Chapter 1

Timber structures and wood products

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SCOPE OF CHAPTER

This chapter presents an overview of the occupancy groups in buildings and the types of timber structures that can be used to design and construct these buildings. Obviously, the types of construction presented in this chapter may have different names in different countries, but the fundamentals and design principles remain essentially the same.

A description of the various timber and engineered wood products available in the market is also provided. It summarises the manufacturing processes, typical end uses and product certifications, when applicable. Given the large variety of timber products around the globe, some of the engineered wood products presented herein may not be available in all countries.

This chapter is not intended to provide an exhaustive historical review of timber constructions and wood products but rather aims to provide sufficient information for designers, builders, building officials/authorities and fire services to better understand and differentiate the various wood products and timber building systems available.

1.1 TYPES OF BUILDING OCCUPANCY

Building codes around the globe dictate the design and construction of buildings. In a prescriptive building code, the type of building occupancy, the building area (per floor basis, or total), the building height and the presence of an automatic sprinkler system will dictate whether a timber structure is permitted (see Chapter 4). For most buildings, designers will follow prescriptive code provisions to demonstrate code compliance. The prescriptive design allows for a straightforward design and reflects the academic training of most designers. However, some building codes allow the use of performance-based design to demonstrate code compliance. This design method is usually more complex but allows for greater flexibility in the selection of materials and systems. This subsection describes a number of building occupancies where timber structures can be used. Some building codes may allow the use of timber for other building occupancies. Further details on performance-based design can be found in Chapter 11.

1.1.1 Residential buildings

Residential buildings typically refer to buildings destined for sleeping purposes, whether the occupants are primarily transient or permanent in nature (ICC, 2021a). The National Building Code of Canada, NBCC (NRCC, 2015) defines a residential occupancy as “an occupancy or use of a building or part thereof by persons for whom sleeping accommodation is provided but who are not harboured for the purpose of receiving care or treatment and are not involuntary detained”. Examples of such residential buildings are single-family dwellings, semi-detached houses, attached houses, hotels, motels and apartments. However, the term “residential buildings” may include other types of buildings based on the applicable building code. In some building codes, assisted living facilities may be classified as residential buildings. Residences offering care services to residents due to cognitive, physical or behavioural limitations would most likely not be included in this category.

Timber is dominant in residential construction in North America. According to a market analysis conducted by FPInnovations (Chamberland et al., 2020), timber structures represented 97% of the market share of one- to four-storey multi-family (residential) buildings constructed in 2018 in Canada and 94% in the United States. For multi-family five-and six-storey buildings in Canada, timber structures increased from 26% in 2014 to 65% in 2018. This sharp increase coincides with the changes in the NBCC to allow five- and six-storey light timber frame residential construction since 2015. In the U.S., similar buildings represent 63% of the market share. Similar market trends can be observed in many other countries. Figure 1.1 shows some examples of residential buildings using various types of timber structures.

Typical residential buildings will have a high degree of fire-rated compartments because the use of many separating elements, such as floors and walls, provides a certain fire resistance rating based on the applicable building code. A localised fire can nevertheless grow to a fully developed fire, and flashover conditions may be reached, while the fire is still contained to the room of fire origin. In a residential building, it is important to note that building codes usually do not prescribe or differentiate the occupants. Their capacity for self-movement, walking speed and need for a wheelchair are not regulated in a residential building. As such, a broad range of occupants may be found in a residential building and means of egress are to be appropriate. According to the International Code Council *Performance Code for Buildings and Facilities* (ICC, 2021b), occupants and visitors in a

Figure 1.1 Residential buildings using a timber structure: (a) Light timber framed mid-rise building in Canada (photo Cecobois); (b) Residential building in Sweden (photo B. Östman).

residential building are assumed to be not awake, alert or capable of exiting without the assistance of others and are familiar with the building. If motels and hotels are classified in this type of occupancy, the same assumptions apply to occupants, visitors and employees, with the exception that employees are awake.

1.1.2 Office buildings

An office building can be defined as a "*building used principally for administrative or clerical work*" (ISO 6707-1). Examples of office buildings include administrative or professional businesses and commercial and low-level storage occupancies. Building codes may however classify such occupancy in another category.

While the aesthetic and biophilic advantages of timber are widely required by architects, timber has only a modest use in office buildings. With recent trends to construct taller and larger mass timber buildings around the globe, it is expected that the use of timber in office buildings will increase. Figure 1.2 shows examples of office timber buildings.

Office building design usually consists of large open spaces with moveable partitions, which result in long floor spans. In such an open-space concept, localised fires may be of primary concern as opposed to a fully developed fire. Travelling fires can also be an important risk to mitigate. In office buildings, it is assumed that occupants are awake, alert, predominantly capable of exiting without assistance from others and familiar with the building (ICC, 2021b). As such, evacuation can be initiated faster in an office building than in a residential building.

1.1.3 Educational buildings

Based on the applicable building code, educational buildings may be buildings where occupants are gathered for educational purposes, as well as day care services for children. In some other codes, they may be classified as

Figure 1.2 Office buildings using timber product: (a) First Tech Credit Union office in Canada (photo Structurlam Mass Timber Corp.); (b) Hybrid office building in New Zealand (photo A. Buchanan)

"assembly" buildings where occupants gather for civic, social, educational or recreational purposes.

Structural timber has a very low use in educational buildings, with some exceptions with low-rise buildings (one and two storeys) mainly due to prescriptive building codes in some countries imposing such limitations. Wood finish materials are however used in several locations in educational buildings for aesthetic reasons. There has, however, recently been a strong increase in structural timber for gymnasiums and sports complexes. Figure 1.3 shows some educational buildings where timber has been used both for structural elements and finish materials.

Construction of educational buildings is a combination of residential and office building types, where they may consist of large open-space concepts with moveable partitions and a high degree of fire-rated compartments between classrooms. Localised fires, fully developed fires and travelling fires are therefore potential risks that warrant mitigation. In educational buildings, it is assumed that occupants are awake, alert and familiar with the building (ICC, 2021b). Younger occupants (e.g. under the age of 10 years) are assumed to require assistance for safe egress, while older occupants will predominantly be capable of exiting by themselves.

1.1.4 Public buildings

A public building would essentially consist of an assembly occupancy where gatherings are taking place for recreational, commercial or mercantile purposes. Typically, building codes do not classify public buildings but will rather classify their type of assembly (e.g. performing arts, arena type or exterior gathering).

Similar to educational buildings, public buildings typically have low use of timber products mainly due to limitations imposed by prescriptive building codes in some countries. Nevertheless, wood finish materials are widely used for aesthetic reasons, with some low-rise buildings constructed with a

Figure 1.3 Educational buildings using timber products: (a) Université Laval in Canada (photo FPInnovations); (b) Atrium space in educational building in New Zealand (photo A. Buchanan)

Figure 1.4 Public buildings using timber products: (a) Formula 1 paddocks in Canada (Photo Nordic Structures); (b) Parking garage in Sweden (Photo AIX Architects).

timber structure. Figure 1.4 shows some examples of public buildings using various types of timber structures.

Localised fires would most likely be the main risk in public buildings with large open floor areas. Similar to office buildings, it is typically assumed that the majority of occupants are awake, alert and predominantly capable of self-evacuation with little to no assistance or prompting from others (ICC, 2021b).

1.1.5 Industrial buildings

As defined in the NBCC (NRCC, 2015), buildings intended for the assembling, fabricating, manufacturing, processing, repairing or storing of goods and materials would be classified as industrial buildings. Some building codes would further sub-divide industrial buildings based on the level of fire hazard represented by the flammable, combustible or explosive characteristics of materials that can be found within these buildings.

Industrial buildings may also be constructed with mixed occupancies, where industrial use would represent most of the building area, and other occupancies such as offices would be secondary occupancies. In such mixed-occupancy groups, most building codes will require fire-resistance-rated separations, or even sometimes firewalls, to separate one occupancy group from another.

Prescriptive building codes typically allow the use of structural timber for industrial buildings in relatively small areas. However, due to various reasons, such as misperception from insurance companies, timber has limited use in these buildings. Moreover, given that industrial buildings usually require high ceilings, light timber frame construction can be limited due to the available lengths of timber studs, unless engineered wood studs are used. Otherwise, post-and-beam construction could also be used, including for support of overhead cranes. Figure 1.5 shows some examples of industrial buildings using various types of timber structures. Special, active fire protection measures, such as deluge or foam sprinklers, can be used to

Figure 1.5 Industrial buildings using timber products: (a) Industrial building using LVL in New Zealand (photo A. Buchanan); (b) Glulam/CLT manufacturing plant in Canada (photo Nordic Structures ©Adrien Williams).

mitigate fire hazards associated with high-risk materials that can be found inside these buildings. Explosions or localised fires would most likely be the main risks, but fully developed fires can also be challenging. In industrial buildings, it is assumed that occupants are awake, alert and predominantly capable of exiting without assistance from others and familiar with the building (ICC, 2021b).

1.2 TYPES OF TIMBER STRUCTURE

Timber structures have historically been classified based on the type of system resisting gravity loads. In prescriptive building codes, the dimensions and configurations of the building systems would typically dictate the type of timber structure that can be used. While some building codes may classify all types of timber structures into a single category, some building codes allow a wider range of possibilities when using mass timber construction compared to light timber frame construction.

The following subsections provide a summary of the construction techniques of a number of timber structures, including the types of products typically used and comments on their fire performance.

1.2.1 Light timber frame construction

Light timber frame construction is the most dominant type of construction for residential buildings, at least in North America for buildings up to six storeys. It essentially consists of repetitive small-size structural elements made of sawn timber, engineered wood products and structural sheathing.

Balloon-framing was mainly used in the early days of the 20th century. This type of light timber frame construction allowed for rapid housing construction. The wall studs were continuous over the storeys, and the floor joists were supported on horizontal ledgers placed inside notches in the studs. This type of construction could have inherent concealed spaces, forming potential paths for a fire to spread from one storey to another, unless construction details were made to provide adequate fire stopping (Figure 1.6a). The lateral loads were typically resisted by either structural panels or diagonal bracing.

Then came platform-framing. In this type of light timber frame construction, the gravity loads remain supported by wood studs, but each wall is assembled one storey at a time and floor framing is installed at every storey (Figure 1.6b). Each wall is enclosed with top and bottom sill plates, creating inherent fire stopping between storeys. Floor framing is also enclosed by rim boards made of sawn timber or engineered wood products, which also create an inherent fire stopping within the floor. Typically, building codes will require that any openings in assemblies be required to provide fire resistance to be properly sealed by fire-stop materials. Guidance on preventing fire spread is given in Chapter 9. The lateral loads are taken by structural panels for both the floor diaphragms and shear walls. Blocks of sawn timber can be used at mid-height between every wall stud to provide additional nailing to the structural panels. When these blocks are used, an additional inherent fire stopping is created within the wall cavities to limit vertical fire spread.

In platform-framing, the wall studs are generally of sawn timber and may be of structural composite lumber (SCL) to increase the axial compression

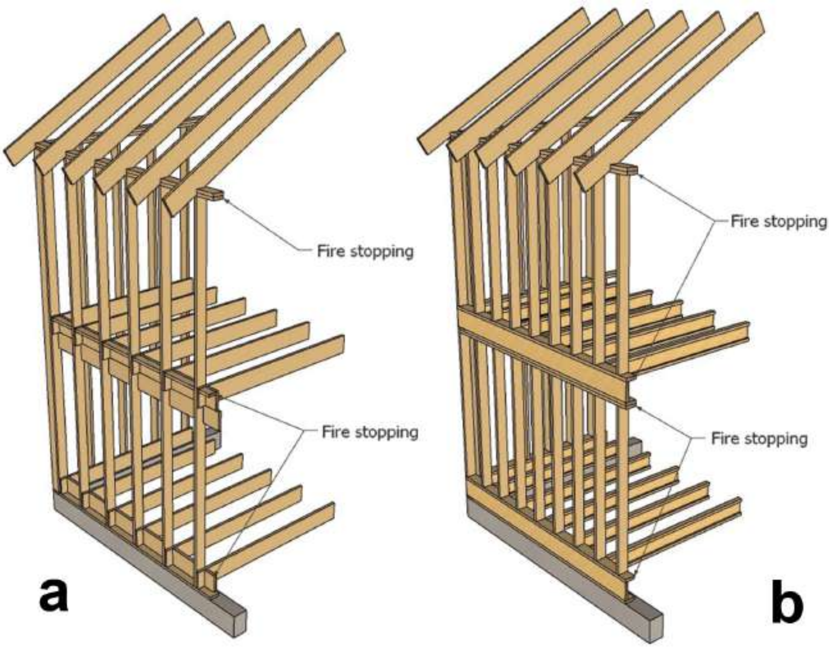

Figure 1.6 Light timber frame construction: (a) Balloon-framing, (b) Platform-framing.

strength of the studs and/or limit shrinkage of the sill plates due to varying moisture content. Using SCL for wall studs can also allow taller walls where sawn timber would otherwise be limited in length, as previously mentioned for industrial buildings. Nowadays, engineered wood products such as prefabricated wood I-joists and metal-plated trusses have replaced many of the traditional sawn timber floor and roof joists. These products allow for increased load-bearing capacities, longer spans for open-space concepts and better dimensional stability.

Given the small dimension of the structural elements, the fire performance of light timber frame construction is typically provided by protective membranes, such as fire-resistance-rated gypsum plasterboards. Service penetrations made through these protective membranes need to be properly protected using fire-stopping devices tested according to the applicable test method in each country. Fire resistance rating of up to 2 hours, and more, can be achieved when tested in accordance with standard test methods such as ASTM E119, CAN/ULC S101 and EN 1363-1, among others.

Light timber frame assemblies can provide excellent fire performance, provided that they are detailed and constructed appropriately. Further guidance on proper detailing is provided in Chapter 9.

1.2.2 Post-and-beam construction

The modern post-and-beam timber construction is the logical evolution of the traditional system called "timber frame". Traditionally, post-and-beam construction, or "heavy timber" construction, used timber structural elements of large dimensions and cast-iron caps to transfer the loads from one storey to the other, as well as connections between main to secondary beams using timber embedment, wood pegs and dovetails, as examples. It then evolved by using metallic fasteners such as bolts, dowels and hangers for side connections, as would be done in steel framing.

Nowadays, post-and-beam timber construction is taking full advantage of timber embedment strength for connections as well as the use of innovative fasteners, such as long and slender self-tapping screws. Engineered wood products such as glued laminated timber and structural composite lumber are now widely used in lieu of sawn timber. Floors and roofs typically consist of timber decking or panels made of glued laminated timber, structural composite lumber or mass timber. With the advances in computer numerical control (CNC), machining of timber elements for drilling holes for fasteners and embedding metallic plates for concealed connections, it is much easier to design and install this type of construction with a high level of precision.

Similar to steel framing, the lateral loads are typically resisted by braced frames or moment-resisting connections (although less popular), while the floors and roof elements act as diaphragms. Figure 1.7 shows examples of post-and-beam timber construction.

Figure 1.7 Post-and-beam timber constructions: (a) Old timber frame in Canada (Photo FPInnovations); (b) Modern post-and-beam construction using braced frames in Canada (Photo A. Buchanan).

Traditional post-and-beam timber construction has a long history demonstrating its inherent fire performance. In some building codes, "heavy timber" construction can be used in many applications where a non-combustible construction would otherwise be required. The large dimensions of the structural elements allow for maintaining their structural strength for long fire exposure. The load-bearing performance of timber elements can easily be calculated using their charring rates and other design assumptions, as detailed in Chapter 7. Information on the fire performance of connections can be found in Chapter 8.

1.2.3 Mass timber construction

Mass timber construction is a new type of timber construction that originated with the strong market acceptance and penetration by European cross-laminated timber (CLT) and was then rapidly adopted by other countries. While the term "mass timber" is relatively new, it is not necessarily a new type of construction as it was traditionally used in old buildings made of post-and-beam construction. The floor construction called "mill floor" consisted of sawn timber elements placed on edge, side-by-side, and nailed together, creating a massive thick timber slab (also called nail-laminated timber (NLT)).

Mass timber construction is the logical continuation of the post-and-beam timber construction detailed above, but with larger and longer plates used as wall and floor panels similarly to precast concrete construction. Cross-laminated timber is among the first modern timber products used in mass timber construction, where it is used for load-bearing walls, partitions, as well as floors and roofs. With the desire to increase the diversity of mass timber panels, mechanically laminated timber, such as nail-laminated timber and dowel-laminated timber, is now slowly gaining popularity. Figure 1.8 shows examples of mass timber panel construction.

Figure 1.8 Mass timber panels construction: (a) Old mill floor in Canada (Photo FPInnovations); (b) Sara Cultural Centre and hotel, 19 storeys, Skellefteå, Sweden (Photo Jonas Westling).

Nowadays, mass timber panels are used in conjunction with post-and-beam construction to reduce the amount of timber, limit the cost and offer greater design flexibility, such as open-space concepts. Engineered wood products such as glued laminated timber and structural composite lumber are used for gravity loads (columns and beams), while mass timber panels are used for floors and roofs, as well as lateral load-resisting systems.

An inherently high level of fire resistance is provided in a building made of mass timber panels, especially when it is fully built with mass timber walls, roof and floor panels. As with post-and-beam construction, the large dimensions of the structural elements allow for maintaining their structural strength for long fire exposure. Panelised elements provide the separating function to limit heat transmission and passage of flames, in addition to the load-bearing performance. Additional information on the separating function and load-bearing performance can be found in Chapters 6 and 7, respectively. Information about detailing of mass timber panels for fire safety can be found in Chapter 9.

1.2.4 Long-span structures

Timber structures also have a long history for long-span structures, in sports complexes and in industrial buildings. These applications however require a high level of expertise and knowledge in timber design and structural engineering so that loads are transferred adequately and long-term serviceability performance, including creep, dimensional changes and durability due to moisture content, is ensured.

From their structural design efficiency, curved arches made of glued laminated timber have widely been used for long-span applications and of various geometric shapes (simple or multiple curvatures). They allow for high roof clearance, as required for ice rinks, soccer stadiums and indoor water parks. Depending on the span, they can be of single, double or multiple elements.

A great engineered timber building is the Moffett Field hangar II near San Francisco, U.S. Completed in 1943, it consists of trusses made of large timbers constructed during World War II to serve the US Navy blimp surveillance programme. The timber structure follows a parabolic shape that is 328 m long by 90.5 m wide and 52 m in height to accommodate the profile of the airships contained in it.

Another structural system used in timber is the grid shell. This system allows for long spans and open-space concepts. An example of such system is the Odate dome built in Japan in 1997. The entire structure has a height of 52 m and an impressive span of 178 m along the major direction and 157 m in the minor direction. Grid shell systems have been used in some projects in Europe and recently for the three domes at the Taiyuan Botanical Garden in China. The domes range from 43 to 88 m in diameter and from 12 to 30 m in height. The dome design team claims that the largest of the three domes is the longest clear span timber grid shell in the world. Figure 1.9 shows examples of long-span timber structures.

As with post-and-beam construction, the large dimension of the structural elements used for long-span applications allows for maintaining their structural capacity for long fire exposure. The load-bearing performance of timber elements exposed to fire can easily be calculated using their charring rates and other design assumptions, as detailed in Chapter 7. In most buildings where arches are used, it is unlikely that a localised, travelling or fully developed fire can generate sufficient hazard to challenge the members and their connections at the top of the building, so more attention should be made to the lower ends. Moreover, it is likely that these buildings would require protection by automatic sprinkler systems.

Figure 1.9 Long-span timber systems: (a) Soccer stadium in Canada (67.6 m span) (Photo Nordic Structures © Stéphane Groleau), (b) Timber grid shells in China (43 to 88 m span) (Photo StructureCraft).

As such, some building codes may not require all the structural elements to be fire resistance rated.

1.2.5 Hybrid structures

All structures are essentially hybrid, as they consist of various materials used together to form a distinct system or structure. Hybrid structures can consist of any mix of materials at various locations within a building. A hybrid structure can consist, for example, of a gravity system made of timber and a lateral load-resisting system made of reinforced concrete core walls or steel braces. Using lateral load-resisting systems made of concrete or steel braces typically allows for using greater ductility and strength capacities. However, some mass timber panels can also provide the same lateral performance as that of concrete and steel.

Hybrid structures can also be horizontal elements made of timber, concrete and steel, such as a timber slab or beam connected to a concrete slab, steel joists or beams connected to a timber slab, etc. The use of hybrid horizontal systems typically allows for longer spans by positioning each material at its best location to take full advantage of its mechanical resistance. They also enhance serviceability performance such as acoustics, floor vibrations and deflections.

Long-span structures, as detailed in the previous subsection, can also be hybrid where timber would be positioned where the elements are solicited mainly in axial compression and steel tendons would be solicited in axial tension. This allows for pre-stressed systems to enhance serviceability performance.

When designing for fire resistance, each material needs to be considered, along with the potential impact from one to the other. As an example, the timber component of a timber–concrete composite slab exposed to fire will char and the residual timber will reduce in size with time and change the stress distribution between the two materials as well as the shear connectors used to fasten them together. Heat transfer between materials may also be a challenge where, as an example, a steel beam connected to a timber slab will accelerate localised charring in the vicinity of the steel beam due to heat conduction. Figure 1.10 shows examples of hybrid structures using timber, concrete and steel.

1.2.6 Prefabricated elements and modules

Industrialised building systems for multi-storey timber construction are being used increasingly in northern Europe during the first decades of the 2000s. They emerged from a long tradition of prefabricated single-family houses starting in the early 1900s. Still about 90% of all single-family houses in Sweden are built in timber. A whole house, or two-dimensional building elements, mainly walls, are built in a factory and brought to the

Figure 1.10 Hybrid structures: (a) Brock Commons in Canada – mass timber construction and reinforced concrete vertical shafts (photo Naturally Wood), (b) Meadows Recreational Center in Canada – Glued laminated timber and steel roof structure (photo Western Archrib).

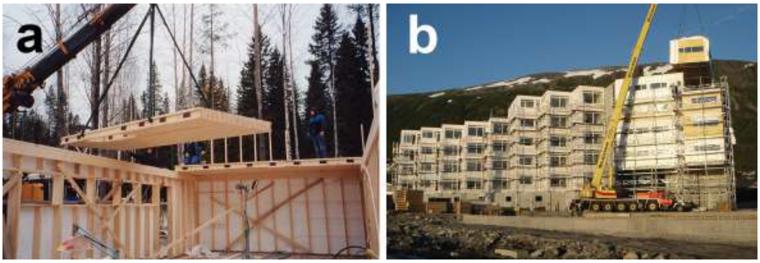

Figure 1.11 Prefabricated elements and modules: a) Prefabricated mass timber floor in Northern Sweden, late 1990s (Photo Martin Gustafsson), (b) Modular houses in Norway (Photo Kodumaja).

building site. This technique has a lot of advantages, including close control of the building process, dry conditions, and a fast building process. Figure 1.11 shows examples of prefabricated elements and modules.

When taller timber buildings became allowed in Sweden in the late 1990s, it was natural to adopt the prefabricated system for multi-storey design. Different techniques have been applied and two-dimensional elements are now often made with CLT panels, while three-dimensional (3-D) volumetric modules are mainly timber frame structures. The 3-D modules may be load-bearing themselves or integrated into a separate load-bearing structure e.g. with post and beam. The latter is the case for the 14-storey high Treet building in Norway.

Prefabricated volumetric modules were initially used for small apartments e.g. accommodation for students, but they are now used for larger apartments consisting of several volumetric components, where the kitchen and/or bathrooms are built as separate modules and put together at the building site. One limiting factor is the size of elements or modules to be road transported.

1.3 STRUCTURAL TIMBER PRODUCTS

There is a wide variety of structural timber products available in the market. In the past few decades, many engineered wood products (EWPs) have been developed and commercialised as a substitute for traditional wood products. These EWPs are designed and manufactured for better use of the raw material, eliminating natural characteristics of timber that may have a negative impact (i.e. knots, wane, etc.), reducing waste from timber sawmills and reducing the amount of timber required for manufacturing a homogenous and stronger product.

Provided that the wood feed-stock is obtained from renewable forestry operations, all of these structural timber products provide great benefits for low carbon construction. The sequestered carbon stored in structural timber far exceeds the small amount of fossil fuel energy required to manufacture the wood products, and this can be used to offset the carbon released in manufacturing the other components of a building. Timber buildings hence have a much lower carbon footprint than similar buildings made from traditional materials such as steel and concrete.

The following sections describe some of the various structural timber products available in the market. The products presented below are largely based on current technologies and products available in North America and Europe.

1.3.1 Sawn timber

Sawn timber is among the oldest construction material. Sawn timber, called lumber (or dimension lumber) in some countries, is defined by ASTM D9 as a product of the sawmill and planing mill, usually not further manufactured other than by sawing, resawing, passing lengthwise through a standard planing machine, crosscutting to length, and matching. In some countries, the term timber can also refer to a wood element of minimum dimensions, differentiating them from smaller elements called lumber. In North America, the structural elements are named based on their nominal dimensions rather than actual sawn dimensions. As examples, a nominal 2″ × 10″ lumber joist is actually 38 × 235 mm (1½″ × 9¼″), and a nominal 6″ × 6″ timber beam is 140 ×140 mm (5½″ × 5½″). Other countries typically specify the actual (net) dimensions rather than the nominal dimension. For structural applications, building codes typically require that sawn timber has a moisture content no greater than 15% to 19% at the time of installation. As such, it is usually dried to a suitable moisture content prior to installation. In light timber-framed buildings of five and six storeys, dimensional changes due to drying during the service life can be significant and considerations should be given to limiting such shrinkage.

There are various types of sawn timber (lumber) used in construction and available on the market. Typically, softwood species are used for structural applications, while hardwoods are used for finishing materials. In some jurisdictions, hardwoods may however be used in structural applications, including the manufacturing of engineered wood products such as glued laminated timber. Structural products are required to be evaluated by their respective standards, such as those of the National Lumber Grades Authority (NLGA) in Canada, the American Lumber Standard Committee (ALSC) in the U.S., the European standard EN 15497 and the Australian/New Zealand standards AS 2858 and AS/NZ 1748.

The most common type of sawn timber is visually graded, which is sometimes also categorised within specific wood species groups. Based on visual observations by a trained inspector, the boards are visually graded into various classes, which are assigned mechanical properties based on regular quality control monitoring by the grading agency. This ensures that the grading is being made properly and that the mechanical properties published in wood design standards are maintained. Some of the visual characteristics used for classifying timber are the slope of grain, moisture content, knots and wane. Distortion of timber boards due to bow, crook, cup and twist also affect their grading. Standard test methods usually specify how to address the potential strength and stiffness reduction factors.

Some sawmills use mechanical grading of sawn timber, such as mechanically stress rated (MSR) and mechanically evaluated lumber (MEL). Both MSR and MEL refer to structural timber that has been graded for stiffness by means of a non-destructive test and subjected to similar visual grading as the visually graded timber. These testing techniques allow for a better evaluation of the raw material by non-destructively testing mechanical properties, mainly the modulus of elasticity. They also allow mills to sort timber exhibiting higher mechanical properties, thus providing a higher structural grade for stronger timber. Non-destructive testing is also widely used in the manufacturing of EWPs so that manufacturers can ensure that the timber used in the manufacturing process meets or exceeds the quality control criteria.

Lastly, sawn timber (lumber) can also be remanufactured into various products, such as finger-jointed lumber, face-glued lumber or edge-glued lumber. These types of EWPs allow for eliminating natural defects that may be present in visually graded lumber by remanufacturing smaller and/or shorter pieces together to form long and dimensionally stable products. The resulting products are widely used in the manufacturing of EWPs, such as those detailed in the following sections. When finger-jointing, face-gluing or edge-gluing is used, the fire performance of the adhesives should be properly evaluated so that the adhesives do not become the weak link in the fire resistance of the resulting product (see Chapter 7).

Due to their small cross-sections, the fire performance of typical sawn timber relies on the use of claddings or membranes (e.g. fire-resistance-rated gypsum plasterboard), unless the applicable building code allows them to remain exposed (unprotected). Otherwise, the load-bearing performance of larger timber elements can be calculated using their charring rates and other design assumptions, as detailed in Chapter 7.

1.3.2 Wood I-joists

Since the creation of prefabricated wood I-joists, the market has rapidly grown as an alternative to solid sawn timber joists and roof rafters, especially in light timber frame construction. A prefabricated wood I-joist is defined as "*a structural member manufactured using sawn or structural-composite lumber flanges and structural panel webs, bonded together with exterior grade adhesives, forming an "I" cross-sectional shape*" (ASTM D9).

Wood I-joists were first commercialised by the American company Trus Joist Corporation in the 1960s (Williamson, 2002). The main advantages of prefabricated wood I-joists are their light weight, longer allowable spans and low cost when compared to traditional sawn timber joists. They are typically used as floor joists and in some applications as roof joists. With an increasing demand for energy-efficient building envelopes, we are now seeing prefabricated wood I-joists used as wall studs. Their depths allow for a greater insulated cavity.

The I-shape cross-section allows for more efficient use of the timber resource, with flanges subjected to axial stress and web panel subjected to shear stress. Flanges are typically made of finger-jointed sawn timber or structural composite lumber (see Figure 1.12). They have various dimensions, resulting in varying bending resistance and stiffness. Web panels used to be made of plywood or hardboard but have changed to oriented strand boards (OSB) over the years. Some producers commercialise wood I-joists

Figure 1.12 Prefabricated wood I-joists: (a) Sawn timber flanges (photo FPInnovations); (b) LVL flanges (photo APA Wood).

with web materials from other types of panels such as high-density fibreboard (HDF).

Wood I-joist manufacturers usually offer their products in standardised dimensions. The available depths typically vary from 235 to 406 mm (9¼″ to 16″), with some special deeper joists. Prefabricated wood I-joists are required to be manufactured and evaluated according to specific standards, such as ASTM D5055 for North America. As an example, ASTM D5055 provides the minimum requirements with respect to procedures for establishing, monitoring, and re-evaluating structural capacities such as shear, reaction (bearing support), bending moment, and stiffness. Requirements for adhesives performance used for flange finger joints, web-to-web joints and web-to-flange joints are typically also provided. While there is currently no standard in Europe, I-joists may conform to the European Assessment Document (EAD 130367-00-0304) for CE-marking.

Due to their inherently small cross-section, the fire performance of prefabricated wood I-joists typically relies on either the use of claddings or membranes (e.g. fire-resistance-rated gypsum plasterboard) or web protection materials, unless they are specifically allowed to remain unprotected by the applicable building code. Manufacturers can provide floor and roof assemblies made with prefabricated wood I-joists that can achieve up to 2 hours of fire resistance. Given the proprietary nature of these products, it is recommended to consult with the manufacturers for proper detailing. Some general guidance is given in Chapter 7.

1.3.3 Metal plate wood trusses

Similar to prefabricated wood I-joists, metal plate timber trusses are used as an alternative to solid sawn timber joists and roof rafters in light timber frame construction. Their main advantages are light weight, longer allowable spans and low cost when compared to traditional sawn timber joists. They are typically used as floor trusses and widely used as roof trusses in North America.

A typical truss consists of top and bottom chords (flanges) and diagonal webs forming a triangular shape using sawn timber or structural composite lumber. Junctions between chords and webs are fastened together using proprietary galvanised steel plates, also called truss plates. Usually, a floor truss would have parallel chords positioned flatwise (i.e. wide dimension of the timber parallel to the floor plan), while roof trusses will have the chords positioned edgewise (narrow dimension parallel to the roof plan) either parallel or sloped. Figure 1.13 illustrates metal plate trusses and some truss plates available on the market.

Some countries have enforced quality control standards for the manufacturing of metal plate timber trusses. Trusses can be designed and manufactured in almost infinite shapes and spans. Given the long roof spans that can be achieved by metal plate timber trusses, proper lateral

Figure 1.13 Images of metal plate trusses: (a) Floor trusses (photo FPInnovations); (b) Roof trusses (photo Naturally Wood).

bracing is crucial to ensure the stability of the compression chords and webs against buckling. The structural design is typically in accordance with the applicable timber design standard and proprietary metal plate design information. As an example, the Truss Plate Institute of Canada (TPIC) and Standards Australia publish standards that establish minimum requirements for the design and construction of metal plate timber trusses, including the materials used in a truss (both lumber and steel), the design procedures for truss members and joints as well as manufacturing and material variances and erection tolerances (TPIC; AS 1720.5). Guidance for lateral bracing is also typically provided in truss design standards. In Europe the metal plate web trusses are produced according to EN 14250 and designed according to Eurocode 5 (EN 1995-1-1 and EN 1995-1-2).

Similar to prefabricated wood I-joists, the fire performance of metal plate timber trusses typically relies on the use of cladding or membranes (e.g. fire-resistance-rated gypsum plasterboard), unless specifically allowed to remain unprotected by the applicable building code. Some manufacturers have floor and roof assemblies made with metal plate timber trusses that can achieve up to 2 hours of fire resistance. Given the proprietary nature of these products, it is recommended to consult with the manufacturers for proper detailing.

1.3.4 Structural composite lumber

Structural composite lumber (SCL) is a generic category of structural engineered wood products that includes laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL) and oriented strand lumber (OSL), as illustrated in Figure 1.14. Structural composite lumber (SCL) is defined as "*a composite of wood elements (for example, wood strands, strips, veneer sheets, or a combination thereof), bonded with an exterior grade adhesive and intended for structural use in dry service conditions*" (ASTM D9). See also Section 1.3.6 on mass timber panels.

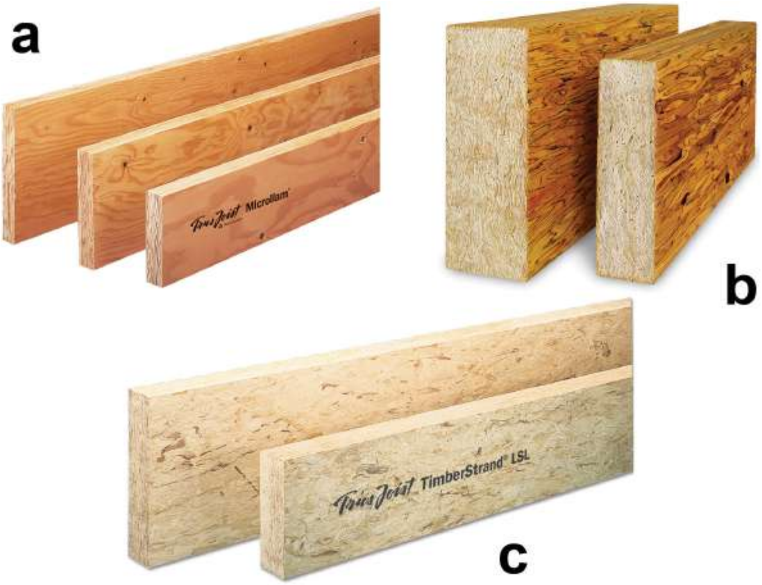

Figure 1.14 Structural composite lumber (photos courtesy of Weyerhaeuser): (a) LVL – Laminated Veneer Lumber; (b) PSL – Parallel Strand Lumber; (c) LSL – Laminated Strand Lumber.

LVL and PSL were first introduced into the market in the 1970s and 1980s, respectively (Williamson, 2002). LSL and OSL were introduced shortly after PSL. Their main advantages are the efficient use of the timber resource, higher strength and stiffness and longer spans. They are typically used as beams, columns, lintels and joists, with some applications as chords in metal plate trusses. SCL is also used as studs in mid-rise light timber frame construction (five and six storeys) where greater axial capacity is required at the lower levels, as well as sill plates for limiting building vertical displacement due to moisture shrinkage. Being manufactured at an initial low moisture content, SCL products tend to be more dimensionally stable than traditional sawn timber when subjected to varying degrees of moisture content during service.

Laminated Veneer Lumber (LVL) is defined as “a composite of wood veneer sheet elements with wood fibres primarily oriented along the longitudinal axis of the member, where the veneer element thicknesses are 0.25 in. (6.4 mm) or less (ASTM D9).”

LVL is manufactured in a similar manner as plywood, with the exception that the wood grain of the veneers is mostly oriented longitudinally to the main strength direction (i.e. towards the LVL length). LVL is often manufactured in a continuous process so the resulting products can be longer and stronger than traditional sawn timber.

Parallel Strand Lumber (PSL) is defined as

> *a composite of wood veneer strand elements with wood fibres primarily oriented along the longitudinal axis of the member, where the least dimension of wood veneer strand elements is 0.25 in. (6.4 mm) or less and their average lengths are a minimum of 300 times the least dimension of the wood veneer strand elements.*
>
> (ASTM D9)

PSL is manufactured by gluing wood strands to form a condensed thick piece of timber in such a way that the wood grain of the strands is oriented longitudinally to the main strength direction (i.e. towards the PSL length). Wood strands may be cut from the residue of plywood or LVL manufacturing plants.

Laminated Strand Lumber (LSL) is defined as

> *a composite of wood strand elements with wood fibres primarily oriented along the longitudinal axis of the member, where the least dimension of the wood strand elements is 0.10 in. (2.54 mm) or less and their average lengths are a minimum of 150 times the least dimension of the wood strand elements.*
>
> (ASTM D9)

Manufacturing process of LSL is somewhat like that of OSB. It requires, however, a higher degree of strand orientation and greater pressure to form the thick piece of timber. As with PSL, wood grain of the strands is oriented longitudinally to the main strength direction (i.e. towards the LSL length). Wood strands may be cut from the residue of plywood, LVL or PSL manufacturing plants. LSL usually has lower strength and stiffness than LVL and PSL.

Oriented Strand Lumber (OSL) is defined as

> *a composite of wood strand elements with wood fibres primarily oriented along the longitudinal axis of the member, where the least dimension of the wood strand elements is 0.10 in. (2.54 mm) or less and their average lengths are a minimum of 75 times the least dimension of the wood strand elements.*
>
> (ASTM D9)

The manufacturing process of OSL is similar to that of LSL, with the exception that shorter strands are used. As with LSL, the wood grain of the strands is oriented longitudinally to the main strength direction (i.e. towards the OSL length). Wood strands may be cut from the residue of plywood, LVL, PSL or LSL manufacturing plants. OSL usually has lower strength and stiffness than LSL.

As with prefabricated wood I-joists, SCL manufacturers offer products in standardised dimensions ranging from 89 to 508 mm (3½″ to 20″) in depth, 38 to 178 mm (1½″ to 7″) in width and up to 18 m (60′) in length. SCL products are required to be manufactured and evaluated according to specific standards, such as ASTM D5456 in North America, which provides the minimum requirements with respect to initial qualification sampling, mechanical and physical tests, analysis, and design value assignments. Requirements for adhesive performance at elevated temperatures and/or fire conditions are typically also provided. While there are currently no other standards equivalent to ASTM D5456 applicable to all SCL products, LVL products are to be evaluated per European standard EN 14374 and Australia/New Zealand standard AS/NZS 4357.0. A European LVL Handbook is also available to provide design information for code compliance (LVL Handbook, 2020).

SCL products can be used as a single element or as built-up elements using nails, screws or bolts. When used as a single element, from either a single and large piece of SCL or an SCL obtained from a secondary face-gluing process, their fire performance and charring behaviour are similar to traditional sawn timber (Dagenais, 2014; White, 2000; O’Neill et al., 2001), provided the adhesive used for secondary gluing is a structural adhesive meeting the requirements to resist elevated temperatures and/or fire conditions. Structural fire resistance of SCL can therefore be determined based on the same design principles as those detailed in Chapter 7.

However, built-up elements made with metallic fasteners may not have the same fire performance as a single element of the same dimensions. Connections used to secure SCL elements together may not prevent the individual elements from separating when exposed to fire, which can lead to increased localised charring between the SCL elements (O’Neill et al., 2001). Proper caution should be taken when built-up SCL elements are required to provide some level of fire resistance.

1.3.5 Glued laminated timber

Glued laminated timber, also called glulam, can be defined as “*a product made from suitable selected and prepared pieces of wood bonded together with an adhesive whether in a straight or curved form with the grain of all pieces essentially parallel to the longitudinal axis of the member*” (ASTM D9). Its manufacturing allows for small or large structural elements, either straight or curved.

Glulam is one of the oldest engineered wood products and still much used in the timber construction market. According to Williamson (2002), glued laminated timber was first patented in Switzerland in the 1890s. It was then first used in the United States in the construction of the USDA Forest Products Laboratory in Madison (WI).

As with other EWPs, the main advantages of glulam are the efficient use of the timber resource, higher strength and stiffness and longer spans. Glulam is typically used as beams, columns, lintels and joists, with some applications as planks and decking in post-and-beam and mass timber constructions (see Figure 1.15). Given their flexibility to meet various shapes, they are also the most widely used EWP for the design and manufacturing of long-span arches. Moreover, being manufactured at an initial low moisture content, glulam tends to be more dimensionally stable than traditional sawn timber when subjected to varying degrees of moisture content during service.

The layup (or configuration) of glued laminated timber is based on the theory of composite materials, where each lamination has its own strength and stiffness characteristics and is positioned to result in effective strength and stiffness of the finished cross-section. Typically, laminations with the greatest mechanical properties are positioned towards the outer surface (also called tension laminations), where the axial stresses are at their maximum in a flexural element. Lower quality timber is used within the core (also called core laminations), with some intermediate requirements in between.

The manufacturing of glued laminated timber is usually regulated by the applicable building codes and standards. In Canada, glued laminated timber is manufactured in accordance with CSA O122 standard and manufacturing plants are to conform with CSA O177. In Europe the product standard is EN 14080, and in Australia/New Zealand AS/NZS 1328.1. These standards provide the minimum requirements for the materials to be used such as the timber and adhesives, as well as the minimum requirements

Figure 1.15 Structural glued laminated timber: (a) Post-and-beam construction using glulam and prefabricated wood I-joists (photo FPInnovations); (b) Curved beams and decking at ATCO commercial centre in Canada (photo Western Archrib).

for qualification testing and quality control. With respect to the fire performance of adhesives used in glued laminated timber, an international survey highlighted significant differences exist between countries (Wiesner et al., 2018). As such, it is strongly recommended to consult the appropriate standards accreditation bodies for assessing whether imported glued laminated timber is suitable and conforms to the applicable building codes and standards in the importing country. Effects of glueline fire performance can be found in Chapters 2, 3, 6 and 7.

Glued laminated timber has excellent inherent fire performance. The large cross-section allows for structural elements to char slowly and at a predictable rate, allowing them to sustain the applied loads for a long duration. Structural fire resistance of glued laminated timber can therefore be determined based on the same design principles as those detailed in Chapter 7.

Moreover, some countries such as Canada and the United States provide special provisions for fire-resistance-rated glued laminated timber beams, without specific calculations being necessary. For example, a beam requiring a one-hour fire resistance rating when exposed to fire from three sides (top is protected) shall be manufactured to the layups specified in the manufacturing standards, except that one core lamination shall be removed and one 38 mm thick outer tension lamination added on the bottom (see Figure 1.16). When such special manufacturing is made, the glued

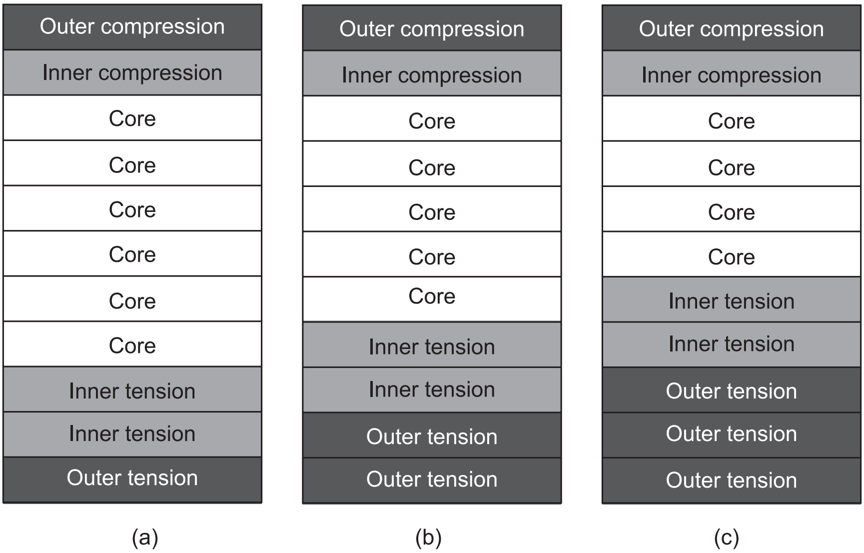

Figure 1.16 Manufacturing provisions for fire-resistance-rated glulam beams, as presented in CSA O86: (a) No fire resistance rating; (b) 1-hr fire resistance rating; (c) 2-hr fire resistance rating.

laminated timber beams should have a mark (stamp) specifying their fire resistance rating.

1.3.6 Mass timber panels

Mass timber panels, or plates, are essentially large timber panels used as floors, roofs and wall panels. They were traditionally used in old timber buildings made of "mill floors", but, with advances in timber engineering and manufacturing processes, new mass timber panels have recently emerged such as cross-laminated timber (CLT), mechanically laminated timber (MLT), mass plywood panels and mass OSB panels.

CLT is defined as "*a prefabricated engineered wood product made of at least three orthogonal layers of graded sawn lumber or structural composite lumber (SCL) that are laminated by gluing with structural adhesives*" (ANSI/APA 2019). In Europe the definition is similar, but the need for fire-resistant adhesives is not mentioned (EN 16351). Laminating orthogonally allows for enhanced dimensional stability and for bi-directional structural elements. However, CLT panels are mainly used as uni-directional structural elements where the laminations oriented along the strength axis carry most of the applied stress. Typically, the strength axis, or major direction, is oriented towards the longitudinal dimension of the CLT (e.g. span of a floor panel or height of a wall panel). Figure 1.17a illustrates a typical CLT panel.

As with glued laminated timber, manufacturing standards such as ANSI/APA PRG 320 for use in North America CLT specifies the minimum requirements for the materials to be used such as the timber and adhesives, as well as the minimum requirements for qualification testing and quality control. In Europe, CLT should comply with EN 16351, although it is not yet adopted by the European Commission as a formal European standard. Canadian, American and Swedish handbooks are also available to provide design information until the product becomes recognised in building codes (Karacabeyli & Douglas, 2013; Karacabeyli & Gagnon, 2019; Swedish Wood, 2019).

CLT is a relatively new EWP, and most building codes and standards do not fully address the use of this product. The international survey referenced

Figure 1.17 Mass timber panels: (a) Cross-laminated timber (Photo APA Wood); (b) Dowel-laminated timber panels (Photo StructureCraft).

in Section 1.3.5 with respect to fire performance of adhesives in engineered wood products highlighted significant differences between countries (Wiesner et al., 2018). It is therefore strongly recommended to consult the appropriate standards accreditation bodies for assessing whether imported CLT is suitable and conforms to the applicable building codes and standards in the importing country. Effects of glueline fire performance can be found in Chapters 2, 3, 6 and 7.

CLT has excellent inherent fire resistance. The large cross-section allows for the elements to char slowly and at a predictable rate, allowing them to sustain the applied loads for a long duration. Structural fire resistance of CLT can therefore be determined based on the same design principles applicable to timber as those detailed in Chapter 7, where the thermal performance of adhesives is explained. Additional information on the separating function performance can be found in Chapter 6, while information about the detailing of CLT structures can be found in Chapter 9.

Mechanically laminated timber (MLT) is an engineered wood product made by connecting graded timber laminations on edge with mechanical connectors that are inserted through the wide face of the laminations. MLT panels are typically used as one-directional structural elements and can be manufactured with various profiles for aesthetic purposes or to improve acoustic performance. While technical guides about best practices are available (BSLC, 2017a and 2017b), there are currently no manufacturing standards for MLT, with the exception of a Canadian standard under development covering the manufacturing, testing and quality control of MLT (CSA O125), planned for publication in 2022.

The oldest form of MLT panel is most likely nail-laminated timber (NLT), which was used as “mill floor” in historic timber buildings. NLT is a solid wood structural element consisting of lumber planks oriented on edge and fastened together with nails. NLT is usually tightly manufactured with lumber of a moisture content no greater than 19 %, which can result in some gaps appearing between boards once the product is conditioned during its service life. Some manufacturers have stringent manufacturing requirements for a lower moisture content and might not exhibit similar dimensional changes.

Dowel-laminated timber (DLT) is a relatively new MLT product that has recently emerged in Canada (see Figure 1.17b). DLT is a solid wood structural panel created by placing lumber planks oriented on edge and friction-fastening the laminations together with hardwood dowels. It does not require any adhesives or metallic fasteners. DLT is usually tightly manufactured with lumber of a moisture content no greater than 19% at the time of inserting the wood dowels, which can result in some gaps appearing between lumber boards once the product is conditioned during its service life. Similar to NLT, the use of stringent manufacturing requirements with a lower moisture content might result in smaller dimensional changes.

NLT and DLT may have a slightly less reliable fire performance than glued wood panels. NLT and DLT which are manufactured with tightly clamped laminations char at a slow, predictable rate, and their structural fire resistance can therefore be determined based on the same design principles as those detailed in Chapter 7. However, due to potential dimensional changes and gaps forming between boards, additional precautions might be needed to fulfil the separating function. See Chapter 6 for additional information on the separating function performance. It is recommended to consult with the NLT and DLT manufacturers for guidance on gap tolerances and dimensional changes for fire design.

The final categories of mass timber panels are those made of plywood, LVL or OSB layers bonded with a structural adhesive and pressed to form a solid panel. The resulting product is similar to CLT, with the exception that they are usually parallel laminated (not orthogonal). Mass plywood panels can also be made of LVL layers so that they are all oriented in the longitudinal (strength) direction. These products are typically manufactured as built-up elements obtained with a secondary face-gluing process. Their fire performance and charring behaviour can be assumed to be similar to traditional sawn timber, provided that the adhesive used for secondary gluing is a structural adhesive meeting the requirements for elevated temperatures and fire conditions. Structural fire resistance of mass plywood and OSB panels can therefore be determined based on the same design principles as those detailed in Chapter 7. There are currently no manufacturing standards for glued mass timber panels made from plywood, LVL or OSB.

1.3.7 Wood-based panels

The last category of wood products refers to the thin wood-based panels typically used in light timber frame construction. These are panels made from veneers, strands and wood fibres, or a combination of these materials. Wood-based panels can be used as floor and roof sheathing, floor and roof diaphragms, wall sheathing and shear walls, as well as a manufacturing component such as the web panel in prefabricated wood I-joists. Figure 1.18 shows some wood-based panels commonly used in timber construction.

Plywood was the first glued wood-based panel ever used, with apparently a background in ancient Egypt. Plywood is manufactured using layers of veneers bonded orthogonally with a structural and moisture-resistant adhesive. It is usually made of an odd number of layers where the outer layers and all odd-numbered layers are oriented in the direction of the panel length, i.e. the strength direction (ASTM D5456). Its orthogonal configuration allows for minimising dimensional changes while maximising strength and stiffness. CLT has essentially been designed based on the principles of plywood but using much thicker layers of timber as opposed to thin veneers. Structural plywood panels are manufactured in accordance with

Figure 1.18 Wood-based panels: (a) plywood (photo APA wood), (b) OSB (photo APA Wood).

regional standards such as CSA O151, PS 1, EN 13986 and AS/NZS 2269.0. Several types of structural plywood can be found depending on the species group and grade of the veneers and its bond classification (interior, exterior, marine, etc.). Plywood can also be a decorative wood panel intended for interior use only. When used as an interior finish material, the surface veneer typically consists of hardwood and is bonded to an assembly of softwood veneers, timber, particleboard or medium-density fibreboard (MDF).

The second type of wood-based panel is the Oriented Strand Board (OSB). This product is comprised primarily of wood strands bonded with a moisture-resistant adhesive under heat and pressure (ASTM D1038). Following a similar manufacturing principle as plywood, OSB is fabricated of compressed strands arranged in orthogonal layers, where the strands in the face layers are generally aligned in the direction of the panel length, i.e. the strength direction. OSB panels typically have a non-skid surface on one side for safety on the construction site for roof applications. In addition to floor, roof and wall applications, OSB is also widely used as rim boards in light timber frame construction. When combined with engineered wood joists (I-joists or trusses), OSB rim boards are cut to the exact depth and exhibit a better dimensional stability than a traditional sawn timber rim board. Structural OSB panels are manufactured in accordance with regional standards, such as CSA O325, PS 2 and EN 13986.

The last category of wood-based panels is medium-density fibreboards (MDF), high-density fibreboards (HDF), and particleboards. MDF and

HDF are composite panel products composed primarily of wood fibres bonded with adhesives and cured under heat and pressure. At the time of manufacturing, MDF density is usually between 500 and 1000 kg/m³ (ASTM D1554). HDF has a higher density than MDF, with no specific targets. Particleboards are similar in manufacturing to MDF but use wood particles rather than fibres. MDF, HDF and particleboards are usually used as decorative panels. When used as structural panels, such as webs in I-joists, they need to be tested accordingly so that their mechanical properties are evaluated and determined correctly. The European product standard for wood-based panels is EN 13986.

Wood-based panels are usually manufactured thinner than panels of timber, SCL, glued laminated timber and mass timber and tend to exhibit faster charring rates than the other wood products detailed in this chapter. As an example, EN 1995-1-2 specifies a one-dimensional charring rate of 0.90 mm/min for a wood-based panel of 450 kg/m³ and at least 20 mm in thickness, while timber with a characteristic density of 290 kg/m³ or greater would have a rate of 0.65 mm/min. Chapter 7 provides the charring rate adjustment factor when a wood-based panel is less than 20 mm in thickness. Their performance against flame-through is also of utmost importance so that the separating function of a floor, roof or wall assembly is maintained adequately. In Europe a test method (EN 14135) is specified to determine the fire protection ability of coverings, with more information in Chapter 6. The flammability/reaction to fire characteristics is explained in Chapter 5.

1.4 CONCLUSION

This chapter introduces timber structures and wood products. Some building codes may limit the use of timber and wood products, either for structural elements or interior finish materials, but these materials are being used throughout the world in many types of buildings and occupancies. With the increasing demand for sustainable buildings and performance-based design, it is expected that timber will gain even more popularity in the near future. Fire performance of timber structures and wood products can be evaluated by the guidance and design methods detailed in the following chapters.

One of the main advantages of timber structures is the variety of systems that can be designed and constructed to suit almost any need and to provide the level of fire performance required in building codes. Traditional light timber frame construction remains the most economical system, widely used in low-rise and mid-rise buildings. Innovative systems such as modern post-and-beam construction, mass timber construction, long-span and hybrid structures allow for expanding the use of timber in impressive and innovative structures, such as taller buildings. Prefabrication of timber elements and modules is also gaining popularity, due to the speed of construction, increased building control and waste reduction at the job site.

Another factor facilitating the use of timber in buildings is the variety of products available to designers. A broad range of structural engineered wood products has been developed over recent years to provide high-valued timber products through more efficient use of the raw material. For most countries, timber and engineered wood products are required to be manufactured, tested and evaluated by applicable standards. Quality control procedures are usually required to ensure high-quality end products and buildings with acceptable fire safety.

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