Structural Sandwich Construction

Structural sandwich construction is a layered construction formed by bonding two thin facings to a thick core (**Figure 4**). The thin facings are usually made of a strong and dense material because they resist nearly all the applied edgewise loads and flatwise bending moments. The core, which is made of a weak and low-density material, separates and stabilizes the thin facings and provides most of the shear rigidity of the sandwich construction. By proper choice of materials for facings and core, constructions with high ratios of stiffness to weight can be achieved. As a crude guide to the material proportions, an efficient sandwich is obtained when the weight of the core is roughly equal to the total weight of the facings. Sandwich construction is also economical because the relatively expensive facing materials are used in much smaller quantities than are the usually inexpensive core materials. The materials are positioned so that each is used to its best advantage.

Specific nonstructural advantages can be incorporated in a sandwich construction by proper selection of facing and core materials. An impermeable facing can act as a moisture barrier for a wall or roof panel in a house; an abrasion-resistant facing can be used for the top facing of a floor panel; and decorative effects can be obtained by using panels with plastic facings for walls, doors, tables, and other furnishings. Core material can be chosen to provide thermal insulation, fire resistance, and decay resistance. Because of the light weight of structural sandwich construction, sound transmission problems must also be considered in choosing sandwich component parts.

Methods of joining sandwich panels to each other and other structures must be planned so that the joints function properly and allow for possible dimensional change as a result of temperature and moisture variations. Both structural and nonstructural advantages need to be analyzed in light of the strength and service requirements for the sandwich construction. Moisture-resistant facings, cores, and adhesives should be used if the construction is to be exposed to adverse moisture conditions. Similarly, heat-resistant or decay-resistant facings, cores, and adhesives should be used if exposure to elevated temperatures or decay organisms is expected.

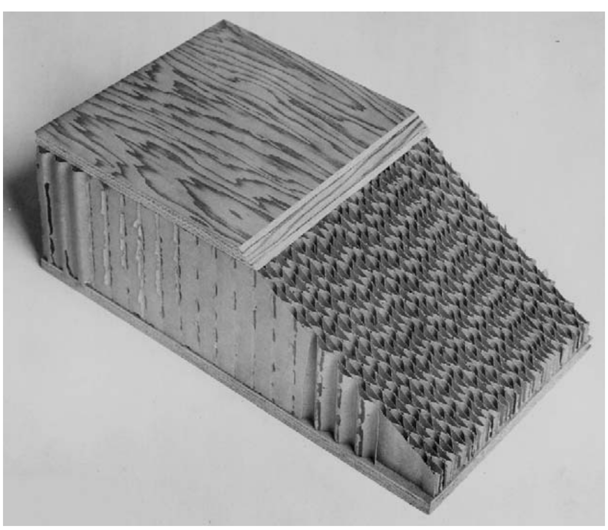

Figure 4 Cutaway section of sandwich construction with plywood facings and a paper honeycomb core.

See also: **Solid Wood Processing**: Adhesion and Adhesives; Machining; Protection from Fire. **Solid Wood Products**: Lumber Production, Properties and Uses; Wood-based Composites and Panel Products. **Wood Formation and Properties**: Physical Properties of Wood. **Wood Use and Trade**: Environmental Benefits of Wood as a Building Material.

Further Reading

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Structural Use of Wood

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Introduction

Wood is an indispensable structural material worldwide and has been so since antiquity. The global prominence of wood as a construction staple is owed not only to its desirable attributes, but also to the fact that the forest resources from which it is derived are universally distributed, abundant, and renewable. Whether in the form of traditional solid-sawn lumber or a modern engineered wood I-joist, wood is unique among load-bearing building products. The only structural material of biological origin, wood has a high strength-to-weight ratio, is easily cut to size and shape with simple tools, is readily joined with fasteners or adhesives to produce strong joints, and is prized for its natural beauty. The perceived limitations of wood as a structural material – combustibility and degradation by decay fungi and insects – were overcome long ago with advances in building design, construction practice, and the advent of preservative and fire-retardant treatments.

North America is both the world's largest producer and consumer of structural wood products. The majority of the structural wood products manufactured in the USA and Canada is used domestically to build more than 1 million single-family houses annually as well as thousands of other wood-frame structures of all kinds. The balance of North America's output of structural wood products is exported to Asia, Europe, and Australia and, more recently, to South America, where it is utilized for much the same purposes, but to a much lesser extent. While nearly all residential structures in North America are framed with wood, concrete and masonry dominate house building in Asia, Europe, and South America. Traditional on-site stick-building of houses is the norm in North America, but off-site factory-assembly predominates in Japan and Europe. Virtually all North American dimension lumber is made from softwoods, while much of Australia's native structural framing is manufactured from hardwoods. Wood-frame buildings in North America seldom exceed four stories in height, but those in Europe increasingly rise to six stories. Despite these and other regional differences, similar structural wood products are used for similar applications worldwide. It is for these reasons that the focus here is on the structural use of wood in North America, and by extension, around the globe.

Today, structural wood products are available in a wide array of forms useful in a broad spectrum of applications. The decision to use traditional solid-sawn products or modern engineered products is made based on the kind of structure under consideration, the distances to be spanned, the magnitude of the loads to be supported, and the desired aesthetics. Solid-sawn options are boards, dimension lumber, timbers, poles, piles, and construction logs. The choice of engineered wood products presently includes glue-laminated timber, laminated veneer lumber, wood I-joists, parallel strand lumber, laminated strand lumber, metal plate connected trusses, and panel products plywood and oriented strand board.

Structural Wood Product Allowable Design Values

Historically, the size of the solid-sawn lumber and timber needed to frame a structure was chosen based on rules of thumb borne from past success. This educated-guess approach of choosing structural wood products that are 'big enough' and thus 'strong enough' for the task at hand is still used locally in some parts of the world. In almost all industrialized nations, however, solid-sawn and engineered wood products intended for use in structural applications are stress-rated to ensure that they will safely support the loads imposed on them in service. This means that they have been assigned allowable design values for various mechanical properties such as modulus of elasticity in bending, extreme fiber stress in bending, tension, compression, and shear, based on the results of destructive tests conducted on full-size members. As a consequence of the built-in safety factor, the actual breaking strength of a structural wood product is four to five times greater than its allowable design value. All wooden structures are designed such that the stresses induced in the structural members by in-service loads are less than the allowable design values.

Allowable design values must sometimes be adjusted as part of the design process to account for the effect on member stiffness and strength of duration of loading, in-service conditions of use, and postgrading treatment. This is true for both solid-sawn and engineered wood products, although the adjustment factors for each type of member may differ. Published allowable design values apply to so-called normal load duration, which is the load that fully stresses a member to its allowable design value, intermittently or continuously, for a cumulative period of 10 years. Because wood can carry much higher loads for shorter periods of time than it can for longer periods, allowable design values for members subject to short-term, high-magnitude loads such as those imposed by snow, wind, and earthquakes must be adjusted for duration of loading. Modification of allowable design values is required whenever wood will experience sustained exposure to temperatures of 38–66°C (100–150°F) and whenever its in-service moisture content will exceed 19% for prolonged periods. Interaction between the chemicals in certain preservatives and fire retardants and heat during the treating process and posttreatment kiln-drying reduces wood's stiffness and strength. Because such formulations are proprietary, allowable design values for treated members must be altered as per the recommendation of the formulator or treater. Depending on the type of member and how it will be used, additional refinements to allowable design values for size, flat use, repetitive use, and curvature may also be warranted.

Solid-Sawn Wood Products

Boards, Dimension Lumber, and Timbers

Sawed directly from logs in an essentially finished form, boards, dimension lumber, and timbers are the oldest and still most widely used structural wood products. The three are differentiated on the basis of their nominal thickness (i.e., their smallest rough dimension as sawed from the log), not their actual thickness (i.e., their smallest finish dimension after surfacing). Boards are less than 38 mm (2 in.) thick; dimension lumber is 38 mm (2 in.) to, but not including, 127 mm (5 in.) thick; and timbers are 127 mm (5 in.) or more in thickness. Within each of the three nominal thickness classifications there are width categories, use categories, and grades. The names of the width and use categories indicate the intended application. Those for dimension lumber, for example, are light framing, stud, structural light framing, and structural joists and planks. Within width and use categories there are grades. Boards, dimension lumber, timbers, poles, piles, and construction logs are predominantly visually graded according to a set of rules that specify the natural and processing characteristics permitted in each grade. The higher the grade, the fewer and smaller the characteristics that are permitted and the higher the allowable design values. The grade names for dimension lumber structural joists and planks, for instance, are select structural (highest grade), no. 1, no. 2, and no. 3 (lowest grade). Dimension lumber used for fabricating trusses and glue-laminated timber, however, is graded mechanically and identified in the grade stamp as machine stress-rated or MSR.

The grade stamp printed on boards, dimension lumber, and timbers identifies the species, grade, and moisture condition of the member when it was machined to finish size. Knowledge of the moisture condition is especially useful in minimizing shrinkage, warpage, splitting, and other moisture-related problems that can arise after a member is placed in service. Solid-sawn products are either green (i.e., water-saturated) or dry (i.e., maximum 19% moisture content) when surfaced to finish dimensions. Most boards and dimension lumber are air- or kiln-dried to 19% moisture content or less prior to surfacing and thus shrink minimally after installation. Timbers are almost always green when surfaced because it is physically and economically impractical to kiln-dry members larger than 102×102 mm (4×4 in.). Consequently, the sometimes considerable postinstallation initial shrinkage of timbers must be accounted for during the design process. Attention must also be given to the initial shrinkage of boards and dimension lumber pressure-treated with water-borne preservatives. These products are saturated with water during treatment and seldom redried afterwards.

Boards Compared with dimension lumber and timbers, stress-rated boards are of minor importance and see limited use. Employed occasionally for wall and roof sheathing, subflooring, collar ties, diagonal bracing, and decking, most are made from the pines, spruces, true firs, and other softwoods. Boards are manufactured in 25-mm (1-in.) increments from 51 to 305 mm (2 to 12 in.) wide; wider boards are made but difficult to find. Most boards are 1.8–6.1 m (6–20 ft) in length, in multiples of 0.3 m (1 ft).

Dimension lumber By far the most widely used solid-sawn structural product, dimension lumber is routinely used for sill plates, wall studs, floor and ceiling joists, roof rafters, ridge boards, purlins, door and window headers, decking, and site-built nail-laminated girders. Manufactured in increments of 51 mm (2 in.) in width and thickness and in 0.6-m (2-ft) multiples in length beginning at 2.4 m (8 ft), virtually all dimension lumber is made from softwoods such as the pines, spruces, true firs, hemlocks, larches and Douglas-fir. Dimension lumber up to 305 mm (12 in.) wide and 4.9 m (16 ft) long is still readily available. Larger members are increasingly scarce because the inventory of large-diameter trees has essentially been depleted. Where wider or longer members are required, engineered wood products are used instead. Two engineered wood substitutes are themselves made from dimension lumber: metal plate connected trusses and glue-laminated timber.

Timbers Made primarily from high-density softwoods and hardwoods such as the hard pines, Douglas-fir and the oaks, timbers are subdivided into two use and width categories: beams and stringers, which are plainly rectangular, and posts and timbers, which are essentially square. The nominal width of beams and stringers is more than 51 mm (2 in.) greater than their nominal thickness, while that of posts and timbers is 51 mm (2 in.) or less. Timbers are sawed in multiples of 51 mm (2 in.) in width and thickness and 0.3 m (1 ft) in length, starting at 1.8 m (6 ft) and ranging to 12.2 m (40 ft) and longer. As the name implies, beams and stringers are used as beams, stringers, girders, sills, purlins and other horizontally oriented primary and secondary supporting members. Posts and timbers are mainly employed as primary vertical supports such as posts and columns. Timbers of both width categories are widely used in pedestrian and vehicular bridges; piers, seawalls and other freshwater and marine structures; and as chords and webs in heavy timber trusses. Rough-sawn timbers are often employed in the construction and renovation of concrete and steel structures as temporary shoring and bracing.

Round Timbers

Poles Essentially tree-length logs shaved of their bark, poles are 127–762 mm (5–30 in.) in diameter at the butt and 6.1–36.6 m (20–120 ft) in length. Because straightness is important, virtually all poles are made from softwood trees whose excurrent form (i.e., a single, tapering main stem) is well suited for this purpose. Utility poles and utility pole structures carry electric power distribution wires and communications cables. Construction poles serve as both the foundation and main vertical supports in pole buildings and highway sound barriers. Often, a narrow flat plane extending from groundline to tip is machined on one face of construction poles to remove taper and facilitate attachment of framing, sheathing, and siding. Because the butt is embedded in the ground, both utility and construction poles function as cantilever beams. As such, they are stress-rated according to their allowable extreme fiber stress in bending. Utility and construction poles are routinely pressure-impregnated with a preservative such as creosote, pentachlorophenol, or chromated copper arsenate because of the decay hazard imposed by soil contact.

Piles Manufactured in the same manner and in essentially the same sizes as poles, piles are used in foundations under buildings and bridges. Most are made from softwoods such as the hard pines and Douglas-fir, although some are oak. End-bearing piles are driven down to bedrock so that the weight of the structure is transferred along the pile to this immovable base. Friction piles are used where soil is so deep that bedrock is inaccessible. So-called skin friction that develops between the wood and the surrounding soil prevents the pile from slipping downward under the load exerted by the structure. Because piles are loaded axially both when hammered into the ground and in service, they are stress-rated according to their allowable compression strength parallel to grain. Straightness is of utmost importance in minimizing pile breakage during driving. Often, the butt end of a pile embedded in soil is above the water table or even partially exposed above ground and thus vulnerable to decay fungi and insects. The submerged portion of piles supporting piers and other marine structures is susceptible to marine borers, while the above-water segment is threatened by decay fungi and insects. For these reasons, piles are routinely pressure-treated with the same preservatives as poles.

Construction logs Stacked vertically to form the walls of log buildings, construction logs are typically 203–305 mm (8–12 in.) in diameter and 2.4–9.1 m (8–30 ft) long. Virtually all construction logs are milled from softwoods such as the cedars and pines. They are made by passing tree-length logs or rough-sawn timbers through a four-sided cutterhead that machines the member to a circular or rectangular profile that is uniform along its length. A construction log's vertical faces, which are rounded or flat with beveled edges, become the exterior and interior surfaces of the wall. A system of tongues and grooves or grooves and splines is milled on the top and bottom faces so that construction logs interlock when stacked. Construction logs made from softwoods that lack natural decay resistance are treated by nonpressure dipping or spraying with a waterborne borate preservative to deter decay fungi and insects. Milled when green, construction logs shrink considerably in diameter after erection. Door and window openings in log buildings must be designed to accommodate this shortening of wall height.

Engineered Wood Products

During the last four decades of the twentieth century, traditional solid-sawn boards, dimension lumber, timbers, poles, piles, and construction logs were joined by numerous structural-engineered wood products made by gluing together small pieces of wood with a waterproof structural adhesive. The roster continues to expand as new products are introduced, but currently includes glue-laminated timber, laminated veneer lumber, wood I-joists, parallel strand lumber, laminated strand lumber, and panel products plywood and oriented strand board. Metal plate connected wood trusses are the nonglued exception.

Engineered wood products will eventually supplant the larger sizes of high-grade solid-sawn dimension lumber and timbers. A nonrenewable resource in truth, the old-growth forests from which large, high-grade dimension lumber and timbers were sawed are almost gone. Most of what is left has been set aside in national parks, wilderness areas, and other holdings that prohibit harvesting. Today's forest resources consist primarily of second- and third-generation trees managed under sustainable forestry practices for harvesting on 30–80-year rotations. Trees are thus smaller in diameter when felled, and the dimension lumber and timbers sawed from them contain more natural characteristics such as knots and juvenile wood that affect strength and in-service performance. While smaller sizes of dimension lumber (up to 51×254 mm (2×10 in.))

and timbers (up to 254×254 mm (10×10 in.)) will always be plentiful, the future availability of larger members, especially in the higher grades, is arguably uncertain. For these reasons, glue-laminated timber, laminated veneer lumber, wood I-joists, parallel strand lumber, laminated strand lumber, metal plate connected trusses, plywood, and oriented strand board represent the future of structural wood products. All of these engineered wood products can be made from trees no larger than 305 mm (12 in.) in diameter or from dimension lumber no wider than 102 mm (4 in.), and in lengths substantially longer than can be sawed from today's logs. Because knots and other natural strength-reducing characteristics are restricted to a single lamination, veneer, or strand, they are smaller and harmlessly dispersed throughout the product's volume. As a result, the range of stiffness and strength among individual pieces of engineered wood products is considerably narrower than that of solid-sawn dimension lumber and timbers. Allowable design values are consequently higher, as is the predictability of in-service performance.

Except for plywood and oriented strand board, which are commodity products, engineered wood products and their allowable design values are proprietary. This means that the allowable design values for an otherwise identical product made by two different manufacturers will almost certainly differ. As such, a wood I-joist fabricated by one manufacturer cannot necessarily be substituted for that made by another simply because both are the same depth. Because of the complications that arise from this present situation, some voices in the construction community have called for the production of commodity-engineered wood products that share the same allowable design values and are thus interchangeable. Whether this happens remains to be seen.

With the exception of trusses, engineered wood products are manufactured from wood kiln-dried to a moisture content of 12% or less, which is well below the 19% typical of boards and dimension lumber. Consequently, they shrink, warp, and split much less than solid-sawn boards, dimension lumber, and timbers after being installed. Fastener pops, floor squeaks, drywall cracks, and other shrinkage-related problems are virtually eliminated. Camber is routinely built in to nonpanel-engineered wood products to counter dead load deflection and creep (i.e., progressive sagging of a member under sustained load over a very long time).

Glue-laminated timber Glue-laminated timber or glulam is made by face-laminating softwood dimension lumber that has been finger-jointed end-to-end. With this method, beams and columns that are longer, wider, and deeper than sawn timbers can be fabricated, as can curved members and arches. Lengths up to 30.5 m (100 ft) are common, as are depths and widths of 0.3 (1 ft) to several meters (feet). While small stock sizes are manufactured for residential use, the majority of glulams are custom-made. Efficient use of wood is made when designing glulams by strategically placing the highest-grade laminations where in-service stresses are highest, then filling out members with lower-grade laminations where stresses are lower. Glulams are used in structures where long, clear spans and/or appearance are of primary importance, such as factories, warehouses, sports arenas, aircraft hangars, churches, auditoriums, and large office, hotel, retail, and institutional buildings. Preservative-treated members are utilized in bridges, piers and other freshwater and marine structures, power transmission towers, and as the main vertical supports in postframe buildings. Due to their large size, connections between members are made with through-bolts and steel gusset plates and framing anchors. Because glulam is made from dimension lumber at 12% moisture content, initial shrinkage after installation is small. However, connections must be designed so that members can shrink and swell freely in-service without overstressing the surrounding wood (**Figure 1**).

Laminated veneer lumber Composed of multiple sheets of veneer bonded together such that the grain of each ply is parallel to the product's length, laminated veneer lumber (LVL) is essentially reconstituted

Figure 1 Glue-laminated timbers provide both structural support and pleasing aesthetics for this curling rink. Courtesy of APA – The Engineered Wood Association.

dimension lumber. Like glulam, veneers are graded for stiffness and strength, then strategically positioned within the product to maximize allowable design values. Manufactured in the same and slightly larger thicknesses as dimension lumber, but in greater widths and in lengths up to 24.4 m (80 ft), LVL is widely used in residential and commercial construction for beams, girders, headers, joists, purlins, posts, and columns. LVL is also used extensively for scaffold planks and for the flanges of wood I-joists. Most is made from high-density softwoods such as the hard pines and Douglas-fir, and medium-density hardwoods like yellow poplar. LVL pressure-treated with waterborne preservatives and fire retardants is available (**Figure 2**).

Wood I-joists I-shaped in cross-section and light in weight, wood I-joists come in many depths and flange widths and in lengths up to 24.4 m (80 ft). Flanges are LVL or dimension lumber, while webs are plywood, oriented strand board, and sometimes, dimension lumber. As their name suggests, most I-joists are used for framing floors in houses and low-rise office, hotel, retail, and institutional buildings. The small mass and long span typical of an I-joist floor system occasionally interact to produce annoying vibrations underfoot. Blocking, cross-bracing, and strongbacks are needed to stiffen these floor systems and dampen vibrations. Increasingly, I-joists are being utilized as rafters and purlins in residential and commercial roofs. Because of their unique cross-section, the proper way of designing and building with wood I-joists may not be apparent to those accustomed to using boards, dimension lumber, and timbers. As such, I-joist manufacturers supply design manuals and software to ensure their correct use (**Figure 2**).

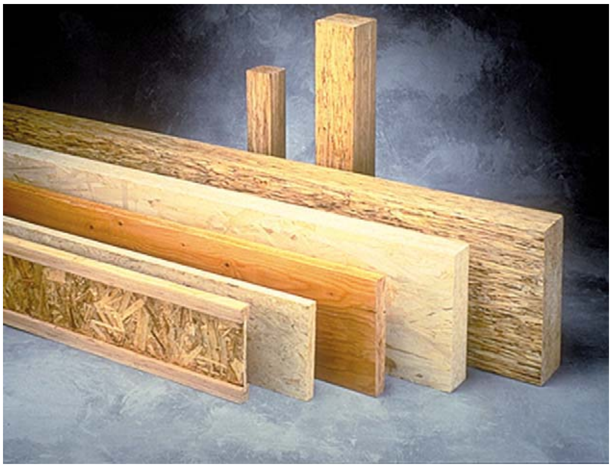

Figure 2 Engineered wood products such as wood I-joists (far left), laminated strand lumber (left, right), laminated veneer lumber (center), and parallel strand lumber (far right) are replacing the larger sizes and higher grades of solid-sawn dimension lumber. Courtesy of TrusJoist A Weyerhaeuser Business.

Parallel strand lumber Offering the highest allowable design values of today's engineered wood products, parallel strand lumber (PSL) competes for the same applications as timber and glulam. Because of its pleasing appearance, PSL beams, stringers, girders, headers, purlins, posts, and columns are typically left exposed. Composed of long, narrow strips of Douglas-fir, larch, hard pine, and yellow-poplar veneer bonded together and oriented parallel to the product's length, PSL is available in lengths up to 21.3 m (70 ft) and in widths and thicknesses ranging from 102 to 508 mm (4 to 20 in.). PSL readily treats with preservatives and fire retardants (**Figure 2**).

Laminated strand lumber The most recent engineered wood innovation, laminated strand lumber (LSL) consists of short, thin strands of underutilized, fast-growing mixed softwoods and hardwoods consolidated with heat and pressure into dimension lumber-sized products. To date, its use is limited to rim joists, studs, blocking, and light-duty headers in residential construction (**Figure 2**).

Metal plate connected wood trusses The dimension lumber chords and webs of metal plate connected wood trusses are joined not with adhesive, but with toothed metal plates pressed into the wood. Routinely used for framing roofs of virtually any shape in residential construction, trusses are commonly utilized in many types of commercial, industrial, and agricultural buildings as well. Lengths range from 4.6 to 24.4 m (15 to 80 ft) and more, with truss height dictated by roof pitch. Stock roof trusses are fabricated for residential use, but most trusses are designed to order using sophisticated engineering software. Because dimension lumber grade is matched to in-service stresses on a chord-by-chord and web-by-web basis, trusses make especially efficient use of wood. Where a conventionally framed roof might use 51×203 mm (2×8 in.) rafters spaced 406 mm (16 in.) on-center, for instance, trusses for the same roof, made from members 51×102 mm (2×4 in.) and spaced 610 mm (24 in.) apart, use 15–25% less wood. More and more, floors and low-slope roofs in nonresidential buildings are being built with parallel chord trusses whose open webs simplify and speed the placement of piping, ductwork, and wiring. Where spans and/or in-service loads are very large or appearance is important, heavy timber trusses are employed. Made from timber, glulam, or PSL, the chords and webs of these heavy-duty trusses are joined with through-bolts inserted into steel gusset plates, framing anchors, split-ring connectors or shear plate connectors. Depending upon their configuration, these massive trusses may span up to 90 m (300 ft) (**Figure 3**).

Plywood and oriented strand board Two structural panel products – plywood and oriented strand board – are routinely used in all types of wood-frame buildings. Most plywood is made from softwood veneer, while oriented strand board consists of small, thin strands of mixed softwoods and hardwoods. Both panels are cross-laminated such that the grain of each layer is perpendicular to that of adjacent layers. Most commonly manufactured in 1.2×2.4 m (4×8 ft) sheets 12.7–38.1 mm (0.5–1.5 in.) thick, plywood and oriented strand board are employed as roof and wall sheathing, subflooring, and underlayment. Special grades of both panels are made for use in engineered applications such as diaphragms and shearwalls in wind- and earthquake-resistant structures, as well as in stressed skin panels. Plywood is widely utilized for concrete formwork, while oriented strand board is the preferred facing for foam-core structural insulated panels. Plywood and oriented strand board panels intended for structural use are selected according to the span rating and exposure durability class found in the grade stamp. The span rating is a two-number code such as 812/406 (32/16). The number on the left is the maximum recommended on-center spacing in millimeters (inches) for framing when the panel is used as roof sheathing. The right-hand number is the maximum recommended on-center spacing of framing when the panel is used as subflooring. In all cases, panels are to be installed with their long dimension perpendicular to framing and across three or more supports.

Exposure durability class indicates a panel's ability to resist the damaging effects of exposure to the weather or to moisture. Panels marked exterior or marine are the only choice for those that will be permanently exposed to the elements or to high moisture. Exposure 1 panels are intended for applications where long delays in construction or high moisture in service is possible. Interior panels are meant for dry, protected uses. Fire retardant-treated plywood is readily available, as is the preservative-treated plywood used in permanent wood foundations. Because treatment reduces plywood's stiffness and strength, the appropriate adjustment factors must be obtained from the formulator or treater. With oriented strand board, strands are treated before consolidation, so no adjustment is needed (**Figure 4**).

Wooden Structures

While the number of potential structural applications for wood is limited only by the imagination, the majority of structural wood products are used in constructing buildings and bridges. Wood-frame buildings are classified according to the size of the members used and the geometry of the structural skeleton they form. Five basic types are light-frame, log, post-frame, pole, and heavy timber. In addition, many very large, special-purpose buildings such as domed and arched sports arenas are constructed with solid-sawn and engineered wood products. The fundamental types of wooden bridges – beam, deck, truss, arch, and suspension – are named after the

Figure 3 Roofs of virtually any shape can be framed with metal plate connected wood trusses fabricated from dimension lumber. Courtesy of the Wood Truss Council of America.

Figure 4 Plywood and oriented strand board are routinely used for roof and wall sheathing in all types of residential and commercial construction. Courtesy of APA – The Engineered Wood Association.

configuration of their superstructure. Variations on these five archetypal designs abound.

Wood-Frame Buildings

Light-frame buildings By far the most common wood-frame structure, light-frame buildings are constructed largely from dimension lumber, wood I-joists, and roof and floor trusses spaced 406 or 610 mm (16 or 24 in.) on-center and sheathed with plywood or oriented strand board. Examples include single-family houses; garages and outbuildings; apartment and condominium buildings; and low-rise office, hotel, retail, and institutional buildings. The traditional method of stick-building – framing a structure on-site member-by-member – is gradually yielding to automated building in which structures are made from factory-fabricated subassemblies that are joined on-site. Leading this trend are panelized buildings made from preframed and sheathed wall, floor, and roof subassemblies and modular buildings consisting of three-dimensional boxes that are stacked on-site. Greater control over the quality of assembly, more efficient use of materials, freedom from the vagaries of weather, rapid on-site erection, and reduced on-site generation of construction waste are driving the switch (**Figure 5**).

Log buildings The walls of log buildings are made from construction logs, and sometimes profiled timbers, that are stacked vertically. Floors and roofs are framed with dimension lumber, wood I-joists, trusses, or exposed construction logs. Most log buildings are single-family dwellings, although many are park structures and retail shops where this rustic look is appropriate. Virtually all log buildings are sold as kits, with each log precut to length and marked for sequential stacking on-site. Typically, all other materials needed to complete the shell such as roof framing, sheathing, shingles, and doors and windows are included (**Figure 6**).

Post-frame buildings Construction of a post-frame building begins with embedding in the ground preservative-treated nail-laminated dimension lumber, timber, or glulam posts, also known as wall columns. Horizontal wall girts of dimension lumber are then fastened to the posts, and plywood or oriented strand board sheathing and/or siding is affixed to the wall girts. This framework is capped with metal plate connected roof trusses installed on 1.2–3.6-m (4–12-ft) centers, with dimension lumber purlins spanning across or between trusses to support plywood or oriented strand board sheathing, and/or metal roofing. Formerly used only for livestock barns, equipment sheds and other agricultural structures, post-frame buildings are today erected for use as retail shops, warehouses, factories, fire stations, commercial garages, and recreational facilities (**Figure 7**).

Pole buildings The forerunner of post-frame buildings, pole buildings have declined markedly in popularity. Constructed in virtually the same manner as post-frame buildings, pole buildings are occasionally erected for agricultural use and as bulk storage sheds for road deicing chemicals. Structures supported by poles such as highway sound barriers and billboards, however, are common.

Heavy timber buildings

Timber frame buildings Timber frame construction represents the oldest formal use of wood as a

Figure 5 Light-frame buildings constructed from dimension lumber and plywood or oriented strand board sheathing such as these houses are the most common wood-frame structures. Courtesy of APA – The Engineered Wood Association.

Figure 6 Typically sold as kits, modern log buildings are increasingly complex in design. Courtesy of Original Lincoln Logs Ltd. and Craig Murphy Photography.

structural material. For over 20 centuries, timbers have been employed as the structural framework for all types of buildings. Members were connected with mortise and tenon joints pegged with wooden dowels called trunnels to prevent the tenon from pulling out. These same joints are still used today, especially where appearance is important, although mechanical fastening is increasingly common. While most timber frame buildings utilize timber, glulam usage is growing. The skeleton of a modern timber frame building differs little from that of its ancestors, but the walls and roof are now made of structural insulated panels. Applied to the outside of the timber frame, these energy-efficient panels have a foam core sandwiched between oriented strand board faces. Floor decks and interior partitions are typically built with dimension lumber. Although many types of modern buildings are of timber frame construction, including office, hotel and retail complexes, most are single-family residences (**Figure 8**).

Figure 7 Diagonal bracing holds the dimension lumber walls and roof trusses of this post-frame building plumb and square before sheathing is applied. Courtesy of National Frame Builders Association.

Figure 8 Diagonal braces lend rigidity to the timber frame of this future retail shop. Courtesy of Bensonwood Homes.

Mill buildings Infrequently constructed today, mill buildings have a masonry exterior and an interior framework of timber beams and columns. Floor and roof decking is usually tongue-and-groove dimension lumber. Originally built as factories and warehouses, thousands of nineteenth- and twentieth-century mill buildings have been renovated in the last few decades into retail and office complexes, and apartments and condominiums.

Wooden Bridges

Contemporary beam, deck, truss, arch, and suspension wooden bridges are used almost exclusively on secondary and rural roads where traffic volume and vehicular weights are relatively low. Components of the superstructure, which consists of the primary longitudinal supports, bracing, floor decking, railings, and other minor members, are preservative-treated timber or glulam. PSL and LVL are beginning to be used as well. Concrete abutments and intermediate supports of concrete or treated wooden piles form the underlying substructure. Beam bridges consist of longitudinal main carrying members with timber or glulam decking laid perpendicular to them. Spans are limited to about 7.6 m (25 ft) with timber supports, while 30 m (100 ft) or more can be achieved with glulam. The superstructure of a deck bridge is dimension lumber, timber, or glulam placed on edge and nail-laminated or, more commonly, drawn tightly together with threaded metal through-rods in a process known as stress-laminating, into a massive plate that doubles as both main support and decking. Because of the composite action that develops, deck bridges can span up to 11 m (36 ft). Parallel chord or bowstring trusses of timber or glulam form the sides and main supports of truss bridges. Bowstring trusses permit spans up to 30 m

Figure 9 Hinged glue-laminated timbers support the deck of this graceful arch bridge. Courtesy of APA – The Engineered Wood Association.

(100 ft), while 75 m (250 ft) is possible with parallel chord trusses. The familiar railroad trestle bridge is actually a beam, deck, or truss superstructure supported on wooden piles. Arch bridges have a timber or glulam deck that is supported by glulam arches. These graceful structures can span up to 60 m (200 ft) (**Figure 9**). The longest spans are achieved with suspension bridges, virtually all of which, however, are for pedestrian use only. Consisting of a timber or glulam deck hanging from wire rope cables, these bridges are up to 150 m (500 ft) long.

See also: **Solid Wood Products**: Construction; Logs, Poles, Piles, Sleepers (Crossties); Glued Structural Members; Lumber Production, Properties and Uses; Wood-based Composites and Panel Products. **Wood Use and Trade**: Environmental Benefits of Wood as a Building Material.

Further Reading

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Lumber Production, Properties and Uses

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Lumber production or sawmilling is the process of sawing and/or chipping logs to form rectangular pieces of wood (lumber, cants, or timbers) for buildings, packaging, furniture, and many other applications. Lumber production may have begun in Egypt as early as 6000 BC, where handsaws and planes were utilized to fashion small volumes of crude lumber. Today, facilities for lumber production (sawmills) range from those with one or two slow-simple machines powered by electric motors or internal-combustion engines to those with many high-speed computerized machines powered by electric motors and hydraulic pumps. Some modern high-speed sawmills are capable of producing as much as 2000 m^3 (1 million board feet) of lumber per day. Sawmills often also include equipment for drying and shaping the sawn lumber into finished products. Properties important to lumber products include strength, stiffness, straightness, appearance, and proportion of clear wood. Standards have been established for grading lumber based on these properties.

Log Supply

Lumber manufacturing begins in the forest. Many large lumber-producing companies own forest land, and they obtain at least a portion of their log supply from that land. Other lumber-producing companies purchase logs or standing trees (stumpage) from private forest landowners or government agencies. Independent logging contractors are often hired to harvest and transport logs to the sawmill. In other cases, logs (gate wood) are purchased from individuals who deliver noncontracted logs to the sawmill. Logs may be cut to lumber lengths plus trim allowance, multiple lumber lengths (multisegment logs) plus trim allowance, or tree length. The trim allowance is a small amount of extra log length that