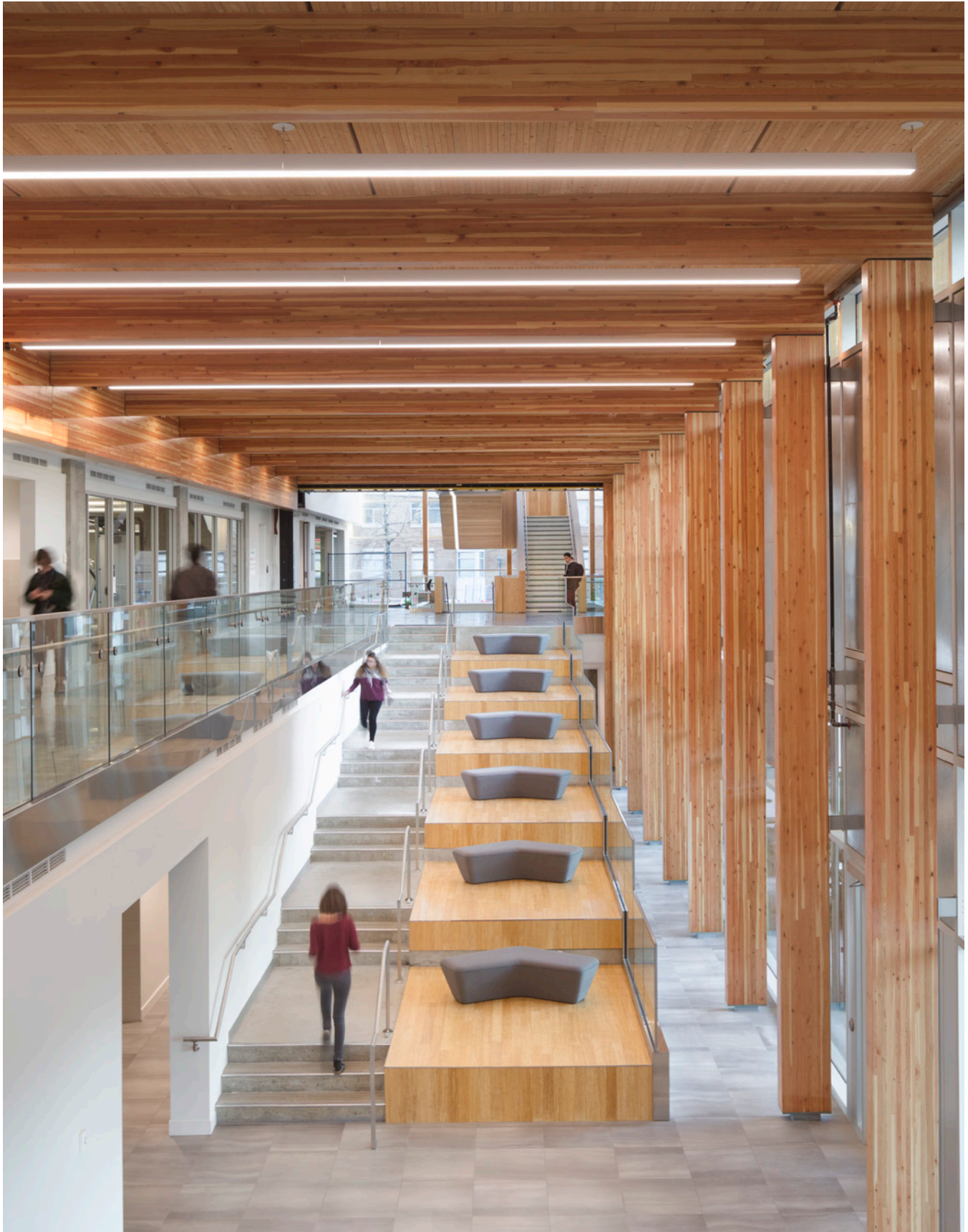
4.1.1 Additional Modification Factors

Additional modification factors are required in cases where NLT laminations are butt jointed in between supports and/or NLT is fabricated from laminations of varying depths.

Layup Factor (K_{layup})

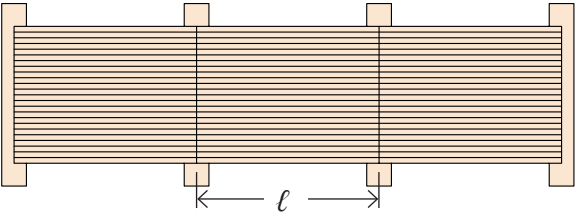
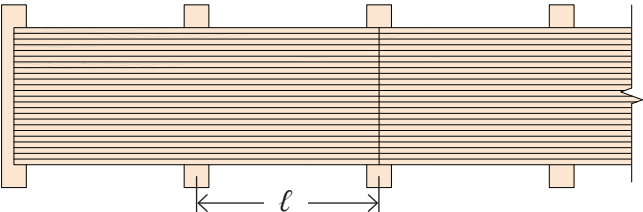
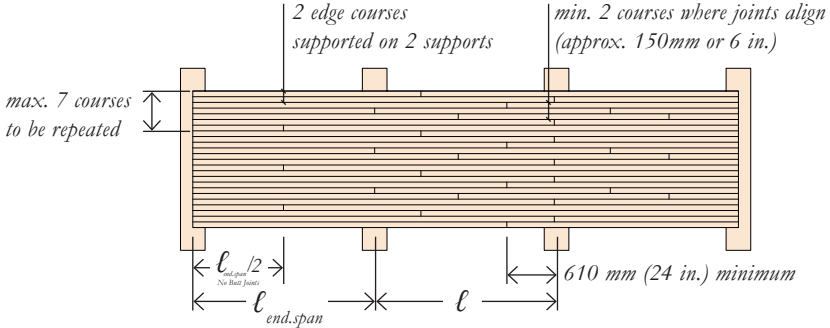
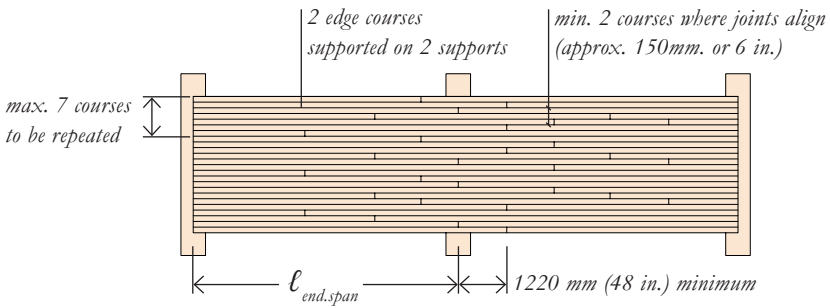
Butt jointing laminations between supports is a common approach to reduce the cost of NLT, because it permits use of a variety of lumber lengths. However, these modified layups result in reduced strength and stiffness that must be accounted for in design.

Table 4.1 provides a number of layup types and the associated modification factors for bending strength and stiffness. These factors provide a simplified way to account for stress redistribution between the laminations. Some have been derived based on CSA O86 Table 6.5.11.4 others are based on European research [1], [2], [3].



Above Orchard Commons, Vancouver, BC. Architecture: Perkins+Will. (Photo credit: Michael Elkan)

TABLE 4.1 NLT LAYUP TYPES AND ADJUSTMENT FACTORS

| LAYUP TYPE | |
|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Laminations continuous and single span |  |
| Laminations continuous and multi-span |  |
| Laminations with controlled random butt joints over 4 or more supports |  |
| Laminations with controlled random butt joints over fewer than 4 supports |  |

| ADJUSTMENT FACTOR | | NOTES |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BENDING STRENGTH ($K_{layup,B}$) | STIFFNESS ($K_{layup,E}$) | |
| $K_{layup,B} = 1.0$ $M = \frac{w\ell^2}{8}$ | $K_{layup,E} = 1.0$ $\Delta = \frac{5w\ell^4}{384E (d^3/12)}$ | <p>Maximum bending strength for a given depth. Typical maximum length for laminations of 5 to 6 m (16 to 20 ft.). Longer laminations can be fabricated with NLGA SPS 1 finger joints.</p> |
| $K_{layup,B} = 1.0$ $M = \frac{w\ell^2}{8}$ | $K_{layup,E} = 1.0$ $\Delta = \frac{w\ell^4}{185E (d^3/12)}$ | <p>Maximum bending strength and stiffness for a given depth. Typical maximum length for laminations of 5 to 6 m (16 to 20 ft.). Longer laminations can be fabricated with NLGA SPS 1 finger joints.</p> |
| $K_{layup,B} = 0.80$ $M = \frac{w\ell^2}{10}$ | $K_{layup,E} = 0.69$ $\Delta = \frac{0.0069w\ell^4}{E (d^3/12)}$ | <p>Maximum stiffness for a butt-jointed system. Rules for joint locations are given in CSA O86 Clause 6.5.11.3.2 and Table 6.5.11.4, and illustrated in the adjacent figure.</p> |
| $K_{layup,B} = 0.29 \frac{(\ell/d)^{1/4}}{s^{1/9}} \quad M = \frac{w\ell^2}{8}$ <hr/> <div style="display: flex; justify-content: space-between;"> <div> $K_{layup,E} = \frac{(\ell/d)^{3/10}}{12s^{1/5}}$ </div> <div> <p>for single span:</p> $\Delta = \frac{5w\ell^4}{384E(d^3/12)}$ <p>for double span:</p> $\Delta = \frac{w\ell^4}{185E(d^3/12)}$ </div> </div> | | <p>Based on European research [2][3][4], rules for joint locations per CSA O86 should be amended as follows:</p> <p>Where butt joints occur in the same general line, they must be separated by a minimum of three intervening laminations.</p> <p>Each lamination must extend over a minimum of one support.</p> <p>See Section 4.3.1 for minimum nailing requirements.</p> |

Where:

d = NLT depth

E = modulus of elasticity

ℓ = span

s = nail spacing in direction of span, in millimeters

w = uniformly distributed line load

Use consistent units, except where specific units are noted.

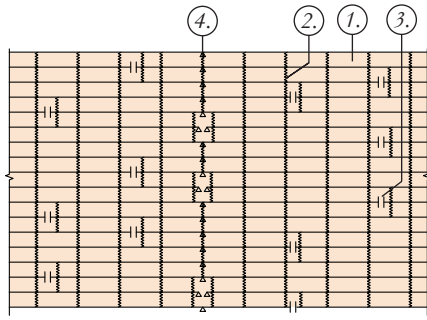


Figure 4.2: *Grillage Model*

Key

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 pinned supports at each lam)

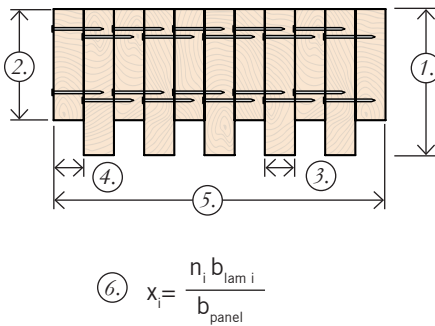


Figure 4.3: *Staggered NLT Cross-Section*

Key

1. NLT deep lamination depth (d_1)
2. NLT shallow lamination depth (d_2)
3. NLT deep lamination thickness (b_{lam1})
4. NLT shallow lamination thickness (b_{lam2})
5. NLT panel width (b)
6. Ratio of lamination depths (x_i), where n_i = the number of laminations of depth d_i

Additional layup types are also possible; options such as combination simple/two-span and mixed cantilever are described in the American Wood Council's publication on Tongue & Groove Roof Decking [4]. For these layouts and others not addressed here, or where the requirements noted are not met, appropriate modification factors can be developed through a finite element analysis using a grillage model. Figure 4.2 is an illustration of a grillage model, where the laminations, modelled as beam members, are 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 [1], Kramer [2], and Haller [3].

Cross-Section Factor (K_{section})

Staggered NLT cross-sections can 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. In some cases, staggered NLT can also be used to accommodate venting as discussed in Chapter 5.

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 capacity. Summing the capacity of all the laminations (deep and shallow) is therefore not conservative. Instead, when the deeper lams reach their full capacity, only a portion of the shallower lams' strength is engaged, based on their relative stiffnesses. The section strength and stiffness can be determined based on flat NLT of full depth (d_1) modified in accordance with Table 4.2. For NLT using more than two lamination depths, the shallowest laminations, with the smallest contribution, can be ignored, or a similar approach based on relative stiffnesses can be developed.

TABLE 4.2 STAGGERED NLT ADJUSTMENT FACTORS

| STIFFNESS ($K_{\text{SECTION.E}}$) | BENDING ($K_{\text{SECTION.B}}$) | SHEAR ($K_{\text{SECTION.V}}$) |
|---------------------------------------------------------------------|---------------------------------------------------------------------|----------------------------------|
| $K_{\text{section.e}} = X_1 + X_2 \left[\frac{d_2}{d_1} \right]^3$ | $K_{\text{section.b}} = X_1 + X_2 \left[\frac{d_2}{d_1} \right]^3$ | $K_{\text{section.v}} = X_1$ |

Note that 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 ”).

The factor provided for shear strength is simplified to account only for the deeper laminations. This approach is conservative, but shear rarely governs the design.

4.1.2 Strength

Strength design of NLT floors and roofs is based on CSA O86 provisions for bending moment resistance, shear resistance, and compressive resistance perpendicular to grain (bearing).

Bending Moment

Design NLT for bending using CSA O86 provisions, ensuring the factored bending moment (M_p) is less than the factored bending moment resistance ($M_{r,NLT}$). Determine the bending capacity in accordance with CSA O86 Clause 6.5.4.1 modified by additional factors to account for layup type (K_{layup}) and cross-section type ($K_{section}$) as described in Section 4.1.2.

$$M_{r,NLT} = \phi F_b S K_{zb} K_L K_{layup,b} K_{section,b}$$

Shear

Shear rarely governs the design of uniformly loaded NLT, but a review of the design approach is provided for completeness. Design NLT for shear forces using CSA O86 provisions, ensuring the factored shear force (V_p) is less than the factored shear resistance ($V_{r,NLT}$). For shear design of NLT with controlled random butt joints, calculate shear at interior supports as if all laminations are continuous multi-span, and calculate shear at exterior supports as if all laminations are single-span. Determine the shear capacity in accordance with CSA O86 Clause 6.5.5.2 modified by an additional factor to account for cross-section type ($K_{section}$) as described in Section 4.1.2.

$$V_{r,NLT} = \phi F_v (2/3) A_n K_{zv} K_{section,v}$$

Design NLT with notches in accordance with CSA O86 Clause 6.5.5.3 modified by an additional factor to account for cross-section type ($K_{section}$) as described in Section 4.1.2.

$$V_{r,NLT} = \phi F_v A_g K_n K_{section,v}$$

Bearing

Bearing rarely governs the design of uniformly loaded NLT. Design NLT for bearing using CSA O86 provisions, ensuring the factored bearing force (Q_p) is less than the factored compressive resistance ($Q_{r,NLT}$) of the NLT perpendicular to grain. 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.

$$Q_{r,NLT} = \phi F_{cp} A_b K_b K_{zcp}$$

4.1.3 Deflections

Analyze NLT deflections using a simplified beam analogy, and compare the results to code-prescribed and/or project-specific limits. Base stiffness properties on specified modulus of elasticity values given in CSA O86 Clause 6, adjusted in accordance with CSA O86 modification factors given in Clause 5.4.1 and additional factors described in Section 4.1.1.

$$EI = E_s K_{layup,E} K_{section,E} \frac{b_{panel} d^3}{12}$$

TABLE 4.3 CREEP FACTORS

| SERVICE CLASS | CREEP FACTOR |
|---------------|--------------|
| 1 | 1.6 |
| 2 | 1.8 |
| 3 | 3.0 |

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 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 wood’s moisture content. CSA O86 addresses long term loading in Clause 5.4.3 but does not provide specific guidance on calculating deflections in sawn lumber due to creep; additional guidance can be found in the US and European wood codes and design standards (National Design Specification for Wood Construction [5] and Eurocode 5 [6], respectively). Eurocode provisions for creep are based on three service conditions rather than simply “wet” and “dry”; they are designated as Service Classes 1-3. Service Class 1 is defined as indoor conditions with low humidity and wood moisture content not exceeding 12%. Service Class 2 is exterior to the building envelope but sheltered from direct rain and snow exposure, and wood moisture content not exceeding 20%. Service Class 3 is direct exposure to the elements and/or high humidity, with wood moisture content of 20% or higher. In each of these cases, elastic deflections due to long-term loads should be multiplied by the factors given in Table 4.3.

Moisture Service Condition

Use NLT only in dry or sheltered service conditions (Service Classes 1 and 2 according to the definitions given in the previous section). Wet service conditions (Service Class 3) will create problems with durability and will impact strength properties and long-term deflections.

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 evaporation 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 7 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. The stiffness of an NLT floor with butt-jointed laminations should be calculated as discussed in Section 4.1.2. Beyond this modification, basic vibration design procedures for NLT are based on loads, mass, damping, and stiffness, similar to any other type of floor system. Discuss vibrations early in the project to determine the end users' expectations and set appropriate design criteria. Limits on vibrations can vary widely, because occupancy and individual sensitivity to vibration impact what a person views as "acceptable."

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.

For any NLT floor with potential vibration concerns, perform a detailed design by calculating maximum accelerations, which are a better performance measure than deflections or frequencies. Pay particular attention to structural

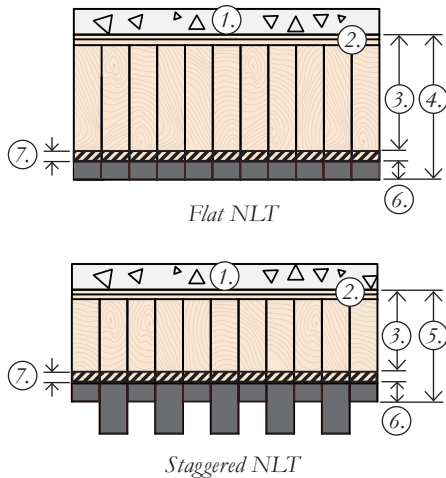


Figure 4.4: Charred NLT Cross-Section

Key

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 shallower lams (d_2)
6. Char depth (x_c)
7. Zero strength layer (x_l)

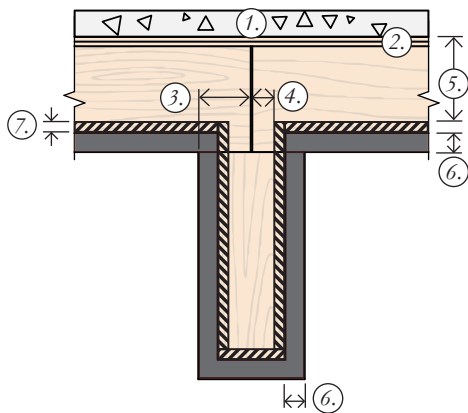


Figure 4.5: Bearing Reduction where Supported on Exposed Charred Timber Beam

Key

1. 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_l)

supports and their effect on the overall performance of the floor. For example, NLT supported on walls will perform better than NLT with the same span supported on beams, because the beams will also contribute to vibrations. Non-structural components such as floor build-ups and partition walls can also have a major influence on performance because of their effects on mass, stiffness, and damping. In the absence of more specific information, a damping value of 3% for bare NLT is a reasonable lower limit, matching the value given for mechanically laminated timber (“Brettstapel”) in the German timber code [7].

CSA O86 Annex A and 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 [8] 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. ISO 10137 [9] provides additional recommendations.

4.1.5 Fire Design

As described in Chapter 3, 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.

In situations where ratings are calculated using char, the char rate should be based on project-specific fire modelling performed by a code or fire consultant. Refer to Section 3.2.2 for discussion of char. After subtracting the depth of the char and zero strength layers, perform strength and stability checks with the revised NLT section depth, illustrated in Figure 4.4.

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.

The layup modification factor for bending strength ($K_{layup,b}$) described in Section 4.1.2 is still applicable for NLT with butt-jointed laminations in the char analysis case. The cross-section modification factor ($K_{section,b}$) need not be applied, however. The post-fire section for staggered NLT is based on the char and zero-strength layer depths calculated for the shallowest lams, as illustrated in Figure 4.4. This simplified approach accounts for the char that occurs on three sides for the portion of the deeper lams projecting below the shallower lams.

If the NLT is supported on an exposed wood member, such as a glued-laminated beam, check bearing based on the reduced bearing length of the NLT as shown in Figure 4.5.

4.2 Lateral Load Design Procedures

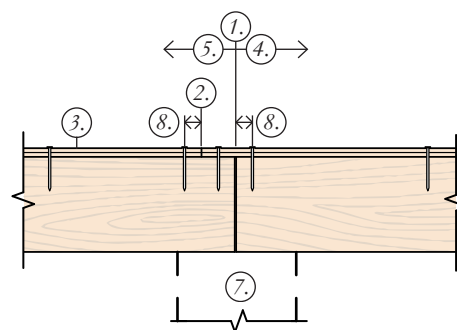
NLT is typically used in floor and roof applications; lateral design for NLT is therefore often limited to providing diaphragm action. Though less common, NLT can also be used for shear walls. In both cases, a separate layer of structure takes in-plane shear loads. Design shear walls and diaphragms based on CSA O86, with additional guidance provided in the following sections.

4.2.1 Diaphragms

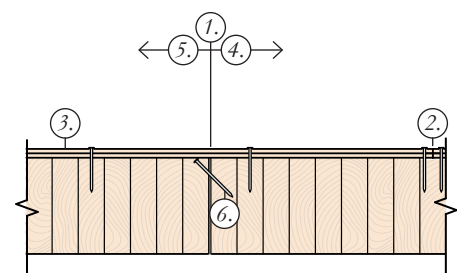
In-plane load transfer across lamination joints is not well understood, nor is the contribution of those joints to the in-plane shear and bending stiffness of NLT. Relying on diaphragm capacities given in CSA O86 for plywood/OSB diaphragms is an appropriate, conservative approach. Generally, the diaphragm can be considered fully blocked. CSA O86 also recognizes diagonal lumber sheathing; this system is more common in historic structures and is not addressed here.

Where over-framing or an inverted staggered cross section is provided to accommodate venting as discussed in Chapter 5, the connection between the plywood/OSB diaphragm and the NLT is provided in only one direction, and the diaphragm should be designed as unblocked. Where additional blocking between the staggered lams or over-framing is provided, a fully blocked diaphragm design is appropriate. Ensure continuity of the load path between the diaphragm and the vertical lateral-resisting elements.

Distributing shear to the vertical lateral-resisting elements is more complex than for typical joist floors. The connections between laminations likely create a stiffer diaphragm than a typical plywood/OSB diaphragm, but calculating a semi-rigid diaphragm stiffness is difficult to do accurately; the analysis will be highly sensitive to assumptions about nail stiffness and load transfer between laminations. A simplified approach to determine load distribution is to perform two separate analyses, one assuming flexible diaphragms and one assuming rigid diaphragms. A full envelope design (taking the worst case from both analyses) may be overly conservative; use engineering judgment to determine final design forces.



Panel Joint Perpendicular to NLT Span



Panel Joint Parallel to NLT Span

Figure 4.6: Prefabricated NLT Panel Sheathed On-Site

Key

1. NLT panel joint location
2. Plywood/OSB panel joint location with panel edge nailing
3. Field-installed plywood/OSB diaphragm with intermediate 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 per CSA O86

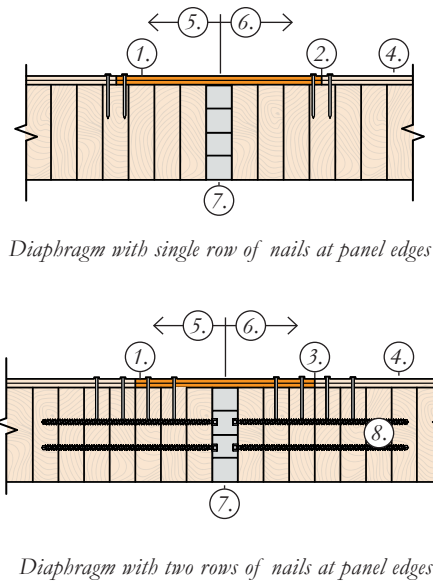


Figure 4.7: Prefabricated Pre-Sheathed Panels

Key

1. Field-installed Plywood/OSB
2. Plywood/OSB splice location with single row panel edge nailing
3. Plywood/OSB splice location for diaphragm 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

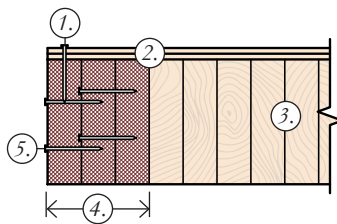


Figure 4.8: Effective Discrete Chord Element

Key

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

Plywood/OSB

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, the plywood/OSB panel joints parallel to the direction of the NLT span should always be centred on an individual lamination to allow for proper load transfer across the joint, as shown in Figures 4.6 and 4.7. Where multiple rows of fasteners are required at panel edges and boundaries, the NLT laminations must have sufficient nailing to transfer the shear load across the joint. A simple approach is to provide equal 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. 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 4.7.

Chords and Collectors

Similar to the approach for light-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 Clause 11.8.6; however, the forces need not exceed those determined using an $R_d R_o$ of 1.3. The tension and compression forces in these chords and collectors can be resisted in a number of 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.¹ 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 in a given load combination; use the modification factors outlined in Section 4.1.1. This approach requires careful consideration of load transfer across the lamination joints within the discrete chord element, as shown in Figure 4.8.

The design of NLT chords in the direction of the NLT span is relatively straightforward. Design individual laminations as tension or compression elements, laterally restrained about the lamination weak axis (i.e. slenderness factor $K_c=1.0$). Ensure the factored chord force is less than the individual

¹ This approach ignores the potential contribution of laminations further inward and therefore is conservative, but a pure linear elastic stress distribution in the NLT laminations would be inaccurate. Load transfer from the sheathing to the laminations occurs at discrete locations, primarily at the plywood/OSB panel edges, rather than uniformly across the full diaphragm.

lamination factored resistance developed in accordance with CSA O86 Clauses 6.5.6 (compression) and 6.5.9 (tension).

If the outermost single lamination does not meet the strength requirements, spread the load among multiple laminations as required. In such cases, ensure the laminations are sufficiently nailed together and nailed to the plywood/OSB, as shown in Figure 4.8. A simple approach is to provide equal nailing between the edge laminations to that provided in the plywood/OSB at the diaphragm boundary. Compression force transfer across the lamination butt joints is provided by direct end-grain bearing. Transferring tension across a 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. Consider using light-gauge steel straps as a simpler approach.

For chords perpendicular to the direction of the NLT span, one option is to provide a rim board to take both the tension and compression forces. Where a single rim board does not provide sufficient tension strength, consider using light-gauge steel straps. Where a single rim board does not provide sufficient compression strength, another option is to resist the force with perpendicular-to-grain bearing in the NLT laminations. Calculate the width required to resist the compression force in accordance with CSA O86 Clause 6.5.7, and evaluate the result for reasonableness. Widths of over 150 mm (6 in.) may result in excessive crushing at the extreme edge of the diaphragm. Relying on a rim board or perpendicular-to-grain bearing to resist chord forces increases the flexibility of the diaphragm, which must be considered in accordance with CSA O86 Clause 11.7.2. Chord-splice slip values must be accounted for; in the case of perpendicular-to-grain bearing, the elastic modulus is much lower than that for parallel-to-grain loading.

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.

4.2.2 Shear Walls

NLT is not as commonly used for walls but can be designed as a vertical lateral-resisting element. Similar to diaphragms, lateral capacity is provided by plywood/OSB, which can be applied to either side of the wall. Follow the approach provided in CSA O86 Clause 11 for blocked shear walls; special detailing may be required to accommodate hold-down connections.



Above Mountain Equipment Co-op Head Office, Vancouver, BC. Architecture: Proscenium Architecture+Interiors. (Photo credit: Ed White Photographics)

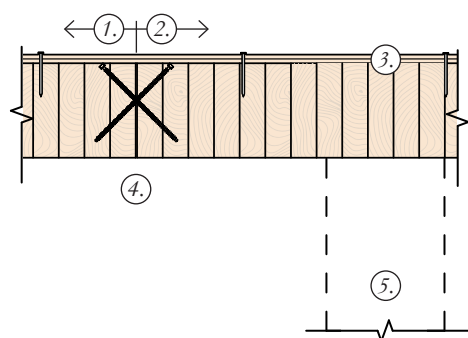


Figure 4.9: Prefabricated NLT Panels with Varying Support Conditions

Key

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

4.3 Connections

A complete NLT design includes details and specifications for connections, both within the NLT and from the NLT to its supports.

4.3.1 NLT Connections

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 vertical shear transfer, forces the laminations to deflect equally, and pulls the laminations tight together. Recommended nailing for NLT fabricated with 2x lamination stock (38 mm [1-1/2 in.] actual thickness) is provided in Table 4.4 and Figure 4.10.

TABLE 4.4 MINIMUM LAMINATION NAILING

| NLT TYPE | NLT DEPTH | NAILING PATTERN | |
|----------------------------|-------------------------------------|---------------------------------------------------------|---------------------------------------------------------|
| | | 76 MM (3 IN.) LONG, 3.76 MM (0.148 IN.) DIAMETER NAILS* | 76 MM (3 IN.) LONG, 3.33 MM (0.128 IN.) DIAMETER NAILS* |
| Continuous Laminations | Up to 140mm (6 in. nominal) | One row at 450 mm (18 in.) o.c., staggered | |
| | Greater than 140 mm (6 in. nominal) | Two rows at 450 mm (18 in.) o.c., staggered | |
| Butt-Jointed Laminations** | Up to 140mm (6 in. nominal) | One row at 175 mm (7 in.) o.c., staggered | One row at 125 mm (5 in.) o.c., staggered |
| | Greater than 140mm (6 in. nominal) | Two rows at 350 mm (14 in.) o.c., staggered | Two rows at 250 mm (10 in.) o.c., staggered |

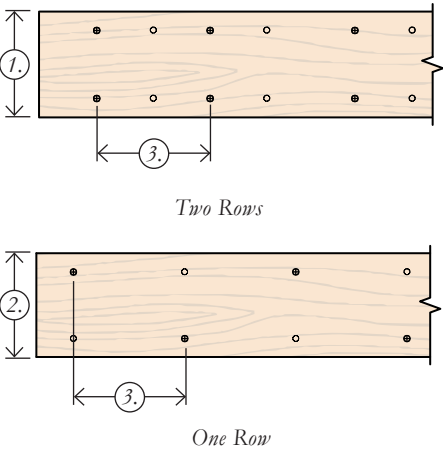
*Nails are smooth shank galvanized steel nails.

**Provide two additional nails on each side of every butt joint.

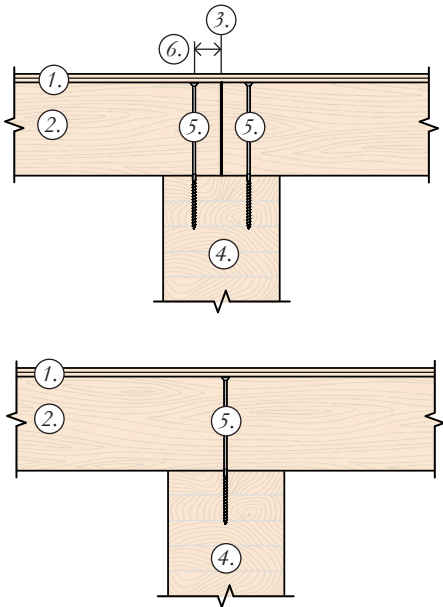
The use of 76 mm (3 in.) nails for 2x laminations is a departure from CSA O86 Clause 6.5.11.3.1, which requires 102 mm (4 in.) nails at 450 mm (18 in.) spacing in either one or two rows, depending on the lamination depth.² These nailing requirements are difficult or impossible to meet with standard pneumatic nailers, which are commonly used to fabricate NLT. If required by the authority having jurisdiction, the nail sizes and patterns proposed in Table 4.4 and Figure 4.10 can be presented for approval on an engineering judgment basis.

For butt-jointed NLT, the structural purpose of the nails is to share vertical 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 continuous NLT, where all the lams are self-supporting, 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 4.10: Lamination Nailing****Key**

1. >140 mm (6 in. nominal)
2. ≤ 140 mm (6 in. nominal)
3. Nailing spacing
 - Nailing in face layer
 - Nailing in layer beyond

**Figure 4.11: NLT Connections to Wood Beam****Key**

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

² Nailing every course is required to meet the standard intent.

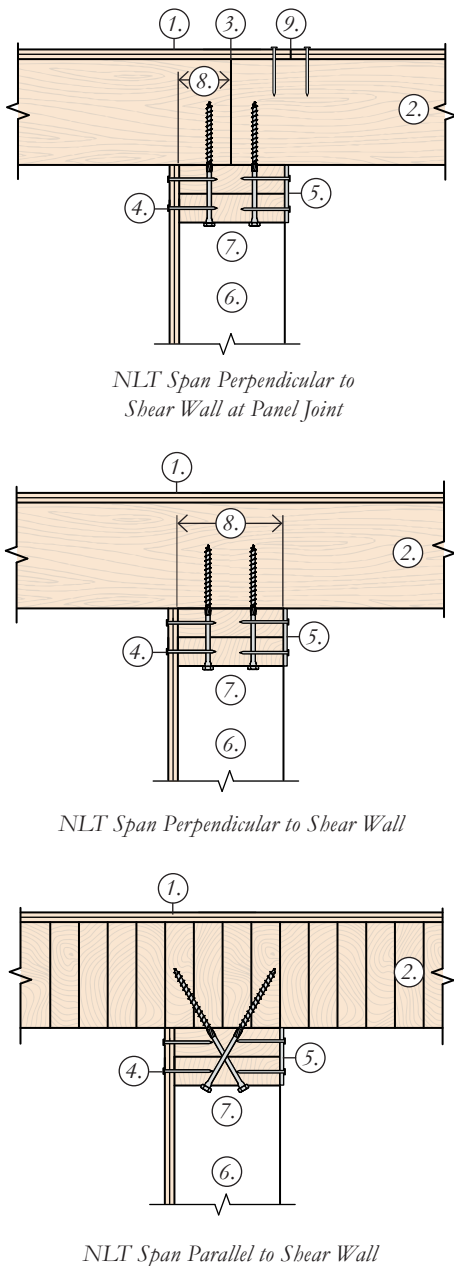


Figure 4.12: NLT Connection to Interior Wood Shear Walls

Key

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 plate to NLT
8. NLT bearing length
9. Diaphragm plywood/OSB sheathing joint with diaphragm nailing

Panel-to-Panel Connections

For prefabricated NLT, panel-to-panel connections are provided by the plywood/OSB. In order to maintain diaphragm continuity and in-plane shear transfer, plywood/OSB joints must be located a sufficient distance from NLT panel splices. For plywood/OSB joints parallel to the NLT span, the distance must also be sufficient to prevent differential gravity deflection between NLT panels. Refer to Figures 4.6 and 4.7 for examples of panel-to-panel connections.

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 a 38 mm (1-1/2 in.) gap (one lam) approximately every 6 m (20 ft.), as shown in Figure 4.7. After the building is operational and the NLT reaches its equilibrium moisture content, as discussed in Chapter 7, the gap can be filled if desired for aesthetics or to maintain fire separation between floors, as discussed in Chapter 3. Alternatively, if larger gaps in the NLT are being provided for sprinklers, electrical, or mechanical services, these gaps can be used to accommodate swelling.

For prefabricated NLT panels, support conditions may create discontinuities in deflection between adjacent panels. In such cases, additional panel-to-panel connections should be provided 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. For example, one panel could be clear spanning 5 m (16 ft.) while the adjacent panel could be supported on wood stud walls every 1.2 m (4 ft.) for 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 4.9, the adjacent unsupported panel will experience a larger deflection unless the two panels are tied together.

4.3.2 Support Connections

Detailing of 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.

Gravity 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 toenail requirements are given in CSA O86 Clause 6.5.11.3.1. Prefabricated NLT panels, however, cannot be toenailed. One common approach is to provide partially threaded self-tapping screws through the NLT into the support beams, as shown in Figure 4.11. Alternately, at steel beam supports, provide screws up through the steel top flange into the NLT from below, as shown in Figure 4.13. 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. Design support connections at minimum to provide equal lateral strength, shear stiffness, and withdrawal capacity to the CSA O86 toenail requirements, 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 in withdrawal, subject to the minimum requirements listed previously. If beams are used as drag elements, design the screws to transfer the necessary forces into the beam.

Shear Walls

Where NLT is continuous over a wood shear wall below, the lateral load path between the plywood/OSB and the shear wall must pass through the NLT lams. Typical connections where NLT passes over an interior shear wall are shown in Figure 4.12. Connections between NLT and perimeter walls are shown in Figure 4.14. For interior shear walls, provide screws from the underside of the top plate through the NLT. Similar to connections at beams, the screws should either be 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. Where drag elements are required beyond the wall, use the same approach discussed for chords and collectors in Section 4.2.1.

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, similar to any typical light-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.

In cases where a perimeter shear wall continues past the NLT (balloon frame), wood ledgers are an option, as shown in Figure 4.15. Provide a ledger connection to the shear wall designed for full transfer of the gravity and shear forces with either

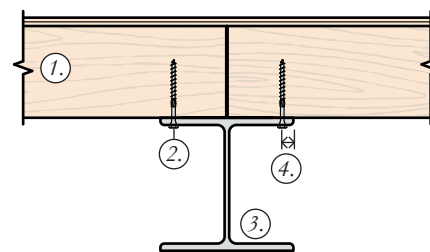
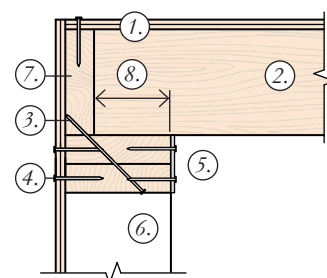


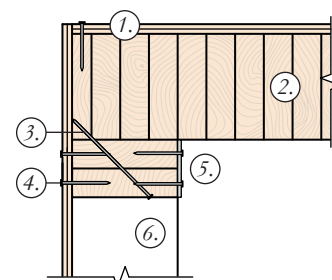
Figure 4.13: NLT Connection to Steel Beam

Key

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



NLT Span Perpendicular to Shear Wall



NLT Span Parallel to Shear Wall

Figure 4.14: NLT Connection to Exterior Wood Shear Wall

Key

1. Diaphragm plywood/OSB sheathing
2. NLT
3. Toenail 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

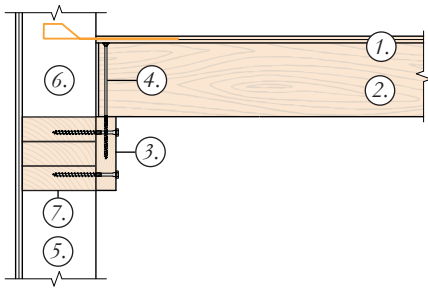


Figure 4.15: NLT Support at Balloon-Framed Wood Shear Wall

Key

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

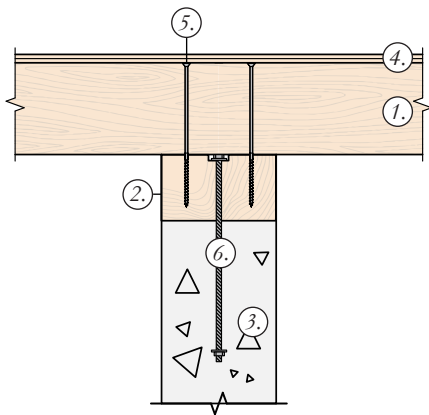


Figure 4.16: NLT Connection to Concrete Wall

Key

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

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.

For NLT connecting to a concrete wall, install a continuous wood ledger at the top of the wall. For site-built NLT which is toenailed 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 4.16.

4.4 Additional Design Considerations

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

4.4.1 Point Loads

Point loads on NLT will be shared by multiple laminations but must be checked independently from uniform loads. Based on the authors' engineering judgment, a reasonable lower limit for the effective width of NLT resisting a point load is 300 mm (12 in.), which accounts for load spreading throughout the section depth plus 1-2 additional laminations on each side being engaged by the nails. If the actual width of the load plus half the NLT depth ($d/2$) on each side is greater than 300 mm (12 in.), use this larger dimension. 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.

4.4.2 Openings

NLT is a one-way system, which means that openings often require additional analysis and reinforcement. Based on the authors' engineering judgment, this Guide defines small openings as 228 mm (9 in.) wide or less (up to 6 laminations for NLT fabricated from 2x material); other openings are considered large.

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

Small cores up to 76 mm (3 in.) diameter, such as for conduit or small pipes, can often be accommodated without reinforcement. For larger openings up to 228 mm (9 in.) wide, provide reinforcement with fully threaded self-tapping screws or supplementary steel framing.

Fully threaded self-tapping screw reinforcement is a simple way to transfer shear around an opening. Installing screws at a 45-degree angle allows the screws to act primarily in withdrawal, which is a stiffer and stronger load path than the screws acting in shear. Design each screw for the appropriate withdrawal force associated with the lamination it supports. In addition to the “basic” shear from the terminated lams, which is calculated based on design loads, shear is also generated due to imposed deformation. The terminated lams must deflect equally to the adjacent full-length courses, which creates shear proportional to the equivalent uniform load required to deflect the terminated lams the same amount as the continuous courses. In grillage model studies, discussed in Section 4.1.2, the additional shear can be significant. Refer to Figure 4.17 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 manufacturer’s minimum requirements.

Steel reinforcement of small openings, as shown in Figure 4.18, is another option. The steel framing acts as a beam, taking the end reactions from the terminated laminations and spreading them to the adjacent continuous courses. 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. 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 4.18. 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 80% of the NLT depth. Alternately, Figure 4.18 (right) shows a steel channel supporting the terminated lams through a simple bearing connection with nominal screws provided. For this approach, the terminated lams are supported by partially threaded self-tapping screws installed through the horizontal leg and centred 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.

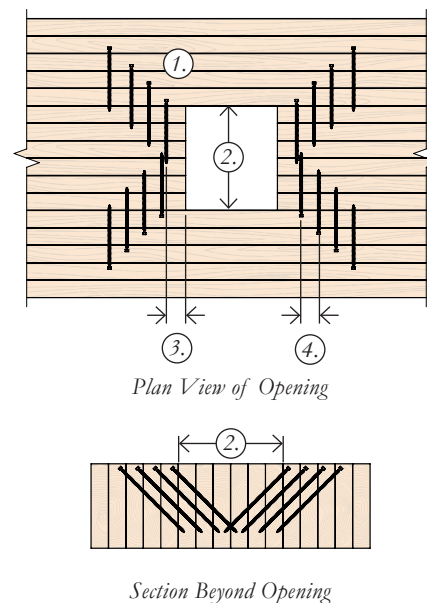


Figure 4.17: *Small Opening with Fully Threaded Screw Reinforcing*

Key

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

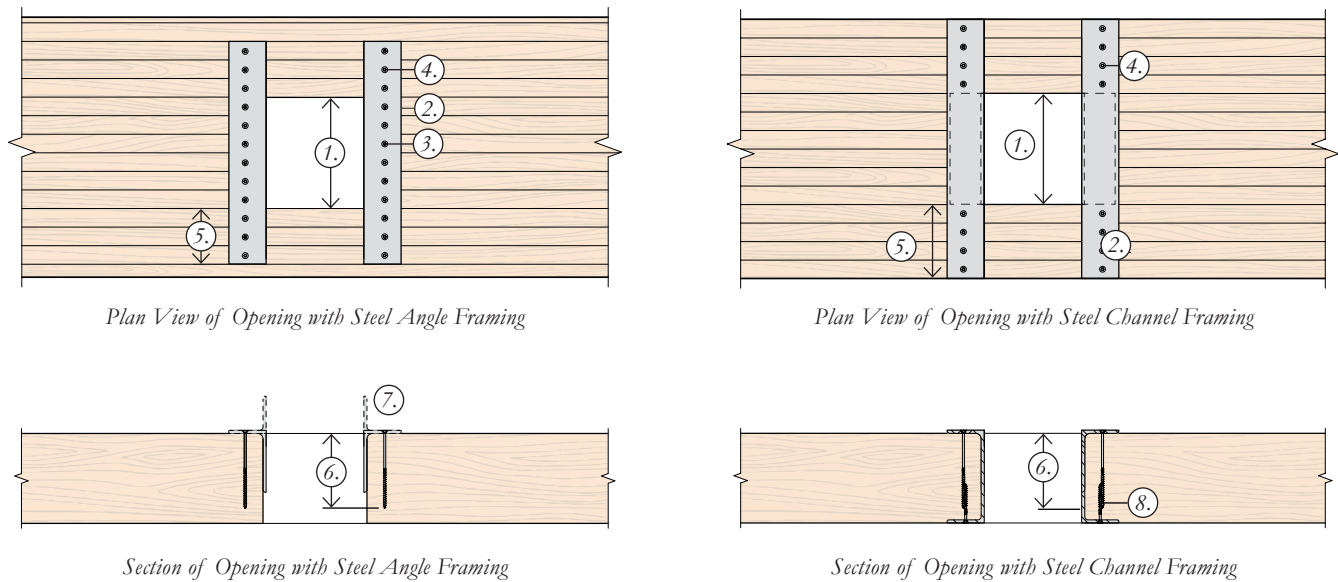


Figure 4.18: *Supplementary Steel Framing at Small Openings*

Key

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

Large Openings (Greater than 228 mm [9 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 4.19. 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 lams can be detailed similar to those for small openings.

4.4.3 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, similar to the screw-reinforced openings shown in Figure 4.17. Based on the authors' engineering judgment, a weak-axis cantilever of 228 mm (9 in., six lams for 2x material) 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 further in Chapter 5, best practice is to extend the enclosure to encapsulate the overhang. However, this strategy does not allow the NLT to remain exposed, which is often desirable for aesthetic reasons. In cases such as these, ensure enclosure 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 4.20.

Providing sealant between each lam 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. Although preferable from a structural strength and stiffness perspective, this strategy will create a “bulge” in the NLT at the enclosure line. Products are available with less than 3 mm (1/8 in.) thickness, but even these will add up. 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 NLT is hung from outriggers using self-tapping screws, as shown in Figure 4.20, 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 4.20. 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.

4.5 Specifications

NLT does not have an accepted standard for production, so project specifications must help address this gap. The raw material is standardized via the National Lumber Grades Authority (NLGA), and some requirements for assembly (such as nailing and butt joint locations) are contained in CSA O86, but these standards are not sufficient to ensure proper quality control on NLT projects. Issue stand-alone NLT specifications as a complete resource for the fabricator and contractor teams. In particular, require the general contractor to submit a weather protection plan appropriate to the local

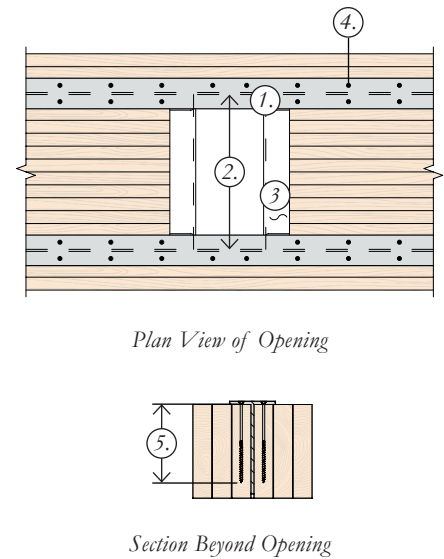


Figure 4.19: Supplementary Steel Framing at Large Openings

Key

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 of 80% of NLT depth

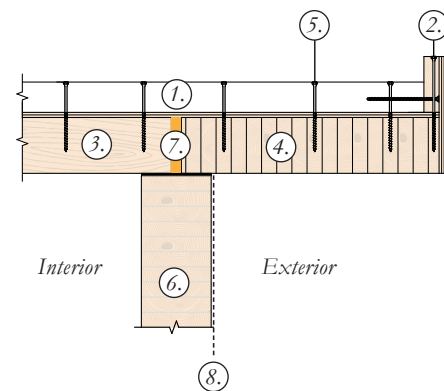


Figure 4.20: Wood Outrigger Supports for NLT Overhang

Key

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/vapor barrier
8. Building enclosure

climate and the specific project. Also outline all requirements for samples, mock-ups, and site review.

Refer to Appendix B for a sample NLT specification section. This section is intended for projects with prefabricated NLT panels but can be adapted for site-built NLT.

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Above Tsingtao Pearl Visitor Centre, Qingdao, China. Architecture: Boblin Cywinski Jackson. (Photo credit: Nic Lebourg)



Above Pitt River Middle School, Port Coquitlam, BC. Architecture: Perkins+Will. (Photo credit: Latreille Delage Photography)

5 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. The design must account 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. Careful consideration of enclosure interfaces and transitions is critical.



In This Chapter

- 5.1 Managing Heat-flow*
- 5.2 Air-flow*
- 5.3 Water Vapour Transport*
- 5.4 Liquid Water*

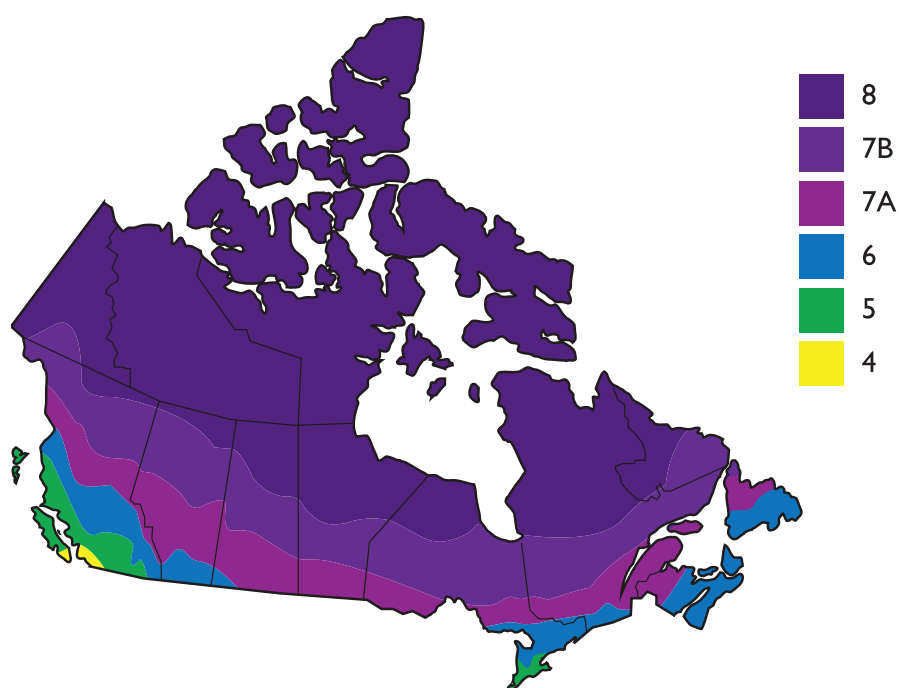


Figure 5.1: *Climate Zones Across Canada based on NECB 2015 Heating Degree Days [1]*

5.1 Managing Heat-flow

Managing heat-flow across the enclosure is important to reduce energy consumption, minimize condensation risk, and increase occupant thermal comfort. The National Energy Code of Canada for Buildings [1] or project-specific energy targets will dictate the required thermal resistance (R-values) or thermal transmittance (U-factors) for the enclosure assemblies. For horizontal 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; the thermal insulation, other enclosure layers and surface air films all provide resistance to heat flow. The overall effect is minimal in well insulated buildings.

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. Where the NLT lamination species is unknown, the thermal conductivity and thermal resistance per thickness may be approximated as $0.115 \text{ W/m}^2\text{K}$ ($0.8 \text{ Btu-in/h-ft}^2\text{-}^\circ\text{F}$) and $\text{RSI-}0.0087/\text{mm}$ ($\text{R-}1.25/\text{inch}$), respectively [2].

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 modeling exercises performed for CLT, a mass timber product of similar mass [3].

To meet the minimum insulation R-value or maximum assembly U-factor requirements of the NECB [1] provisions, thermal insulation is usually required with NLT. In all climate zones, it is best practice to locate the thermal insulation of NLT assembly on the outboard 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. Placing insulation on the outside also allows the NLT to remain exposed on the interior as discussed in Chapter 2.

TABLE 5.1 THERMAL CONDUCTIVITY AND RESISTANCE VALUES OF COMMON NLT SOFTWOOD LAMINATIONS AND SHEATHING

| A. THERMAL CONDUCTIVITY VALUES FOR COMMON NLT SOFTWOOD SPECIES | | |
|-----------------------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------------------------------------------|
| SPECIES | THERMAL CONDUCTIVITY W/mK (Btu-in/hft ² °F) | THERMAL RESISTANCE - RSI/MM (R/INCH) m ² K/W (ft ² °Fhr/Btu) |
| Spruce-Pine-Fir | 0.12 (0.82) | 0.0085 (1.22) |
| Douglas Fir-Larch | 0.15 (1.01) | 0.0069 (0.99) |
| Hemlock-Fir | 0.12 (0.83) | 0.0084 (1.21) |

| B. TYPICAL NLT LAMINATION R-VALUES | | |
|-------------------------------------------|------------------------------------------|-------------------------------------------------------------------------------------|
| WOOD LAMINATION NOMINAL DIMENSION | ACTUAL THICKNESS MILLIMETERS (INCHES) | THERMAL RESISTANCE – RSI (R-VALUE) m ² K/W (ft ² °Fhr/Btu) |
| 2x4 | 89 (3.5) | 0.61-0.75 (3.5-4.3) |
| 2x6 | 140 (5.5) | 0.97-1.18 (5.4-6.7) |
| 2x8 | 184 (7.25) | 1.26-1.56 (7.2-8.8) |
| 2x10 | 235 (9.25) | 1.61-1.99 (9.2-11.3) |

| C. TYPICAL SHEATHING R-VALUES | | | |
|--------------------------------------|------------------------------------------------------------------|--------------------------------------|-------------------------------------------------------------------------------------------|
| SHEATHING TYPE | RSI/MM (R/INCH) m ² K/W (ft ² °Fhr/Btu) | THICKNESS MILLIMETERS (INCHES) | THERMAL RESISTANCE - RSI (R-VALUE) m ² K/W (ft ² °Fhr/Btu) |
| Plywood – Douglas Fir | 0.0111 (1.6) | 13 mm (1/2) | 0.14 (0.82) |
| | | 16 mm (5/8) | 0.18 (1.0) |
| | | 19 mm (3/4) | 0.21 (1.2) |
| OSB | 0.0098 (1.4) | 11 mm (7/16) | 0.11 (0.61) |

**All material properties referenced from NECB 2015 Users Guide.*

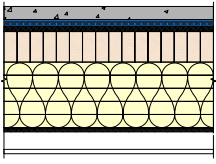
In a circumstance where all or a portion of the thermal insulation is located on the interior side of the NLT, carefully evaluate the assemblies for long-term moisture performance and durability. Table 5.2 describes conventional and inverted roof membrane assemblies commonly used with NLT. Where tapered roof insulation is used, calculating the assembly's effective thermal performance becomes more complex. Refer to RDH Building Science Inc Technical Bulletin No. 005 for additional discussion for effective R-value design tables [4]. 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.

TABLE 5.2 CONVENTIONAL ROOF MEMBRANE ASSEMBLIES

| CONVENTIONAL ROOF MEMBRANE ASSEMBLIES | | | |
|---------------------------------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | DETAILS | TYPICAL ASSEMBLY LAYERS (TOP TO BOTTOM) | ASSEMBLY CONSIDERATIONS |
| Sloped Over-Framing | | Roof membrane Coverboard Rigid insulation Air/vapor control membrane/TMMS Structural Plywood/OSB Sloped over-framing, Air cavity, vented to interior. (Refer to section 5.4.1) NLT Roof support (beyond) | <p>The air and vapor control membrane may also serve as a temporary moisture management system (TMMS), as further discussed in Section 7.6. Carefully consider the vapor permeance of all assembly layers relative to the NLT and interior/exterior environmental conditions.</p> <p>The air and vapor control membrane is an applied membrane and exists on the warm side of the insulation.</p> |
| Tapered insulation | | Roof membrane Coverboard Tapered rigid insulation Air/vapor control membrane/TMMS Structural Plywood/OSB NLT Roof support (beyond) | |
| Sloped Structure | | Roof membrane Coverboard Rigid insulation Air/vapor control membrane/TMMS Structural Plywood/OSB NLT Sloped roof support (beyond) | |

| INVERTED ROOF MEMBRANE ASSEMBLIES | | | |
|-----------------------------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | DETAILS | TYPICAL ASSEMBLY LAYERS (TOP TO BOTTOM) | ASSEMBLY CONSIDERATIONS |
| Sloped Over-Framing | | Overburden/ballast Extruded polystyrene insulation Drainage composite Roof membrane/TMMS Structural Plywood/OSB Sloped over-framing Air cavity, vented to interior NLT Structural support (beyond) | <p>The roof membrane and TMMS may be the same assembly component where they occur within the same location in the assembly. Some structural sheathing substrates or TMMS (where separate from the 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.</p> <p>Carefully consider the vapor permeance of all assembly layers relative to the NLT and interior/exterior environmental conditions.</p> <p>The fully adhered roof membrane typically serves as the primary air and vapor control membrane.</p> |
| Tapered Insulation | | Overburden/ballast Extruded polystyrene insulation Drainage composite Roof membrane Coverboard Tapered rigid insulation Air/Vapor Control Membrane/TMMS Structural Plywood/OSB NLT Structural support (beyond) | |
| Sloped Structure | | Overburden/ballast Extruded polystyrene insulation Drainage composite Roof membrane/TMMS Structural Plywood/OSB NLT Structural support (beyond) | |

TABLE 5.3 EXTERIOR SOFFIT ASSEMBLIES

| FLOOR/SOFFT ASSEMBLY | | | |
|--------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | DETAIL | TYPICAL ASSEMBLY LAYERS (TOP TO BOTTOM) | ASSEMBLY CONSIDERATIONS |
| Air Permeable Insulation |  | Interior finish and acoustic components TMMS Structural Plywood/OSB (air control layer) NLT Air-permeable or -impermeable thermal insulation (between structure beyond) Air barrier membrane (vapor-permeable water-resistive barrier membrane optional) Furring and vented cavity Exterior vented soffit panel | <p>The preferred air control layer of 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. In smaller soffit applications, the air control layer may be an air barrier membrane over sheathing at the underside of the soffit.</p> <p>Thermal insulation in this assembly may be batt, rigid board, or spray applied insulation to fit tightly to the structure.</p> <p>A waterproof finish floor coating should be considered where wet conditions or risk of plumbing failures exist at interior space.</p> <p>Carefully consider the vapor permeance of all assembly layers relative to the NLT and interior/exterior environmental conditions.</p> |

5.2 Air-flow

Managing air flow across the building enclosure is a requirement of the National Building Code of Canada (NBC) [5], and is key for reducing energy consumption, increasing thermal comfort, and minimizing the movement of water vapor into an assembly (refer to Section 5.3 for more on managing water vapor 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 has five basic requirements as described by Straube [6]; consider these requirements specific to NLT assemblies as follows:

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 5.3). In a horizontal NLT assembly, this is overcome by providing 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.

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

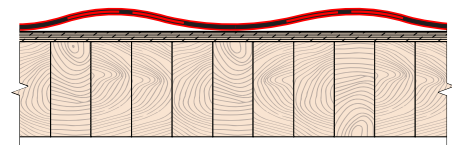


Figure 5.2: *Potential Deformation or Deflection of Air Barrier System from Forces of Air Pressure.*

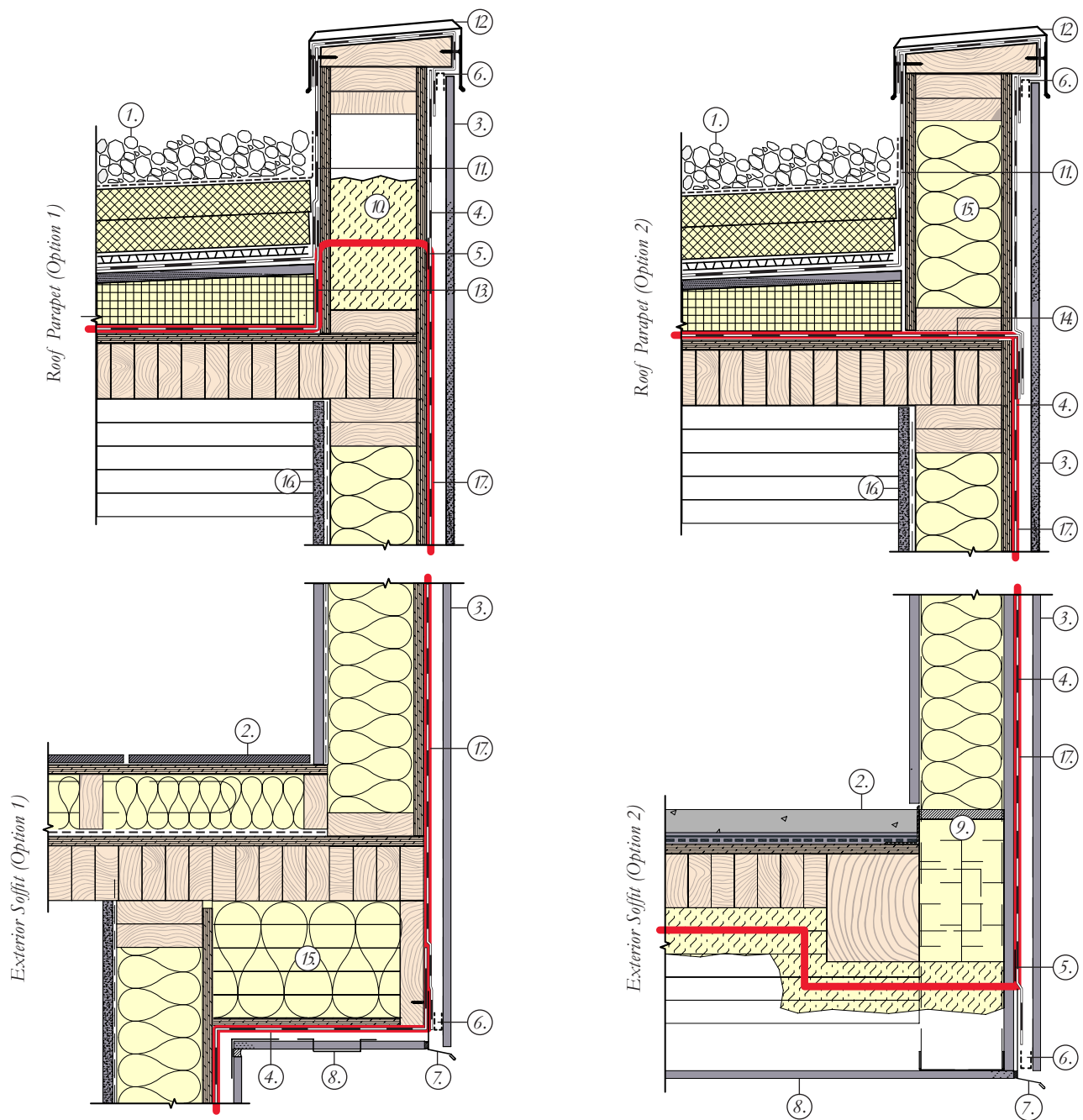


Figure 5.3: Example Horizontal NLT Assembly Details

Key

- | | | |
|-------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| 1. Typical roof assembly - Refer to Table 5.2.2. | 7. Sheet metal drip flashing, shingle lapped by Item 4 | 13. Air/vapor control membrane, upturned at parapet |
| 2. Typical soffit assembly - Refer to Table 5.3.3. | 8. Soffit panel (often vented) | 14. Air/vapor control membrane, continuous under parapet with a sealed lap over Item 4 |
| 3. Typical exterior wall assembly with drained (and often vented) cladding. | 9. Approved smoke seal | 15. Air permeable insulation |
| 4. Water-resistive and air barrier membrane, shingle lapped and continuously taped/sealed | 10. Continuous air impermeable insulation | 16. Drywall |
| 5. Air barrier transition seal | 11. Roof membrane up parapet | 17. Continuous air barrier system. Details may vary by climate zone and building use. |
| 6. Insect screen | 12. Sheet-metal coping over high temperature membrane and sloped treated blocking | |

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.

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. Refer to Figure 5.2 for example details. Where the NLT is part of the air barrier system as shown in Figure 5.4, refer to Section 5.2.1 for guidance on special considerations.

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.

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 indicated in Tables 5.2 and 5.3.

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 5.4. 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). Successfully sealing these gaps for long-term air barrier system performance can be challenging. The protruding NLT shown in Figure 5.4 also creates a thermal bridge at the wall and/or window head that should be considered.

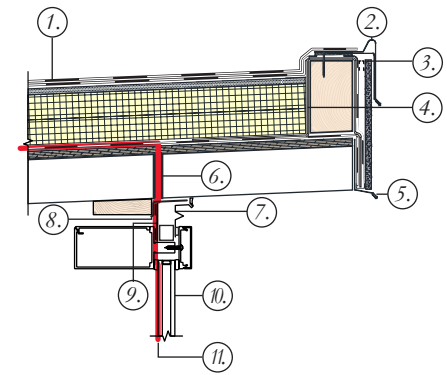


Figure 5.4: Example Horizontal NLT Roof Assembly to Soffit Transition Detail at Window Head

Key

1. Typical roof assembly. Refer to Table 5.2
2. Typical roof termination detail
3. Insect screen
4. Air/vapor control/TMMS membrane
5. Sheet metal flashing with hemmed drip edge
6. NLT panel air seal
7. Sheet metal closure flashing with crimp, sealed to underside of exposed NLT
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.
12. Note: Details may vary on climate zone and building use.

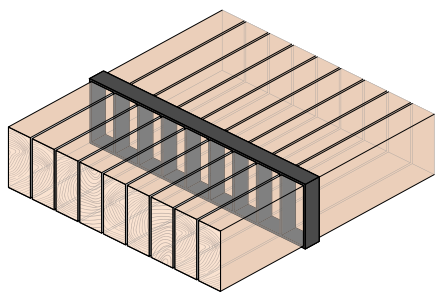


Figure 5.5: *NLT Panel with Preformed Tape*

The air sealing materials used within the Figure 5.4 detail need to withstand mechanical pressures between each layer while maintaining continuity and adhesion throughout shrinkage/swelling (refer to Appendix C). Preformed butyl tape and expanding foam tape products shown in Figure 5.5 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 distort alignment. To maintain straightness and overall uniform panel dimensions, it may be necessary to install tape or shims throughout the NLT. Avoid sealant and spray foam products for air sealing this transition; most of these products 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 transitions, such as the outrigger support concept presented in Section 4.4.3, may be considered. However, the NLT roof and soffit panel interface, as shown in Figure 4.20, 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 discussed in Chapter 4, outrigger support connections can be sensitive to moisture.

5.3 Water Vapour Transport

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 joints as noted in Section 5.2.

To avoid water vapour accumulation within NLT and to ensure 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 5.2 and Table 5.3.

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. 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.

Decay of the NLT lamination and sheathing: decay can impact the serviceability of the NLT lamination and sheathing should prolonged moisture exposure occur.

Accordingly, it is critical to minimize NLT moisture exposure and maintain an NLT moisture content consistent with the in service equilibrium moisture content.

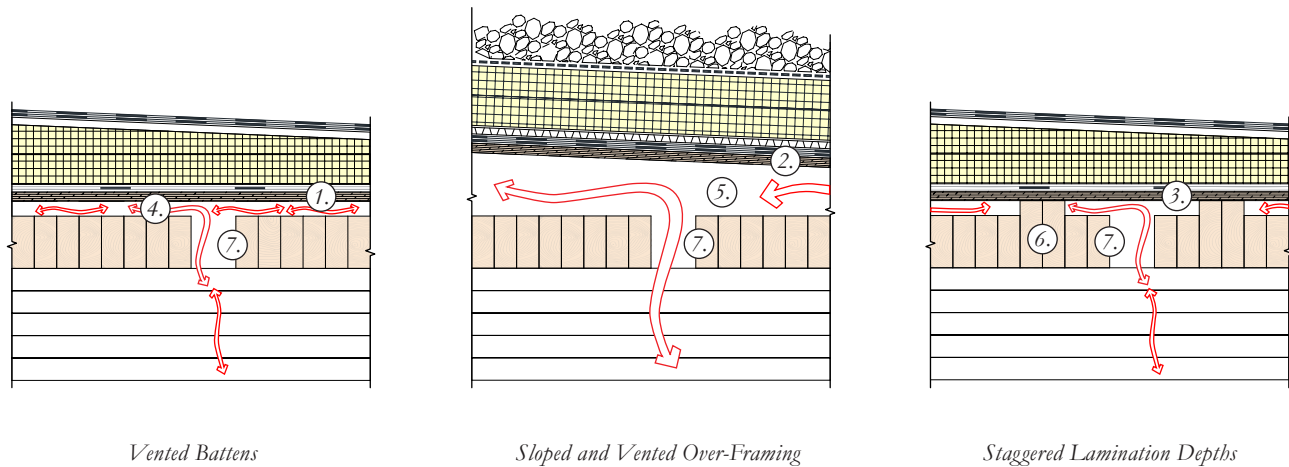


Figure 5.6: *Venting Options for NLT Roof Assemblies**

Key

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

**In all cases venting occurs between the NLT laminations and sheathing and is vented to the building interior.*

Liquid water at the roof is managed by the roof membrane; the location of this membrane and additional considerations are discussed in Tables 5.2 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 7.6). Refer to the local provincial roofing contractors 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 through the use of deflection mechanisms such as base-of-wall sheet-metal flashings as shown in Figure 5.2.

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.

5.4.1 Leak Detection and NLT Venting

Detecting a leak through the roof membrane is difficult because the NLT can absorb moisture, and structural sheathing can further mask the presence of water. The use of a leak detection system within the roof assembly, vented NLT as described in Figure 5.5, or both, can help identify and locate leaks, minimizing the risk of exposing the NLT to long-term moisture and mitigating the associated effort and cost to dry it.

An active electronic leak detection system or vented panel is recommended when a temporary roof membrane over the NLT is not provided, or when a green roof system is used. Locate the leak detection system below the roof membrane or as recommended by the roof manufacturer. Alternatively, consider venting to facilitate drying the topside of the NLT to the interior.

When venting is used, locate the structural plywood/OSB on top of battens or sloped over-framing. 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 7.6. Finally, the air cavity vented to the interior may exclude the NLT from the assembly effective thermal performance calculations however, confirm with the local authority having jurisdiction for energy code compliance requirements.

Where a clear air cavity vent space is not possible, consider another means of leak detection or NLT drying. In such instances, consider the following potential limitations:

- Fire code may require the air cavity to be filled with insulation, negating the purpose of the vented cavity. Where this is required, consider limiting the cavity insulation R-value to less than one third of the total assembly insulation R-value, to minimize the risk of condensation within the assembly.
- Some applications may not allow 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.
- Structural sheathing perimeter attachment requirements may prevent a clear air cavity connection to the interior, negating the benefit of venting the panel to the interior.

References

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- [2] American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2016. *2016 ASHRAE handbook: fundamentals*. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers.
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Above Orchard Commons, Vancouver, BC. Architecture: Perkins+Will. (Photo credit: Michael Elkan)



*Above Tsleil-Waututh Administration & Health Centre, North Vancouver, BC. Architecture: Labor Trubka Associates Architects
(Photo courtesy of naturallywood.com)*

6 Supply and Fabrication

6.1 Materials

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

6.1.1 Lumber

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

Lumber Grades and Species

Lumber species and grade affects both strength and appearance of 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 will be exposed to significant moisture during construction. Workability and hardness also differ between species and generally relate to density; for instance, Douglas Fir is more dense than SPF, which can result in more resistance when nailing or cutting, although only slightly.

Grade also matters where 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



In This Chapter

- 6.1 *Materials*
- 6.2 *Tools and Equipment*
- 6.3 *Fabrication Process*
- 6.4 *Manufacturing Standards*



Figure 6.1: NLT Showing Blue Staining from Beetle-Killed Wood (Photo Courtesy of Perkins+Will)

knots) to better address aesthetic criteria. Using Select Structural grade lumber will provide improved structural properties while reducing 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 NLT.

Research and consider locally available lumber grades before ordering lumber for NLT. In some regions, SPF includes 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 the NLT can be challenging.

Where high-quality, exposed NLT is desired, fabricators ordering No. 2 and better material should expect to visually cull it for consistent quality and anticipate a typical waste factor of 15% to 20%. To assist with visual culling it may be helpful to identify visual characteristics of acceptable lumber in



Figure 6.2: Example of Aesthetic Grade Boards for NLT Panels (Photo Courtesy of StructureCraft Builders Inc.)

advance to facilitate a consistent look. Refer to Figure 6.2 for an example of board selection criteria for NLT panels used in the T3 project in Minneapolis. 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 NLT Appearance Chart in Appendix A provides further examples of different levels 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.



Figure 6.3: *Finger-jointed Lumber. (Photo courtesy of StructureCraft Builders Inc.)*

Spliced Panels and Finger Jointing

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 splices in the panel with a layup specific pattern or use 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 4.1.2 for further discussion on structural design for spliced panels and Section 6.3.1 for more on layup pattern fabrication.

Finger-jointed lumber is used widely for manufacturing other mass timber products such as GLT and CLT; it can also be used for NLT where butt joints are undesirable for structural or aesthetic reasons. Finger-jointed lumber typically represents a 15% to 20% cost premium in some markets. Moreover, it can impact the amount of material required, as the thickness of finger-jointed lumber will generally be 1.58 mm (1/16 in.) narrower than typical dimension lumber. Structural requirements for the type of finger joint should be assessed and specified by the structural engineer as not all finger joints are intended for use in bending applications as per the ALSC finger jointing standards. Appendix B provides a sample specification noting acceptable finger joints. If finger-jointed lumber is used, the joints should be staggered 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 or OSB are generally used over NLT floors or roofs and on one or both sides of NLT walls. 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.

6.1.2 Fasteners

Assemble exposed NLT using galvanized nails to join laminations and for fastening plywood/OSB. If non-galvanized nails are 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 commonly specified, engineers may specify 10D (3.7 mm [0.131 in.]) nails; in such cases, expect a cost premium.

Self-tapping screws are often used to connect NLT to its supports and can be used to reinforce panels at other conditions in panel assemblies such as openings, overhangs, or weak-axis cantilevers. Where self-tapping screws are needed, use zinc-plated screws to prevent iron staining; galvanizing this type of screw reduces the strength of the steel, and is rare and expensive. Although self-tapping screws have much higher structural capacity than nails, requiring fewer per NLT panel, using screws will increase fabrication time, increasing labour costs. For example, adding one pair of screws to every course at a spacing of 305 mm (12 in.) on centre increases assembly time by a factor of approximately three.

6.1.3 Coatings

Coatings include sealers and stains often applied to exposed faces of NLT floors, roofs, and walls for aesthetic purposes. They can be applied in the shop, on site, or both. While coatings can mitigate water staining, they will not prevent swelling and are not an effective construction moisture control system. Water staining is typically minimal for horizontal NLT even without coatings, as the laminations create a natural drip edge every 38 mm (1-1/2 in.). Site-applied coatings can be cost effective depending on size and complexity of the project. Many different types of coatings are available and the appropriate product is generally coordinated between the coating manufacturers and the project architect. Penetrating coatings usually perform better than film building coatings, as natural movement in the NLT panel with time can lead to shrinkage or expansion and cracking in the film. For exterior panels, carefully consider coating specification and maintenance requirements.

6.2 Tools and Equipment

The mechanisms for handling 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 shop setup and required equipment. Refer to Chapter 8 for more on lifting and handling.

6.2.1 Jigs

The best way to assemble NLT is on jigs made from pony walls, back and end stops, and back fences as shown in Figure 6.4. 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. Different setups can be used to create NLT that is curved in plan or warped in elevation.

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.

6.2.2 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 5 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 work stations wherever possible.

Where large 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.



Figure 6.4: NLT Fabrication Set-up (Photo courtesy of StructureCraft Builders Inc.)

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 as specified in the structural drawings with a pneumatic nailer. Where self-tapping 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.

6.2.3 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 cutting 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 6.2.2), the steel nails located throughout NLT do present a challenge for cutting. For this reason, NLT panels 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 6.1 for saw types and sizes with corresponding cut depths.

TABLE 6.1 SAW TYPES AND CUTTING DEPTH

| SAW SIZE AND TYPE | MAXIMUM VERTICAL DEPTH |
|--------------------------|------------------------|
| 250 mm (10 in.) beam saw | 89 mm (3-1/2 in.) |
| 400 mm (16 in.) beam saw | 165 mm (6-1/2 in.) |
| 450 mm (18 in.) beam saw | 187 mm (7-3/8 in.) |
| Carpenter's chainsaw* | 406 mm (16 in.) |

**A chainsaw is not recommended due to high probability of cutting through nails.*

Cutting notches and penetrations is similar to 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 easily cut with a hole saw. Custom hole saw manufacturers can create saws up to 330 mm (13 in.) diameter; while custom saws are expensive, they may be a worthwhile investment if many identical penetrations are required.

6.2.4 Coating Application

Coatings are applied to the underside of NLT to add aesthetic quality to exposed soffits or where NLT is used in exterior conditions. They typically do not provide weather protection. The performance of coatings will vary with species, along with resistance to decay.

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 the 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 6.5). 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 NLT is in place over the structural supports.

6.2.5 Temporary Moisture Management System Installation

Where a temporary moisture management system (TMMS) requires partial shop installation (refer to Section 7.6), 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.

Take care during storage and shipping to ensure the pre-installed TMMS is not damaged prior to panel installation. Refer to Chapter 7 for more on storage and shipping approaches.



Figure 6.5: *Shop Applied Coating on NLT (Photo courtesy of StructureCraft Builders Inc.)*

6.2.6 Panel 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 8 for more on lifting requirements.

Forklifts and Telehandlers: Ensure that forks are clean and covered to prevent damage to the panels. Use plastic covers are recommended, not carpet or cardboard covers. Keep panel widths to a maximum of 1.8 m (6 ft.) where overhead cranes are not available.



Figure 6.6: *Combined NLT and Support Beams (Photo courtesy of Fast+Epp)*

6.3 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.

6.3.1 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 lam with care. For boards with grading stamps present on the faces, ensure the stamps are present on the non-exposed side of the NLT.

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 4.1.2 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.

6.3.2 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, hold it back from the NLT panel edges, allowing infill strips to be installed on site to provide diaphragm continuity as shown in Figure 4.7. 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 4.2.1 and 4.3.1 for more.

6.3.3 Plan Layout of Panels

Panels can be arranged in various ways within a roof or floor plate, with short spans offering more options. Consider combining a single-span NLT deck with its supporting beams in the shop. The combined beam/deck shipping piece can be provided at every other span, and simple NLT panels can infill the gaps as shown in Figure 6.6. This strategy will reduce the overall number of crane picks required on site and can add out-of-plane stability to the panels, though transporting the combined beam/deck pieces to site is less efficient than shipping NLT panels alone.

6.4 Manufacturing Standards

Industry-wide manufacturing standards and tolerances for NLT do not exist. The following criteria are based on past experience and provide an acceptable, achievable level of quality. Refer to Appendix B for a sample specification with additional quality control and assurance requirements.

6.4.1 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 NLT fabrication. 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.

6.4.2 Tolerances

Reasonable manufacturing tolerances on panel width, length, and squareness help speed erection and maximize the benefit of prefabricated NLT panels. Refer to Appendix B for example tolerances for panel fabrication. Consider the following:

Panel Width: To maintain a consistent panel width, it is important to check width frequently during assembly, and use localized shimming or board planing.

Panel Length: Tight tolerances on length are easily met with accurate cutting after the panel is nailed.

Out-of-Square: Square panels are easy to achieve by constructing and maintaining a sturdy, square jig.

6.4.3 Quality Control and Documentation Review

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 also usually required for architectural review and approval and can be the best way to communicate finish quality.

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 most 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 ensure coordination with other trades. Simulation platforms such as Navisworks may be helpful to merge models from different trades and support clash detection (refer to Figure 6.7).

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); and
- 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.

Quality Control Checklists

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

Samples and Mock up Panels

Samples or larger mock-up panels are often required by the architect for review and approval to ensure 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.

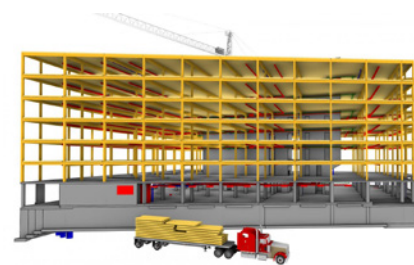


Figure 6.7: 4D Sequencing with Navisworks for T3, T3, Minneapolis, MN. (Image courtesy of StructureCraft Builders Inc.)



*Above Tsleil-Waututh Administration & Health Centre, North Vancouver, BC. Architecture: Labor Trubka Associates Architects
(Photo courtesy of naturallywood.com)*

7 Construction and Installation

7.1 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:

- Just-in-time delivery;
- Sorting and staging on site; and
- 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.

7.2 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 generally 4.1 m (13 ft.-6 in.) above the ground. Over-height permits may be allowed up to 4.3 m (14 ft.-2 in.), but this is rare.



In This Chapter

7.1 *Organization*

7.2 *Shipping*

7.3 *Storage*

7.4 *Unloading*

7.5 *Installation*

7.6 *Construction Phase*

Moisture Management



Figure 7.1: *Shipping with Dunnage and Stickers (Photo courtesy of StructureCraft Builders Inc.)*

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.

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 7.1. 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.

Reducing the thickness of the dunnage and stickers can maximize the number of panels that fit on a truck. Ensure 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.

7.3 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. Ensure the lumber wrap or tarps are opaque to prevent light from penetrating, as 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 can be 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 in cases of 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 7.2).

Renting trailers can be 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 in cases of 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 7.2).

7.4 Unloading

When clean, dry forklift forks are used, no additional protection during unloading should be required. If fork protection is desired, shrink wrap 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 8 for erection engineering guidance. In either case, NLT-specific safety requirements would follow standard safety rules for loading, offloading, and general material handling.

7.5 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. The typical installation sequence involves placing the panels, support attachment, panel-to-panel connections,

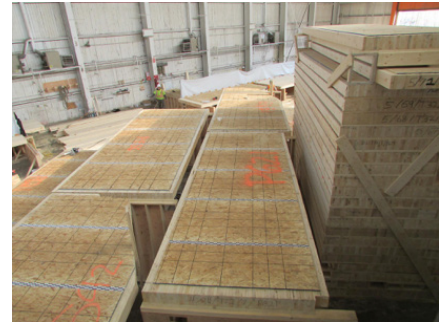


Figure 7.2: *Storage Set-up with Dunnage and Stickers. (Photo courtesy StructureCraft Builders Inc.)*



Figure 7.3: NLT Panel Installation Sequencing Model (Image courtesy of StructureCraft Builders Inc.)



Figure 7.4: Installed Roof Panels with Gaps for Expansion. (Photo courtesy of StructureCraft Builders)



Figure 7.5: NLT Install of Prefabricated Pre-Sheathed Panels (Photo courtesy of Seagate Structures Ltd.)

and sheathing, and then installing integrated mechanical/electrical/plumbing and other service runs within the NLT if necessary. A sequencing model is shown in Figure 7.3. Refer to Chapter 4 for structural details and to Chapter 8 for more on erection requirements for stability.

Ensure the panels are placed per the structural drawings and details, which may include gaps as shown in Figures 7.4 and 7.5. NLT panels are an engineered system; no notching or cutting is permitted without approval. Where high-strength screws are used for the connection to supporting structural elements, never use an impact drill, to avoid stripping the wood. Refer to Section 6.2.2 for more on high-strength screw installation.

7.6 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 [1]. Moisture can be properly managed during construction with the right design and construction practices. A lack of proper care during the construction phase can affect aesthetics, structural capacity, dimensional tolerances, enclosure integrity, and even indoor air quality.

Sources of construction phase moisture include rainfall and 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 [2]. 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 [1]. Attempting to fix this problem retroactively with tenting or large-scale drying is costly and can delay the construction schedule.

Consider the following strategies alone or in combination to minimize the risks associated with construction phase moisture:

- Provide a temporary moisture management system (TMMS) over NLT (refer to section 7.6.1 for more);
- 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;



Figure 7.6: *Horizontal NLT Floor Panel Subjected to Snow (Photo courtesy of StructureCraft Builders Inc.)
Snow melt was later cleared from the NLT TMMS to minimize moisture exposure.*

- Minimize schedule delays between constructions of adjacent floor levels;
- Maximize panel size to decrease the number of site-installed TMMS joints where they are most susceptible to leakage;
- Install enclosure components (e.g. temporary roof membranes, wall WRB, etc.) in parallel or shortly following the structure.

The intent of any moisture management approach is to maintain a moisture content of less than 16% on average, with a maximum of 19%. Temporary or permanent membranes should not be applied unless the moisture content of both the NLT laminations and the plywood/OSB is a maximum of 16%. Refer to The Guide for On-Site Moisture Management of Wood Construction [3] for more on moisture management.

7.6.1 Temporary Moisture Management Systems

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 7.6, especially if construction schedule delays occur. The use of temporary moisture management systems (TMMS) and additional moisture management strategies at both roof and floor assemblies can limit the risk of exposure to moisture during construction.

TMMS 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.

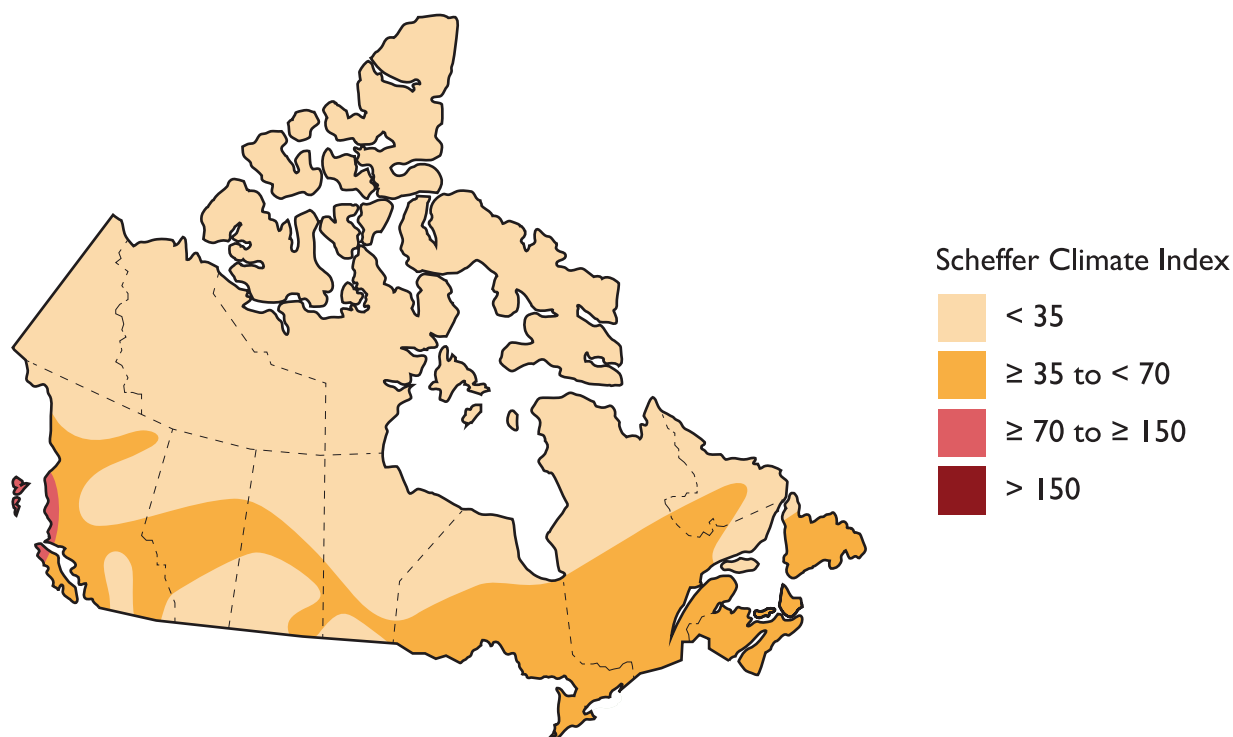


Figure 7.7: *Scheffer Climate Index (As updated by Morris and Wang [6] and modified by RDH Building Science Inc.)*

The need for a 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 [2], [4]. Refer to Figure 7.7 for the four categories of climate indices across Canada, and Table 7.1 for suggested temporary moisture management systems for each climate index category.

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 membrane system, and should be considered as a risk control strategy, as even mild moisture exposure can cause swelling and shrinkage. It may be tempting to use a less robust TMMS than the options presented in Table 7.1 as an initial cost saving measure; however be careful to also consider the increased risk of exposing the NLT to moisture and associated cost of 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

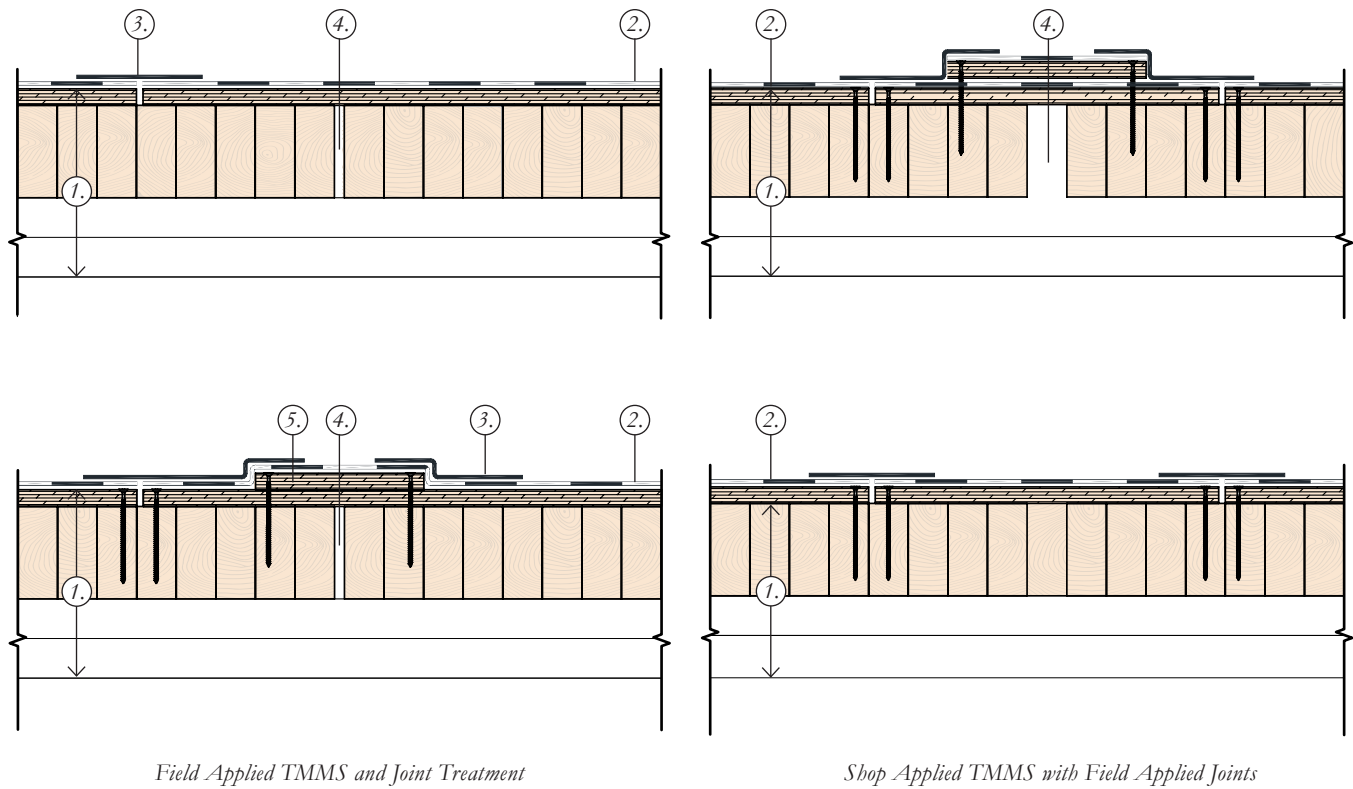


Figure 7.8: *Temporary Moisture Management System Joint Treatment Concepts*

weather station. Refer to A New Decay Hazard Map for North America Using the Scheffer Index by Morris and Wang [4] for more information and city-specific indexes.

In addition to the guidelines provided in Table 7.1, consider the ability of the TMMS to accommodate construction activity without undue risk of workers slipping, the system's compatibility with any interfacing roof membranes or flooring systems to be installed later in construction, and the TMMS sensitivity to UV exposure relative to the project schedule. Where the TMMS is also to be used as the permanent air barrier system and vapor control layer, ensure the TMMS has the appropriate properties to function as these elements and is repaired as needed prior to cover. Also consider that the TMMS may impact the adhesion of a concrete topping slab.

Take care where fasteners penetrate through the TMMS at elements such as fall arrest anchors (refer to Chapter 8), scaffolding supports, or structural outriggers (refer to Chapter 4). Detail fastener penetrations through the TMMS and consider additional protection for high rainfall areas. Any removed fasteners or damaged TMMS areas should be promptly repaired.

Key

1. Sheathing, NLT, and structure beyond
2. TMMS membrane
3. TMMS joint treatment
4. Movement gap per structural engineer
5. Sheathing per fire engineer

TABLE 7.1 TEMPORARY MOISTURE MANAGEMENT SYSTEMS

| PROTECTION LEVEL | TMMS MEMBRANE / JOINT TREATMENT | BENEFITS |
|-------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  HIGH | <p>Field Membrane: Fully adhered, vapor-impermeable waterproof membrane on sheathing.</p> <p>Joint Treatment: Fully adhered or welded membrane laps.</p> | <p>Factory applied field membrane prior to shipping minimizes errors and weather limitations of on-site application.</p> <p>Field membrane may serve as part of permanent roof membrane or flooring underlay.</p> <p>Allows for immediate installation of joint treatment following panel installation (if skilled workers are available).</p> <p>High durability of membrane laps where torched or welded.</p> |
|  MODERATE | <p>Field Membrane: Precoated, moisture-resistant bonded water-repellent coating on sheathing.</p> <p>Joint Treatment: Taped and/or sealed (e.g. flexible flashing membrane or tape).</p> | <p>Precoated sheathing minimizes need for experienced membrane installers.</p> <p>Sheathing and TMMS field membrane are combined into a single fabrication step.</p> <p>Allows immediate installation of joint treatment following panel installation.</p> |
|  MODERATE | <p>Field Membrane: Fully adhered, vapor-permeable and moisture-resistant membrane on sheathing.</p> <p>Joint Treatment: Taped and/or sealed (e.g. flexible flashing membrane or tape).</p> | <p>Factory applied field membrane prior to shipping minimizes errors and weather limitations of on-site application.</p> <p>Allows for immediate installation of joint treatment following panel installation if field membrane is pre-applied to sheathing.</p> |
|  MODERATE | <p>Field Membrane: None. Exposed plywood or OSB sheathing.</p> <p>Joint Treatment: Taped and/or sealed (e.g. flexible flashing membrane or tape).</p> | <p>Allows for immediate installation of joint treatment following panel installation.</p> <p>Skilled/experienced workers not required for joint treatment installation.</p> <p>Additional applications of water sealer may further increase water resistivity of the sheathing.</p> <p>Cost effective compared to options with field membrane.</p> |
|  LOW | <p>Field Membrane: None. Exposed plywood or OSB sheathing</p> <p>Joint Treatment: None. Exposed sheathing joints.</p> | <p>Cost effective.</p> <p>May minimize schedule impacts.</p> |
|  LOW | <p>Field Membrane: None. Exposed NLT laminations.</p> <p>Joint Treatment: Not applicable.</p> | <p>Accommodates sheathing installation at a later date or following site installation of overframing.</p> <p>May minimize schedule impacts.</p> <p>Cost effective.</p> |
|  ISOLATED AREAS ONLY | <p>Field Membrane: Loose laid sheet over sheathing.</p> <p>Joint Treatment: Taped and/or sealed (e.g. flexible flashing membrane or tape).</p> | <p>Serves as short-term temporary protection for isolated areas.</p> |
|  ISOLATED AREAS ONLY | <p>Field Membrane: Membrane under sheathing and over NLT laminations.</p> <p>Joint Treatment: Varies.</p> | <p>Sheathing protects membrane from trade damage.</p> |

| CHALLENGES / LIMITATIONS | RECOMMENDED CLIMATE INDEX / SEASON |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| <p>Requires pre-coordination with subcontractor installing TMMS.</p> <p>Can trap moisture within the NLT assembly and significantly reduce drying should water penetrate the membrane</p> | All Climate Indices / All Seasons |
| <p>Sheathing attachment penetrates through TMMS field membrane; taped/seal over fasteners.</p> <p>May be susceptible to damage and/or adhesion failure due to trade activities.</p> <p>May have limited exposure time; ponding water may result in water absorption and slow drying.</p> | Climate Index ≤ 70 / All Seasons |
| <p>Requires pre-coordination with subcontractor installing TMMS.</p> <p>TMMS may be susceptible to damage and/or adhesion failure due to trade activities.</p> <p>May require skilled/experienced installer.</p> | Climate Index ≤ 70 / All Seasons |
| <p>Some joint treatment products may not bond to damp or wet sheathing substrate.</p> <p>Joint treatment may be susceptible to damage and/or adhesion failure due to trade activities.</p> | <p>Climate Index ≤ 35 / All Season</p> <p>Climate Index ≤ 70 / Dry Seasons</p> |
| <p>System permits water migration between sheathing joints and into the NLT in wet weather conditions.</p> | Climate Index ≤ 35 / All Season |
| <p>Option permits water migration between NLT in wet weather conditions.</p> | Climate Index ≤ 35 / All Season |
| <p>Low durability.</p> <p>Difficult to seal.</p> <p>Typically slippery and dangerous to walk on.</p> <p>Allows lateral moisture movement beneath membrane.</p> | Isolated Conditions (evaluate for project specific appropriateness) |
| <p>TMMS is inaccessible for quality control review.</p> <p>TMMS below sheathing is difficult to drain and dry; traps moisture within NLT.</p> | Avoid |



Figure 7.9: Fixed Tenting Installation (Photos courtesy of Fast+Epp)

7.6.2 Additional Strategies

Consider the following strategies to supplement or replace the chosen TMMS.

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 7.8. 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.

Water Deflection/Diversion 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 protection to minimize water ingress through openings and penetrations, which may cause puddling on the horizontal assemblies. Close off perimeter wall cavities at the top; leaving the cavities open may divert water onto lower floor areas. Install temporary protection at roof parapets as well as at perimeter wall elements to avoid directing water into the building.

Sheathing splines 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 after placement as possible, and before wet weather conditions occur. 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 Figure 7.9). 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 [3]. 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.

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Above Mountain Equipment Co-Op Head Office, Vancouver, BC. (Photo courtesy of www.naturallywood.com)

8 Erection Engineering

NLT projects usually require specialty erection engineering for panel lifting, fall arrest, and temporary structural stability. This engineering can be performed by the structural engineer but is more often carried out by the supplier's 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.

8.1 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 8.1); and
- 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.



In This Chapter

8.1 Design Loads

8.2 Panel Lifting

*8.3 Fall Arrest and
Horizontal Lifelines*

8.4 Temporary Stability

FIG. 8.1 DYNAMIC ACCELERATION FACTORS (F) [1]

| 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 + |

8.2 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.

8.2.1 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.

8.2.2 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 8.2 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 centred 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.

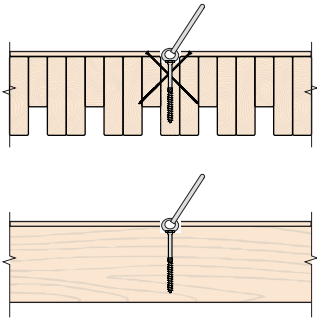

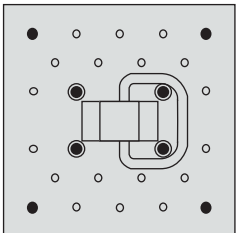
NLT wall panels with vertically oriented laminations and a horizontal top plate require special lifting techniques. Consider the use of choked slings or screws fastened through the top plate, or D-ring plates fastened to the sides of the panel. It is important to consider load transfer between lams, although where plywood/OSB is pre-installed on at least one side this is usually straightforward.

8.2.3 Pick Points

Distribute pick points such that the resulting lifting hook position lies over the panel centre 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 centre 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.

FIG.8.2 LIFTING MECHANISM OPTIONS

| LIFTING MECHANISM | USE AND LOAD RANGES | CONSIDERATIONS |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Screwed in Quick-Release Anchors</p>  | <p>Common system for mid-range panel weights.</p> <p>Load is dependent on the withdrawal capacity of high-strength screws.</p> | <p>Quick-connect system reduces cycle times.</p> <p>Screws must be installed at correct angle.</p> <p>Local reinforcement of panel is required.</p> <p>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.</p> <p>Screws penetrate pre-installed TMMS.</p> |
| <p>Slings</p>  <p><i>(Photo courtesy of Seagate Structures Ltd.)</i></p> | <p>Simple system common for narrow panels or tight spaces (ex: shops).</p> <p>Load is governed by sling capacity and rigging configuration.</p> | <p>Slings can be re-used.</p> <p>Hook-up and release of panels is slow.</p> <p>Typical max width is 4 ft. (use of a spreader bar can increase the sling angle).</p> <p>Sling angles less than 60° increase lifting anchor force (impacts lift rating).</p> <p>Difficult to remove slings, so panels must be landed apart and pulled together.</p> <p>Potential for instability of the panel if slings slip.</p> <p>No penetration through the TMMS (where applicable).</p> |
| <p>Screwed Plates with Lifting Rings</p>  | <p>Governed by plate dimension and number of screws installed.</p> <p>Used for higher load panels (or reduced number of pick points).</p> | <p>D-ring plates and screws can be re-used.</p> <p>Can be time consuming to install.</p> <p>Consider impact to dunnage during shipping for pre-installed plates.</p> <p>Multiple plates required for a project will impact the cost.</p> <p>Provide either swivel lift ring or orient d-ring to pivot in same direction as chains/slugs.</p> <p>Large number of penetrations into the TMMS.</p> |

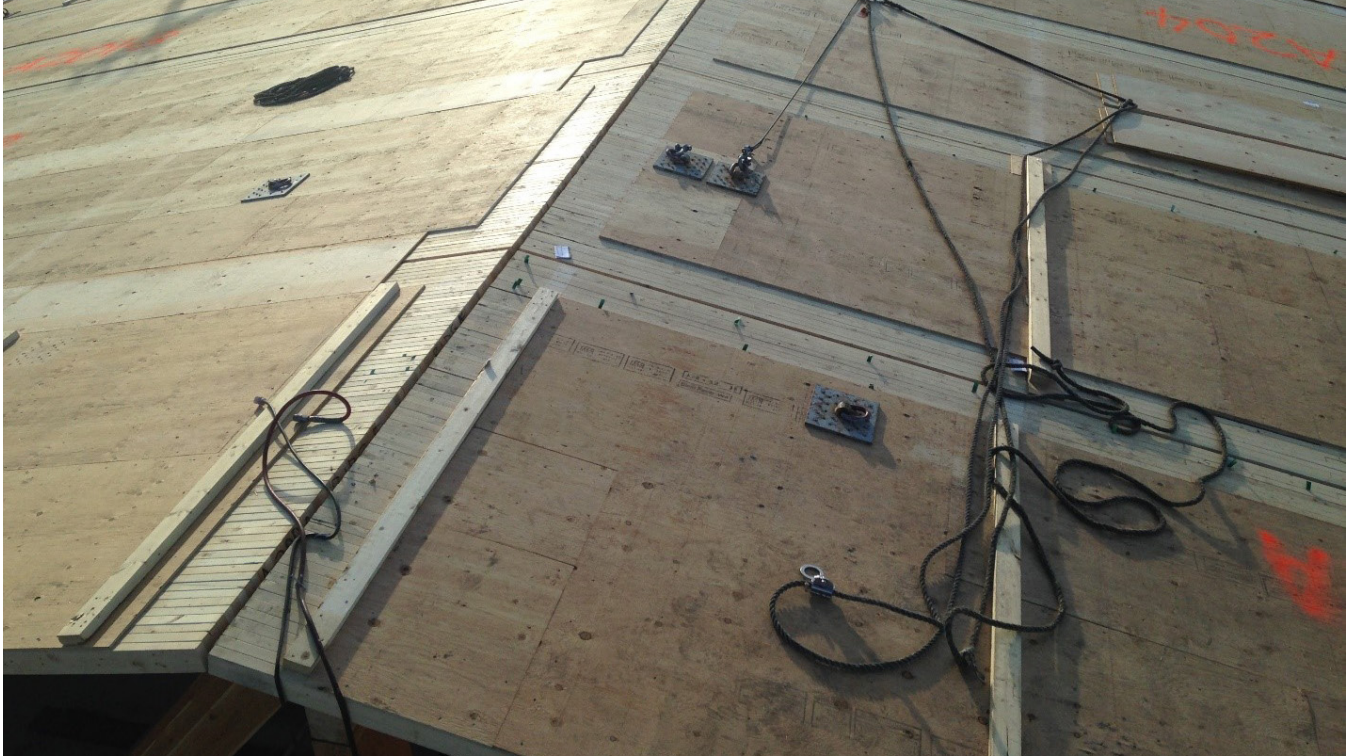


Figure 8.1: *Point Arrest and Lifelines (Photo courtesy of StructureCraft Builders Inc.)*

8.3 Fall Arrest and Horizontal Lifelines

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. Both of these 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 life lines; refer to Figure 8.1. Note that 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 a sufficient number of 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.

8.4 Temporary Stability

To ensure proper alignment of elements before and after NLT installation, temporary stability supports may be applied to the structure supporting NLT floor panels as shown in Figure 8.2. NLT is heavier than light-frame wood 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 limited 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, be sure to 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.

References

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

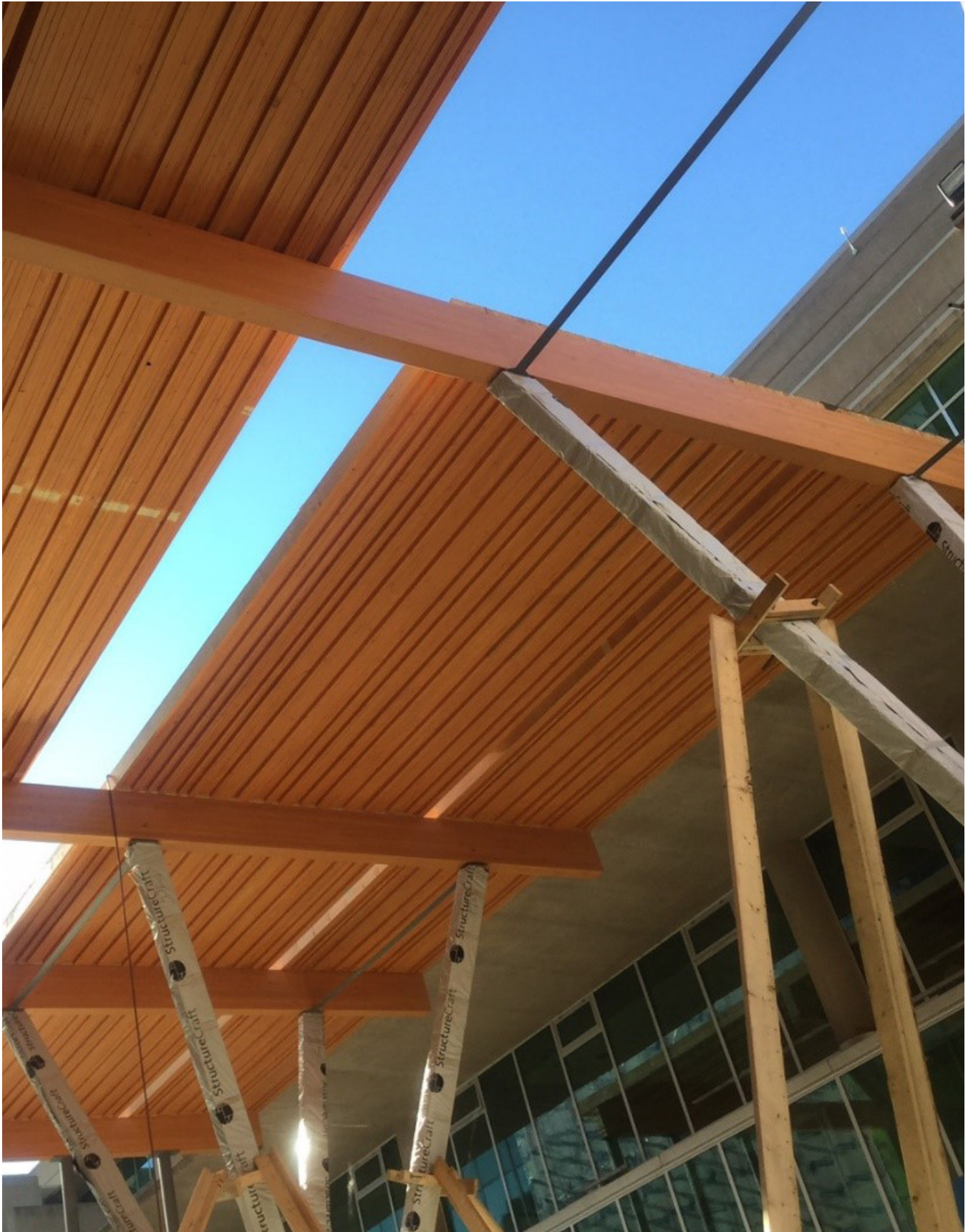


Figure 8.2: *Temporary Stability Supports (Photo courtesy of StructureCraft Builders Inc.)*



Above UBC Bookstore, Vancouver, BC. Architecture: Office of McFarland Biggar Architects + Designers (Photo credit: Ema Peter)

Appendices



Appendices

A NLT Appearance Chart

B Sample Specification

C Swelling & Shrinkage of Wood

Appendix A: NLT Appearance Chart



Figure A.1: Significant wane and knots, inconsistent colouration. Loose vertical tolerance on placement of laminations.



Figure A.2: Minimal wane, some knot holes, variable colouration. Tight vertical tolerance on placement of laminations.



Figure A.3: *No wane, minimal knot holes, variable colouration. Tight vertical tolerance on placement of laminations.*



Figure A.4: *No wane, no knot holes, consistent colouration. Tight vertical tolerance on placement of laminations.*

Appendix B: Sample Specification

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Part 1 General

1.1 SECTION INCLUDES

- .1 Solid dimension lumber floor and roof decking, prefabricated in panels.
- .2 Floor and roof sheathing.
- .3 Connection hardware.

1.2 RELATED SECTIONS

- .1 Section 01 35 18 - Sustainable Design Requirements.
- .2 Section 05 12 00 - Structural Steel Framing.
- .3 Section 09 91 00 - Painting.

1.3 REFERENCES

- .1 ASTM A153/A153M-16a - Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.
- .2 ASTM E488/E488M-15 - Standard Test Methods for Strength of Anchors in Concrete Elements.
- .3 ASTM F1667-15 - Standard Specification for Driven Fasteners: Nails, Spikes, and Staples.
- .4 CANPLY (Canadian Plywood Association) - Grading and certification.
- .5 CSA O86-14 - Engineering Design in Wood.
- .6 CSA O121-08(R2013) - Douglas Fir Plywood.
- .7 CSA O141-05(R2014) - Softwood Lumber.
- .8 ICC-ES ESR-1539 - Power-Driven Staples and Nails.
- .9 NLGA (National Lumber Grades Authority) - Standard Grading Rules for Canadian Lumber, 2014 Edition.
- .10 National Building Code of Canada 2015.
- .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).

1.4 ACTION SUBMITTALS

- .1 Product Data: For each type of factory-fabricated product. Submit proposed sealer for review and approval.
- .2 Shop Drawings: Connections and details, joint patterns, material specifications, and finishes, including an erection layout.
- .3 Provide a letter outlining steps to be taken during construction to ensure adequate weather protection of wood structures.
- .4 Sustainable Design: Per Section 01 35 18.

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1.5 INFORMATIONAL SUBMITTALS

- .1 In lieu of grade stamping lumber exposed to view, submit manufacturer's certificate certifying that products meet or exceed specified requirements.
- .2 The fabricator and erector shall submit a QA/QC log of items such as but not limited to:
 - .1 Environmental conditions at all stages, such as during fabrication, storage, transportation, erection and ideally until building is completely finished.
 - .2 Actual length, thickness and width of the panels. Length, width, thickness and diagonal measurement are to be noted on top surface of panels.
 - .3 Site deliveries, including verified load manifests with notes of damaged or missing materials and elements.
 - .4 Material and element install with sign off for QC on hardware/fastener installation.
 - .5 Equipment used, such as but not limited to torque drills (with torque clutch) for screw installation through steel plates etc.
 - .6 Any changes or modifications.
 - .7 The inclusion of representative pictures within the log is required.

1.6 QUALITY ASSURANCE

- .1 Perform Work in accordance with CSA O86 and the following agencies:
 - .1 Lumber Grading Agency: Certified by NLGA.
 - .2 Plywood Grading Agency: Certified by CANPLY.
- .2 Build mockups to demonstrate aesthetic effects and set quality standards for materials and execution.
 - .1 Build one complete NLT panel with a minimum width of 1.2 meters.
 - .2 Mockup must illustrate typical wood appearance, coating, and finish.
 - .3 Keep mockup available to view as the standard of Work for remaining fabrication.
 - .4 Approved mock-ups may become part of the completed Work if undisturbed at the time of Substantial Completion.
- .3 Build NLT panels in a shop environment for quality control. Shop fit panels during fabrication. Review with Consultant prior to proceeding further.

1.7 DELIVERY, STORAGE, AND PROTECTION

- .1 Store all materials and assembled NLT panels under cover with proper drainage. Take particular care to protect exposed end grain. Protect from staining and damage at all times during fabrication, transportation, and installation.
- .2 Take all necessary precautions to keep NLT dry during and after installation, including temporary sloping tarps and UV protection.

Part 2 Products

2.1 DIMENSION LUMBER

- .1 Lumber Grading Rules: NLGA. All softwood lumber shall conform to CSA O141 and CSA O86.

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- .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.
- .3 Dress lumber, S4S, unless noted otherwise.
- .4 Wood Members: SPF #1/#2 unless noted otherwise on the Drawings, 19% maximum moisture content.
- .5 Finger-Jointed Lumber: Conforming to NLGA SPS 1 and CSA O86.

2.2 SHEATHING

- .1 Floor and Roof Sheathing: T&G Douglas Fir plywood, exterior grade, conforming to CSA O121. Thickness as indicated, not less than 16mm.
- .2 Factory mark panels to indicate compliance with applicable standard.

2.3 CONNECTORS

- .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 Nails, Spikes, and Staples: ASTM F1667.
- .3 Power-Driven Fasteners: ICC-ES ESR-1539.
- .4 Screws, Tight-Fit Pins and Bolts, Through-Bolts, Glued-In Rods, and Specialty Connectors: As specified on the Drawings. All fasteners and connectors shall be hot-dip galvanized or Type 304 stainless steel unless noted otherwise.
- .5 Expansion Anchors: Anchor bolt and sleeve assembly with capability to sustain, without failure, a load equal to six times the load imposed when installed in unit masonry assemblies and equal to four times the load imposed when installed in concrete as determined by testing per ASTM E488 conducted by a qualified independent testing and inspecting agency.
- .6 Metal Straps and Ties: Galvanized Simpson Strong-Tie straps or approved equal where required.
- .7 Structural Steel Connectors: As specified in Section 05 12 00. All steel and connectors shall be hot dip galvanized unless noted otherwise. Fabricate steel hardware and connections with joints neatly fitted, welded, and ground smooth. Test fit in shop.

2.4 MISCELLANEOUS MATERIALS

- .1 Moisture Barrier: Light gauge metal, asphalt-impregnated building paper, 6mm-thick closed-cell foam gasket material, saturated felt roll roofing, or 6 mil polyethylene.
- .2 Wood Sealer: As specified in Section 09 91 00. Sealer shall be compatible with indicated finish. End sealer shall be effective in retarding the transmission of moisture at cross-grain cuts.

2.5 PREFABRICATION

- .1 Hand select members to ensure straightness and architectural-quality appearance.
 - .1 No wane, knot holes, grade stamps, or stains are permitted to be visible in the completed structure.

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- .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.
- .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 Place soffits of timbers so the least number of checks and knots will be visible in the completed structure.
- .3 Placement tolerance for timber soffits is plus or minus 2mm.
- .4 Arrange timbers in staggered pattern or aligned joint pattern as indicated on the Drawings.
 - .1 Staggered pattern: Stagger and nail together as indicated on the Drawings.
 - .2 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.
- .5 Use common steel wire nails unless noted otherwise. Make tight connections between members. Install fasteners without splitting wood. Drive nails snug but do not countersink nail heads unless noted otherwise.
- .6 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.
- .7 Clearly mark top surface of panels for identification during erection.
- .8 Apply a saturation coat of end sealer to ends and other cross-cut surfaces, keeping surfaces flood coated for not less than 10 minutes.
- .9 After end-coat sealing, apply a heavy saturation coat of penetrating sealer on surfaces of each panel, or seal every lam prior to assembling.

2.6 FABRICATION TOLERANCES

- .1 Soffit Elevation of Individual Laminations: plus or minus 1 mm.
- .2 Panel Width: plus or minus 6mm.
- .3 Panel Length: plus or minus 3mm.
- .4 For rectangular panels, the corner-to-corner diagonal measurements should not deviate from each other by more than 3mm.

Part 3 Execution

3.1 EXAMINATION

- .1 Confirm all dimensions prior to fabrication. Coordinate with shop drawings of other trades.
- .2 Examine supporting construction in areas to receive decking, with Installer present, for compliance with requirements, installation tolerances, and other conditions affecting performance of the Work.
- .3 Proceed with installation only after unsatisfactory conditions have been corrected.

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3.2 INSTALLATION

- .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. Any failure to make proper and adequate provisions for stresses during erection shall be solely the responsibility of the Installer. Fasteners required for erection purposes are the responsibility of the Contractor and are to be included in the bid.
- .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.
- .3 Securely attach NLT to supports as indicated on the Drawings.
- .4 Site cutting or boring of NLT, other than shown on the shop drawings, is not permitted without written consent of the Consultant. Coat all field-cut openings with minimum two coats of clear sealer.
- .5 Provide sill gaskets below laminations and non-rigid vapour barrier sealant between laminations where assembly passes over exterior walls.
- .6 Provide moisture barrier at all locations where NLT abuts concrete or masonry construction.
- .7 Provide gaps as required for construction tolerances and swelling. Details and locations shall be discussed with and approved by the Consultant in writing prior to construction. Gaps on the interior of the building are to be filled after the building is fully enclosed and temperature-controlled.

3.3 SHEATHING INSTALLATION

- .1 Do not use materials with defects that impair quality of sheathing or pieces that are too small to use with minimum number of joints or optimum joint arrangement.
- .2 Secure floor and roof sheathing with longer edge perpendicular to deck direction and with end joints staggered.
- .3 Locate sheathing joints away from gaps between panels.
- .4 Fully engage tongue and groove edges where applicable.
- .5 Coordinate sheathing installation with installation of materials installed over sheathing so sheathing is not exposed to precipitation or left exposed at end of the work day when rain is forecast.

3.4 REPAIRS AND FINISHING

- .1 Prior to finishing, remove any stains, marks, or other damage that may have occurred during construction.
- .2 Provide field finish of panels as specified in Section 09 91 00.
- .3 Final approval by Architect will be after installation of all decking. Remove and replace all Work that does not conform to the standard of the approved mockup, at Architect's request. Replacement of defective Work is at Contractor's expense.

3.5 ERECTION TOLERANCES

- .1 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.

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- .2 Overall Surface Levelness (Floors and Flat Roofs): 6mm in 3 meters maximum.
- .3 Elevation: plus or minus 10mm from theoretical.
- .4 Joints: 5mm maximum gap between NLT panels unless noted otherwise.

END OF SECTION

SAMPLE

Appendix C: Swelling & Shrinkage of Wood

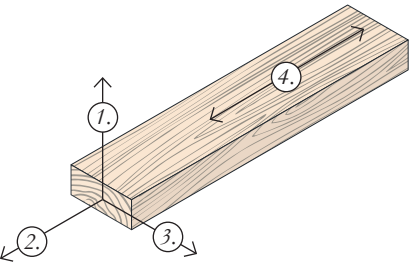


Figure C.1: *The Three Principal Axes of Wood Grain*

Key

- 1. Radial
- 2. Longitudinal
- 3. Tangential
- 4. Fiber direction

Wood is a natural material, therefore its properties vary with the direction of the wood grain. As shown in Figure C.1, 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 vapor permeability.

As a natural hygroscopic material, wood experiences sorption and desorption; its moisture content will change with exposure to both liquid water and water vapor within the surrounding environment. Changes in moisture content at or below fiber saturation point affect wood dimensions and structural properties. With regard to water vapor, 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 C.2.

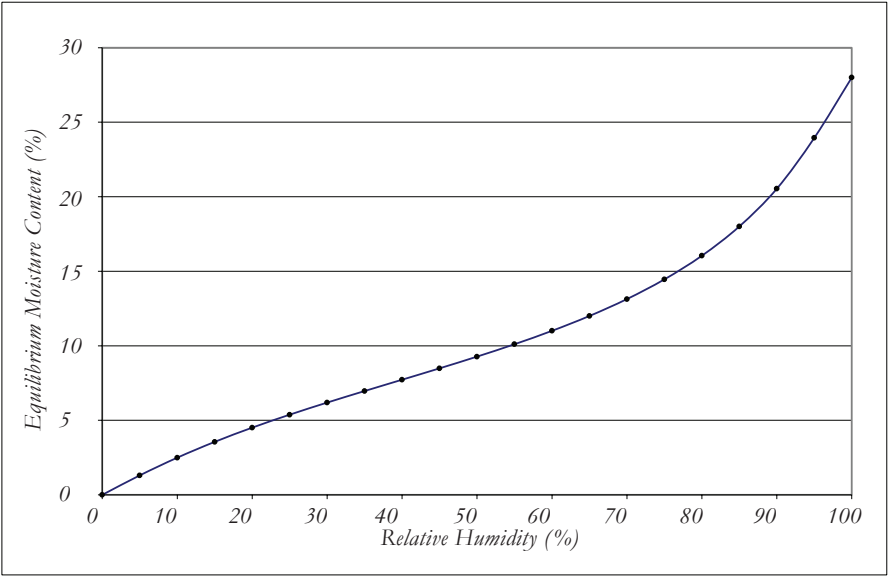
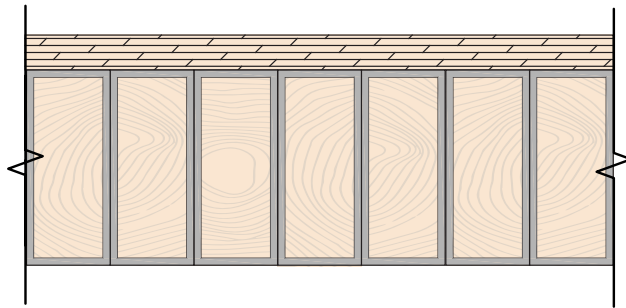
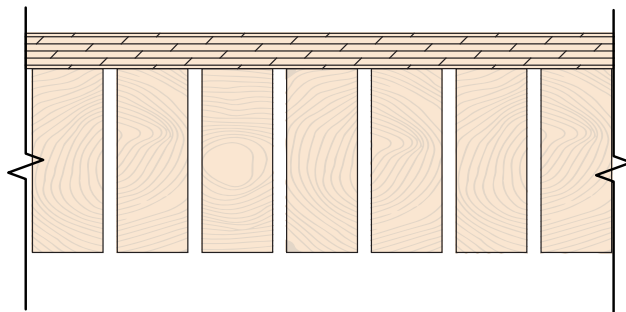


Figure C.2 *Wood Moisture Sorption Isotherm at 20°C.*

Based on data from Forest Products Laboratory, U.S.A. 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



Lamination expansion due to swelling



Lamination position after NLT has returned to lower moisture

Figure C.3: *Swelling and Shrinkage in Individual Laminations (Scale Exaggerated to Show General Effect).*

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 Department 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%.

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 C.3.

