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CONSTRUCTION MOISTURE MANAGEMENT – CROSS LAMINATED TIMBER

PROJECT NUMBER: 301013618

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ABSTRACT

Cross-Laminated Timber (CLT) is a wood product that can be machined to tight tolerances and for uses in structural and/or appearance applications. Because prolonged wetting of wood may cause staining, mould, excessive dimensional change (enough to fail connectors), and even result in decay and loss of strength, construction moisture is an important consideration when building with CLT. This document aims to provide technical information to help architects, engineers, and builders assess the potential for wetting of CLT during building construction and identify appropriate actions to mitigate the risk.

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OVERVIEW

Cross-Laminated Timber (CLT) is a wood product that can be machined to tight tolerances and for uses in structural and/or appearance applications. Because prolonged wetting of wood may cause staining, mould, excessive dimensional change (enough to fail connectors), and even result in decay and loss of strength, construction moisture is an important consideration when building with CLT. This document aims to provide technical information to help architects, engineers, and builders assess the potential for wetting of CLT during building construction and identify appropriate actions to mitigate the risk. Figure 1 illustrates a general sequence of construction moisture management planning and decision making. The most important steps include:

- Understanding the wetting potential of the CLT
- Assessing deterioration risk and potential remediation needs
- Deciding the most effective measures to prevent the CLT from wetting
- Preparing measures to take when incidental wetting occurs

Although the document focuses on wetting, over-drying in a dry environment is briefly covered.

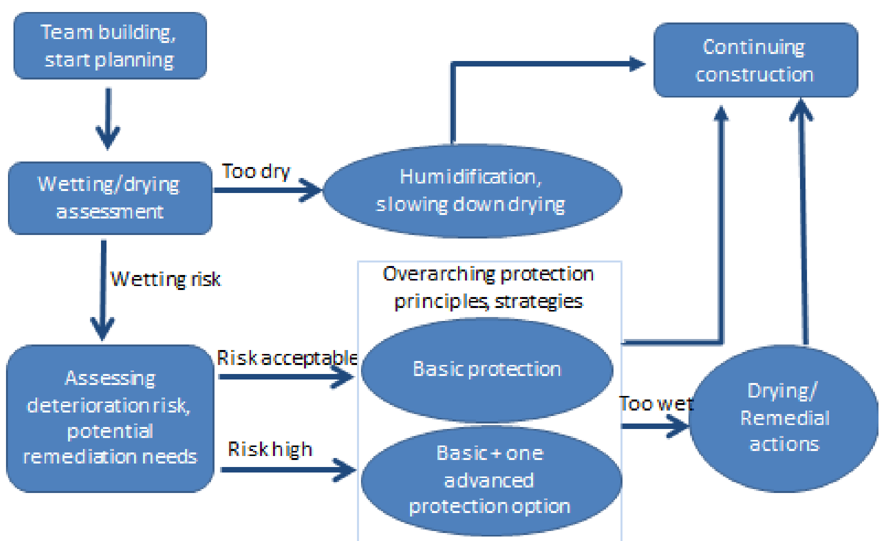

Figure 1 General sequence of construction moisture management planning and decision making for CLT construction.

1 WOOD AND MOISTURE

1.1 CLT basics

CLT is a large engineered wood panel product manufactured by laminating dimension lumber in layers with alternating orientation using adhesives (Figure 2). It is intended for use under dry service conditions and is commonly used to build floors, roofs, and walls. In Canada, most CLT producers use wood species Spruce-Pine-Fir (S-P-F), and sometimes Douglas Fir-Larch (D. Fir-L (N)), together with polyurethane adhesive to make CLT. While the commonly used "S-Dry" dimension lumber has moisture content (MC) of around 19% or lower when it is produced, the MC of the lumber used to make CLT must be with 12±3%, as specified in the PRG 320 standard for North American made CLT. The low initial MC reduces shrinkage[1] and the associate issues when the wood adapts to the drier service environment. While CLT shrinks or swells in its thickness direction with changes in MC; it is highly dimensionally stable in the other two major directions due to the glued cross-laminated structure of CLT.

Figure 2 CLT beams within roof and floor assemblies at the Wood Innovation and Design Centre in Prince George (image courtesy: Michael Green Architecture).

1.2 Wetting from exposure to liquid water

Liquid water sources, such as rain, snow/ice melt, and ground moisture during construction, and plumbing leaks when in service are the typical causes of wetting. On-site protection in wet weather, such as the rainy winter in a coastal climate presents the largest challenge for any construction. Dried Canadian softwoods including S-P-F and D. Fir in general have high resistance

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[1] The shrinkage of sawn dimensional lumber can be estimated using the equation: $S = D \times M \times C$, where, S = shrinkage amount (mm); D = actual dimension of a wood member in a transverse direction (mm); M = percentage of MC change (%), i.e., the difference between the initial MC (≤28%) and the MC in service; C = shrinkage coefficient. A shrinkage coefficient of 0.25% per 1% change in MC is often used for a cross section. For example, 100 mm thick CLT will have its thickness reduced by about 1 mm when it shrinks from 12% to 8% in service.

to moisture penetration. This is especially true for the face grain[2]. Weeks or months of sustained exposure is typically required for water to penetrate deep. However, the following locations in a CLT assembly present the largest risks of wetting:

- End grain of boards; end grain is more water-absorptive than face grain (Figure 3);
- Gaps between lamination, which may trap water;
- The splines at joints. Plywood/OSB is overall much more water absorptive than solid wood (Figure 4).

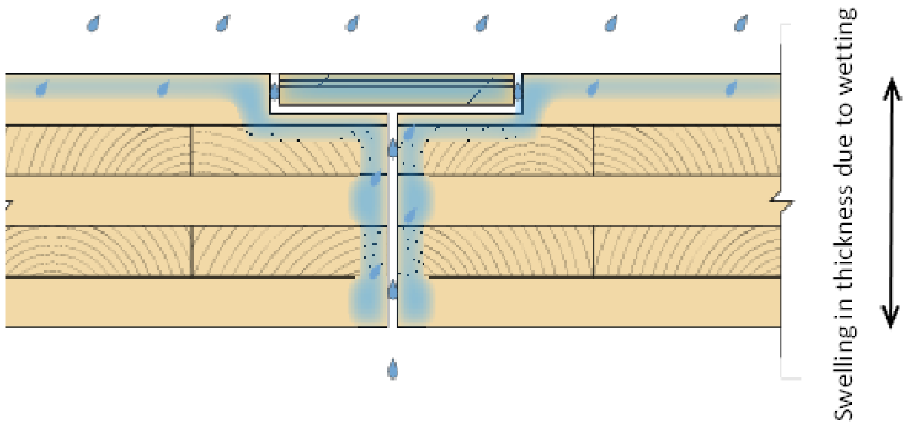

Figure 3 Potential for water absorption at end grain and splines between CLT panels; swelling in the thickness direction.

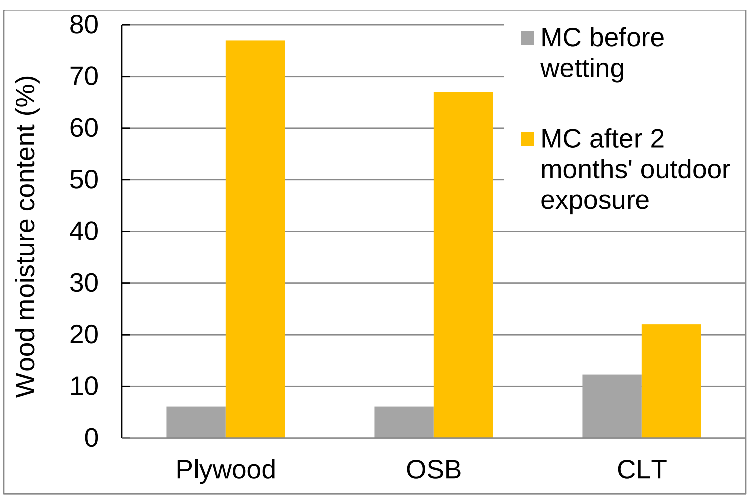

Figure 4 Average moisture content of plywood, OSB and CLT (based on weight changes of 1 ft. by 1 ft. specimens in their common thicknesses), after two months' outdoor exposure in a rainy winter in Vancouver.

[2] Some softwood species, such as southern pines and radiata pine are much more water permeable and require more attention to moisture protection. The wood species treatability is a good indication of whether the wood is more susceptible to moisture penetration or not.

1.3 Wetting from exposure to high humidity

Dry CLT also gains moisture by absorbing water vapour in a humid ambient environment. As a hygroscopic material, wood exchanges moisture with the surrounding air, i.e., sorption behaviour. Under a constant humidity and temperature condition, the wood will reach the equilibrium moisture content (EMC) with the environment when it no longer gains or loses moisture.

Vapour diffusion is an overall slower process, compared to water penetration. Also, it does not increase the MC above the fibre saturation point (about 30% on average), unless vapour condenses on the wood surface under extreme conditions. However, humid and warm environments speed up vapour diffusion. Under near-saturated humidity conditions, capillary water absorption becomes dominant, which greatly increases the MC. Prolonged exposure (e.g., months) to the high humidity alone in the winter in a coastal climate may cause deterioration, such as excessive dimensional change or mould growth.

Figure 5 illustrates a sorption isotherm as well as the transition to capillary water absorption at high humidity levels.

1.4 Drying potential

Once the wetting sources are removed, wetted CLT can dry through moisture evaporation due to the same sorption mechanisms. Warm, low-humidity, and ventilated environment facilitates drying. The locations (e.g., exposed end grain) that are the fastest to wet up during wetting events also tend to dry quickly. However, drying may take long (weeks, and even months) when moisture has penetrated deep in a large CLT member. Drying will become extremely slow or even impossible when the panel is covered with a low vapour permeance material, such as a roofing membrane.

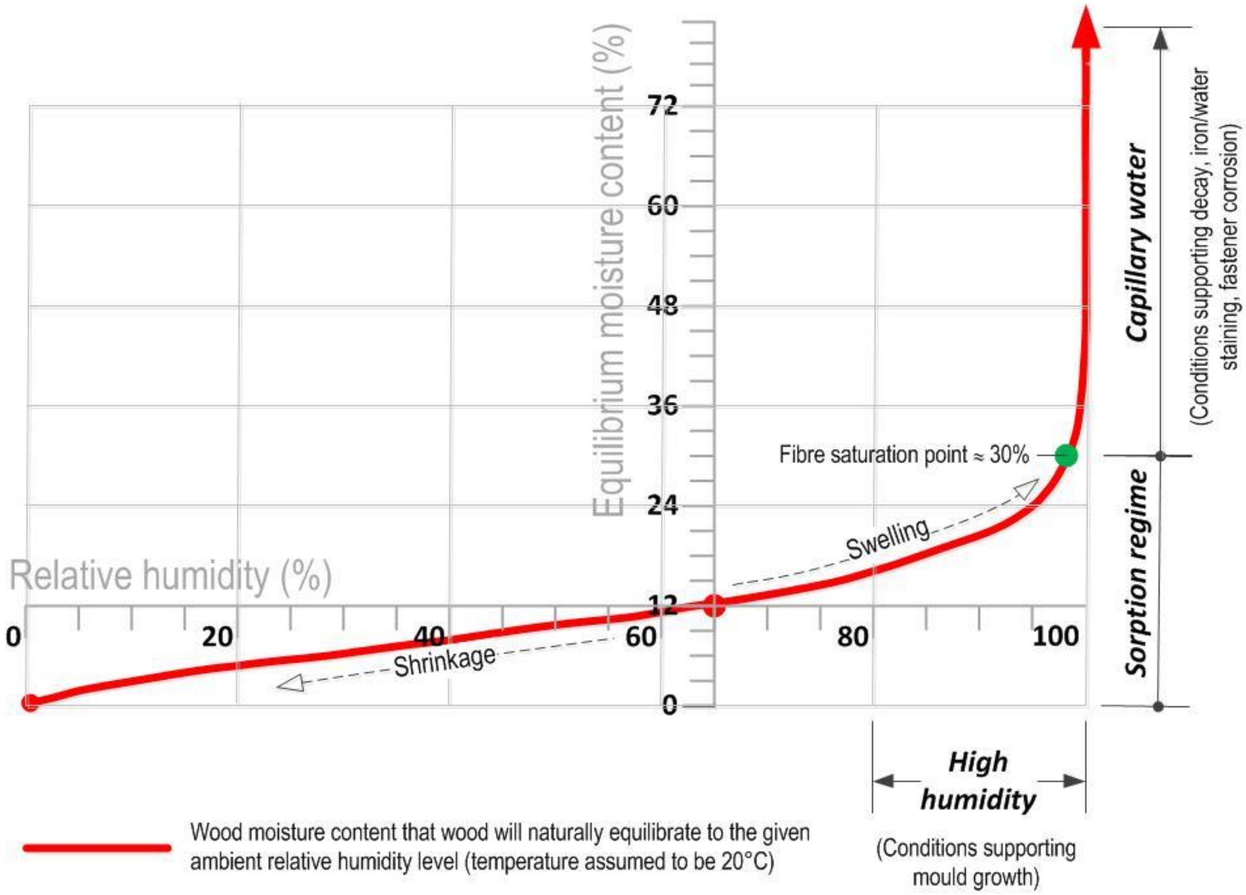

Figure 5 A simplified curve illustrating wood's sorption isotherm under a constant ambient temperature and relative humidity condition, capillary water absorption starting under near-saturated relative humidity conditions, and moisture-associated deteriorations. A theoretical initial moisture content of 12% is assumed for the wood (e.g., CLT).

1.5 Deterioration types, prevention principles

The major types of moisture-related deterioration that may occur during CLT construction and the fundamentals for prevention are indicated in

Figure 5 and summarized in Table 1. Most deterioration types result from prolonged wetting that causes wood MC exceeding 19%.

Table 1 Major deterioration types and prevention principles

Deterioration type	Conditions for deterioration	Impact	Prevention principle
Increased tolerances, screw snapping	Excessive swelling (in panel thickness) resulting from prolonged exposure to moisture (liquid water, high humidity)	Structural performance	Reduce wetting; speed up construction; use more dimensionally stable wood
Water staining	Exposed to liquid water, causing leaching of chemicals	Appearance	Prevent wood from rain and other liquid water
Iron staining	Iron particles (from cutting equipment, fasteners etc.) react with phenolic chemicals in wood, in presence of moisture	Appearance	Prevent wood from moisture sources (e.g., rain); minimize iron particles on wood surfaces
Mould growth	Ambient relative humidity > 80%, ideally in warm weather	Appearance, possibly air quality	Keep wood dry (MC < 19%); keep ambient humidity below 80% if possible. Surface applied mould protection treatments may be an option.
Decay	Wood MC > 26%, ideally in warm weather. Fungi growth also needs a suitable food source and oxygen	Wood loses strength, impact resistance in particular	Keep wood dry (MC<19%). Wood protection treatments or use of naturally durable species may be options.
Fastener corrosion	Fasteners susceptible to corrosion, in presence of moisture (liquid water, high humidity) and oxygen	Fasteners lose strength, cause staining	Keep fasteners from moisture; use galvanized or stainless steel fasteners
Increased tolerances, checking, warping	Excessive/non-uniform shrinkage resulting from low ambient humidity, or highly cyclic environment	Mostly appearance	Prevent rapid decreases in ambient humidity; humidify the space if necessary; use more dimensionally stable wood
Sun burn	Prolonged exposure to sunlight, leading to UV-induced discoloration	Appearance	Reduce exposure to sunlight; keep opaque coverings whenever possible

1.6 Moisture content measurement

The MC of wood is typically measured at a construction site by using a portable pin moisture meter, which is based on measuring the change in electrical resistance (Figure 6, left) with changes. These meters usually have a working range from 6% to 25%. Pins/sensors based on the same principle can be installed at specific locations/depths for continuous monitoring (Figure 6, right). Pins insulated (coated) except at the tips are used to measure the MC between the two tips[3]. The measurements should focus on locations with high wetting potential, such as joints and end grain to provide accurate information for making decisions about moisture protection and use of forced drying.

When conditions allow, MC measurement should be corrected for the effects of wood species and temperature. Special calibration is required for measuring wood-based composites (e.g., plywood and OSB) and preservative- or fire retardant-treated wood, as added chemicals often alter the wood resistance and consequently MC readings. For example, MC readings from damp plywood may overestimate the actual MC by over 10% due to the adhesive and the associated chemicals present.

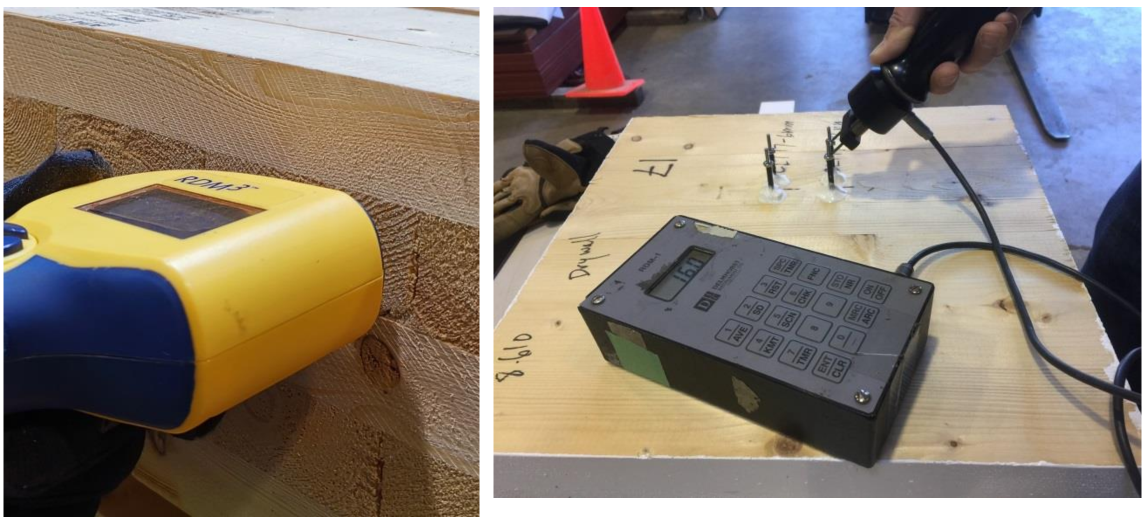

Figure 6 Measuring wood moisture content using a portable pin meter (left) and pre-installed moisture pins (right).

2 CONSTRUCTION MOISTURE MANAGEMENT

2.1 Planning, teamwork

On-site moisture management should be planned for each construction project. This is needed in all climates and becomes particularly important for a large/tall mass timber building in a wet climate/season. As illustrated in Figure 1, the wetting and deterioration risks, potential remedial needs and costs, and protection measures and their costs should be assessed in advance so that when wetting does occur, informed decisions are made and the appropriate actions are promptly implemented.

On-site moisture management requires good communication, cooperation, and coordination among all the parties involved. Major responsibilities include:

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[3] When attempting to measure the moisture content deep in the member, it is important to ensure that the wood moisture around the shaft of the pins do not influence the readings.

- The developer/building owner must recognize the importance of moisture protection and set aside funds to cover extra time and measures needed.
- The project architect should lead in most cases to make sure consistent strategies are applied to protect CLT throughout the entire process (i.e., manufacture, shipping, storage, installation) until the wood is completely protected.
- In jurisdictions, such as British Columbia, where a building envelope consultant is involved, this consultant may be tasked to lead the effort.
- The architect or the building envelope consultant needs to work closely with both the manufacturer and the general contractor to implement specified moisture protection measures.
- The manufacturer and the contractor each should assign a dedicated person to implement protection measures and to monitor wood MC.

2.2 Overarching strategies, principles

The following principles and strategies should be applied to each building project.

- Minimize the time of exposure to the elements, particularly for horizontal elements that allow liquid moisture to pool. As a general rule, the total exposure time of a CLT member should not exceed two months in any climate.
- Take advantage of off-site prefabrication, including precutting and drilling for connections and various service openings to minimize site work and time (Figure 7).
- Schedule timber installation during a relatively dry season, if possible.
- Coordinate material delivery for just-in-time installation to eliminate site storage needs.
- Install the roof and complete the enclosure as early as possible to protect the entire structure.
- The structure and each assembly should be designed to minimize the potential of trapping moisture and to allow drying. For example, some drainage and ventilation mechanisms may be introduced in a CLT assembly.
- The MC of CLT should be kept below 19% before enclosure. Pay more attention to areas with higher risks (e.g., end grain) when measuring MC.
- Be aware that layers that encapsulate or shields the CLT panel (e.g., addition of membranes, concrete layers, and low permeance insulation) slows down drying. A MC of 16% should be targeted before the CLT is covered with a low vapour permeance material4.

[4] This can be generally defined to have vapour permeance below 60 ng/Pa•s•m². It can include all roofing membranes, faced polyiso board, 1.5” and thicker extruded polystyrene, 2” and thicker closed-cell spray foam, 1.5 in. and thicker concrete screed, and vinyl coverings.

Figure 7 Installation of pre-cut CLT in a project in Quebec.

2.3 Basic protection

The following basic moisture protection measures from the perspectives of design, manufacture, and construction are applicable to all building projects.

Related to building design:

1. In connections design, the risk of screw failures should be mitigated by considering the potential forces generated by swelling of wood resulting from on-site wetting.
2. Service openings in CLT floor/roof panels should be concentrated at fewer locations as possible to make it easier to apply site-specific measures to prevent water dripping to lower levels.
3. A self-leveling floor screed with a known low water ratio should be specified to minimize excess water from the mix to be absorbed in the CLT floor base panels after the concrete cures.

A manufacturer should:

1. Provide CLT users with customized instructions on site storage and handling.
2. Apply in the factory an end sealer with proven performance on edges, and on pre-made cuts and service openings to reduce water absorption through end grain.
3. Individually cover each panel prior to shipping with taped and secured opaque lumber wrap, or a self-adhesive membrane, when it is specified.

A contractor should:

1. When temporary site storage is necessary:
    a. Members should be stored based on their final positions and installation sequence to facilitate efficient installation.

b. The CLT should be ideally stored in well-ventilated shelters, using dunnage to keep the wood off the ground. The relative humidity of the environment should be controlled for storage over two months.
c. The original wraps should be kept until the CLT is ready for installation (Figure 8). When a wrap is opened, the wrapping should be opened in a manner that prevents rain penetration and encourages drainage and drying. Do not allow water to pool on wrap, especially if the wrap is in contact with the CLT panel.[5]
d. Inspect shelters and stored materials regularly to prevent moisture accumulation.

Figure 8 Wrapped CLT panels before installation.

2. During the installation:
   a. Erection of a floor level should not exceed one week's time.
   b. Promptly remove standing water/snow/ice on installed CLT floors/roofs.
   c. Install tarps prior to night/weekend breaks to cover installed top floors or roofs, when rain is forecasted.
   d. Schedule to install plywood/OSB joint splines on CLT floors/roofs just before the next installation (e.g., concrete screed, roof membranes) to protect the splines from wetting.

2.4 Advanced protection

More advanced site protection is strongly recommended for a building project in a wet climate and when the cumulative exposure time to water is expected to exceed two months[Error! Bookmark not defined.]. The higher initial costs are often offset by reduced time loss, increased construction efficiency and quality, and elimination of re-drying and other remedial needs.

[5] Wrap is somewhat vapor permeable and will eventually allow water to seep through if water is allowed to pool.

In addition to the above-described principles and basic measures, one of the following three options is recommended to further reduce the wetting risk.

- **Option 1:** Creating water-proof shells with existing walls and floors through construction sequencing and localized compartmentalization

This aims to utilize existing building components to efficiently shelter the inside structure before a full enclosure is possible. The parts of the building including floors and exterior walls, starting from lower levels should be made completely watertight as early as the construction allows. This also allows the lower floors to be made safer in terms of fire risks, as it allows drywall to be installed early.

a. Install exterior walls quickly following erection of the main structure. Avoid building more than two storeys of open floors without exterior walls during the construction.
b. Install and make continuous as soon as possible water-resistant barriers of the exterior walls.
c. Seal floors using membranes and concrete screed so that they are able to function as a temporary roof (Figure 9; Figure 10).

For example, in a 6-storey platform building with interior load-bearing columns supporting CLT floors, the bottom three levels can be compartmentalized and sealed in advance during the construction. Once exterior walls, with continuous water-resistant barriers are installed on the 4th level, seal the 5th floor as much as possible, for example, by covering the entire floor with tarps. Afterwards install concrete screed on the 4th floor. The CLT floor may need to be dried in advance under natural or forced drying (e.g., space heating) conditions to meet the MC criterion. Additional efforts may also be necessary to ensure no water will drip to the lower levels before joint splines, concrete screed, drywall, and interior services are installed on each of the lower three floors. The top levels follow suit once the roof is installed.

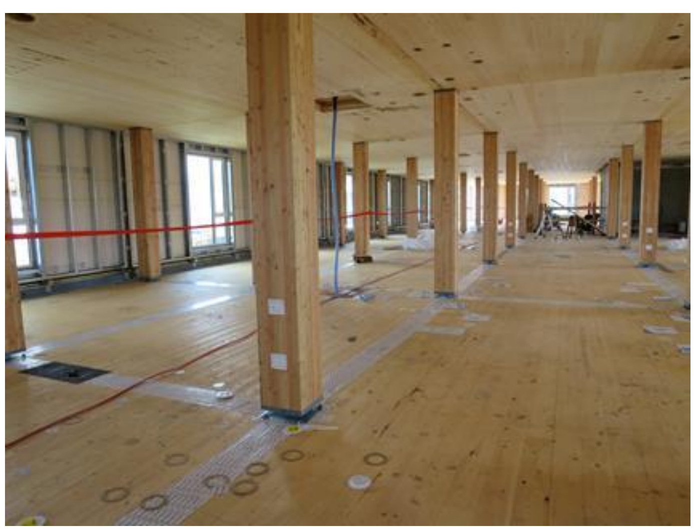

Figure 9 Joints between CLT floor panels sealed with tapes in a project in Vancouver.

Figure 10 A floor is made watertight in a mass timber building in Montreal.

- **Option 2:** floor/roof panel protection through pre-installing self-adhesive membranes

The upper surface of each CLT panel used for a floor or a roof has self-adhered membrane pre-installed in the factory for moisture protection, in addition to applying a sealer on edges and pre-made cuts and service openings.

a. This membrane should resist wear and tear and remain water resistant for the duration of construction.
b. For safety, the membrane used on surfaces where there will be foot traffic during the construction (e.g., floors, roofs) should be assessed to ensure they do not introduce any slipping hazard.
c. A vapour-permeable membrane with proven water resistance should be specified for floor panels. Concrete screed can be directly installed above.
d. For a roof, this membrane will ideally serve permanently as part of the roofing membrane. The installation may require co-ordination with a professional roofer.

e. Any joints and interfaces should be immediately sealed following panel installation to prevent rain/snow melt from seeping through the gaps and getting trapped within the wood members.6
f. Install the exterior walls and the roof as early as possible to provide a complete enclosure.

- **Option 3:** whole-building protection through installing a temporary roof

A temporary roof can be installed to shelter the entire structure or part of the structure. Such weather protection is common in building retrofits to maintain normal living conditions. It will provide the most reliable moisture protection for new construction.

a. A fixed tent, similar to those used in retrofits, can be built with scaffolding and tarps to protect roof and cladding installation (
b. Figure 11; **Error! Reference source not found.**).
c. A movable tent, which is raised as each storey is built, has been used in large timber projects in Europe (see an example in
d. Figure 12). This can provide protection for the entire construction when the budget allows.

Figure 11 Using a temporary tent to protect roof construction in a Vancouver project.

[6] If liquid water has been permitted to accumulate, especially at end grain, assess and take steps to reduce the moisture content. See Drying & Remediation.

Figure 12 Using a liftable temporary roof to protect timber construction in Sweden.

2.5 Drying & Remediation

Wetted wood (including CLT and joint splines) should be dried before it is closed in.

- Actions should be taken to prevent further wetting prior to drying. Any liquid water on the surface should be removed (e.g. by vacuuming or mopping).
- Drying occurs naturally when the ambient environment is favourable; that is, warm air with low relative humidity (e.g., < 65%) (Figure 13).
- Where the ambient environment is not ideal, or the drying needs to be accelerated for quicker enclosure, accelerating the drying process by using fans[7], space heating (electrical heaters preferred), or dehumidification (Figure 14).
- For localized areas, such as joints and connection areas with severe wetting, blowing hot air may provide more efficient drying.
- Non-structural components, such as drywall, insulation, and other coverings may need to be removed or replaced as they may trap moisture and reduce the drying capacity of the wood member.

Other remedial treatments may also become necessary, for example:

- When wetting has caused discolouration (e.g., mould growth, staining) on appearance members, sanding the surface is usually the most efficient way to remove the staining before finishing or refinishing.

[7] Fans may not be effective if ambient relative humidity levels are high.

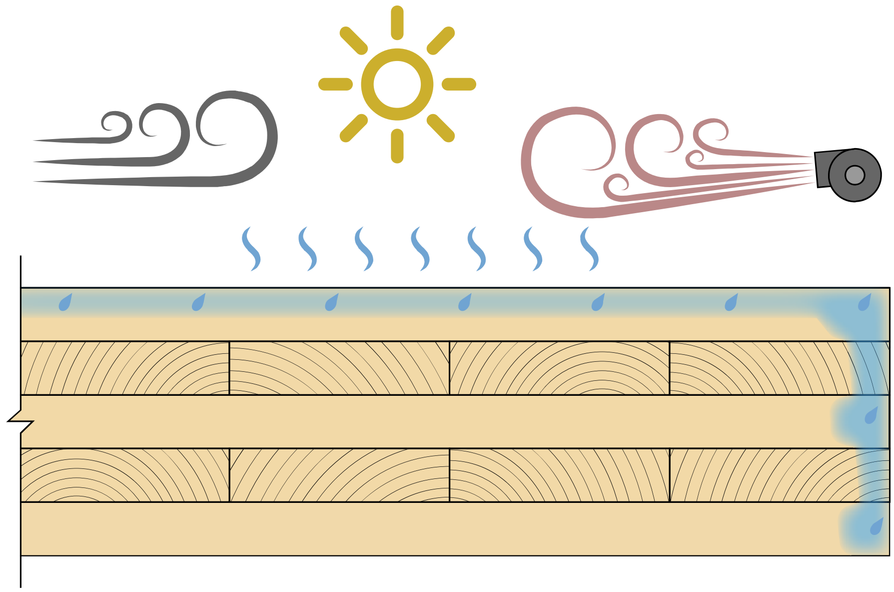

Figure 13 Drying of CLT under favourably environmental conditions.

Figure 14 Drying of timber roof using electrical heating blankets under a temporary roof.

2.6 Protection against Rapid Drying

Aesthetical and dimensional issues arising from excessive checking, cupping, and warping usually result from rapid drying, over drying, or cyclic wetting and drying. They can occur both during construction in a dry climate and in service, particularly when the space is suddenly heated.

- Mechanical humidification is typically applied to maintain the humidity level of the environment and to slow down wood drying.
- A relatively closed space will be needed to apply mechanical humidification during construction in a dry climate.
- Humidity control is important for a mass timber building in its first few years' service to allow the wood to slowly adjust to the service environment.

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