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USE OF TIMBER IN ENGINEERING

MK Mohamad Omar & AW Mohd Jamil

Introduction

Human has used timber or wood persistently throughout history and takes advantage of its many virtues even though the total biological and chemical properties are not well understood. Human used timber for basic survival such as shelter, fuel for fire, weapon, vehicle and tools because timber coexist with human and animals and can easily be obtained. Many archaelogical findings showed that there was an era known as the "stone age", whereby that stone was used as cutting tools, spear and arrow head, and wheel. But timber is not given a proper recognition because there is no record of "timber age" in the human history even though timber is used as an important material to complement the stone tools. A stone axe could not be used effectively without a wooden handle, both tied with rope probably of roots or fibres from plant. Two wheels could not be used to move a vehicle if they were not connected with a wooden axle. And, an arrow or spear would be not called as such if a sharp stone was not tied at the end of a wooden stick. And also when a large rock was needed to be moved from a certain position that was blocking an entrance, for example, a wooden lever was needed to easily execute the task.

Figure 1 Use of timber for marine purpose proves its durability

Early human intermigration between continents of the world was achieved through the use of timber ships, not steel ships. To build steel ships, the process was long and energy intensive starting from the melting of iron nuggets and carbon just to produce the basic raw steel. In the early years, the melting was done by burning of timber before coal was found later as a fuel alternative. Timber was the sacrificial element to produce steel or other metals. To make metal components by casting, an accurate template or mould had to be carved from timber which would later be embedded into casting sand to make mould to receive the molten metal. Therefore timber was used in many aspects of metal making.

Today, timber is still found for multitude of uses. All timber is composed of lignin, cellulose, hemicellulose, and other extraneous materials. The characteristics of timber in terms of its density,

hardness and flexibility are governed by the variation of this composition as well as the cellular structure that makes up the timber. For a certain species this composition is relatively constant such that the selection of timber by species for any particular usage is acceptable without in depth knowledge of the mechanical and physical properties. What the early builder or craftsmen learned by trial and error became the basis for deciding which species were appropriate for a given use in terms of their characteristics. This is how craftsmen decide on the right species for their work.

However, in engineering whereby the most efficient use of material is based on the accurate selection of timber that offers the needed characteristics, the physical and mechanical properties of the timber to be used must be known beforehand.

Historically, some species filled many purposes, while other less available or less desirable species served only one or two needs. For example, because timber such as Chengal is tough, strong, and durable, it is highly prized for shipbuilding, bridges, farm implements, railroad crossties, fence posts, and flooring. Aesthetically pleasing species such as Ramin are used primarily for furniture and cabinets.

The gradual reductions in use of old-growth forests in this country has reduced the supply of large clear logs for lumber and veneer. However, the reliance on high-quality logs has diminished as new concepts of timber use have been introduced.

Timber is as valuable an engineering material as ever, and in many cases, technological advances have made it even more useful.

The advantages of timber

The advantages that keep timber in the forefront of raw materials are:

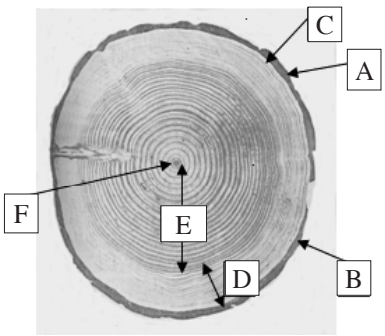
The Advantages of Timber
• Timber has a high strength to weight ratio
• Dry timber has good insulating properties against heat, sound, and electricity.
• Timber is good in absorbing vibration and high impact loads
• The natural grain patterns of timber is aesthetically pleasing
• Timber can resist corrosion, acid and saltwater
• Timber can be regrown, but not metal & cement
• Relatively smaller amount of energy needed to process timber

In addition, timber has high salvage value and can be treated with preservatives and fire retardants, and can be combined with almost any other material for both functional and aesthetic uses.

The structure of timber

The fibrous nature of timber strongly influences how it is used. Timber is primarily composed of hollow, elongated, spindle-shaped cells (straws) that are arranged parallel to each other along the trunk of a tree. When timber and other products are cut from the tree, the characteristics of these fibrous cells and their arrangement affect such properties as strength and shrinkage as well as the grain pattern of the timber.

It should be noted that, even though the heartwood is more durable than the sapwood, the difference in basic strength of both regions is not significant. For naturally durable species only the heartwood can be considered to possess that durability. Sapwood is generally non-durable both in naturally durable timbers such as Chengal and non-durable timbers such as Jelutong.



* In hardwood, growth ring may not be distinct

Region	
A	Outer part of the bark with dead tissues
B	Inner part of the bark with living tissues
C	Cambium layer, new wood cells are formed on the inside of the cambium and new bark cells on the outside.
D	Sapwood contains living and dead tissues, storage of food, carries water or sap from roots to leaves
E	Heartwood contains inactive cells, colour darker than sapwood, more durable than sapwood
F	Pith, a small core of tissue located at the center of tree stems

Figure 2 Cross-section of a log

Species identification

Many species of timber have unique physical, mechanical, or chemical properties. Efficient utilization dictates that species should be matched to end-use requirements through an understanding of their properties. This requires identification of the species in timber form, independent of bark, foliage, and other characteristics of the tree. General timber identification can often be made quickly on the basis of readily visible characteristics such as color, odor, density and grain pattern. Where more positive identification is required, a laboratory investigation must be made of the microscopic anatomy of the timber.

Physical properties and moisture relations of timber

Timber exchanges moisture with air; the amount and direction of the exchange (gain or loss) depend on the relative humidity and temperature of the air and the current amount of water in the timber. This moisture relationship has an important influence on timber properties and performance.

Weight, density, and specific gravity

Two primary factors affect the weight of timber products: density of the basic timber structure and moisture content. A third factor, minerals and extractable substances, has a marked effect only on a limited number of species. The density of timber exclusive of water, varies greatly both within and between species.

Timber is used in a wide range of conditions and has a wide range of moisture content values in use. Moisture in timber varies from green to dry and it constitutes part of the density such that both values, i.e. moisture and density, are determined and reported together. The calculated density of timber, including the water contained in the timber, is usually based on average species characteristics because of the natural variation in anatomy, moisture content, and ratio of heartwood to sapwood that occurs. Nevertheless, this determination of density usually is sufficiently accurate to permit proper utilization of timber products where weight is important. Such applications range from the estimation of structural loads to the calculation of approximate shipping weights.

To standardize comparisons of species or products and estimations of product weight, specific gravity is used as a standard reference basis, rather than density. The traditional definition of specific gravity is the ratio of the density of the timber to the density of water.

Working qualities

The ease of working timber with hand tools generally varies directly with the specific gravity of the timber. The lower the specific gravity, the easier it is to cut the timber with a sharp tool. The specific gravity values can be used as a general guide to the ease of working with hand tools.

Bio-deterioration

Timber can be degraded and destroyed by bio-deterioration in two ways, i.e. decay or insect attack. Decay happens when wet timber is degraded by fungi or bacteria. It is important to note that timber that is kept constantly dry does not decay. Also, if timber is kept continuously submerged in water, even for long periods of time, it will not decay significantly regardless of the species or the presence of sapwood. This is due to the absence of free oxygen that can allow growth of fungi or bacterial activities. The rate of decay is affected by moisture and temperature. Timber deteriorates more rapidly in warm, humid areas than in cool or dry areas. The decay resistance of timber depends on the extractives found in the timber. Sapwood of most species, including the durable ones, and heartwood of non-durable species have low resistance to decay and usually has a short service life under decay-producing conditions.

For less severe decay conditions, non-durable timber can be protected easily by brushing or dipping with preservative. Whilst application of preservative by pressure treatment is required to provide protection for non-durable species under severe decay conditions.

As compared to mold and stain fungi, decay fungi will reduce timber strength by metabolizing the cellulose that gives timber its strength. Decay will affect the mechanical properties of timber. Therefore, to maintain the strength of timber the possibility of decay can be prevented by keeping timber dry as much as possible, i.e. moisture content of below 19% and providing chemical treatment for non-durable species. Decay can also be controlled by design such that water will not be collected at any part of timber component due to improper design and construction detailing.

Insects also may damage timber, and in many situations must be considered in protective measures. Termites are the major insect enemy of timber particularly in tropical regions. Marine borers is also a type of timber-degrading organism. They can attack susceptible timber rapidly in saltwater harbours where they are the principal cause of damage to piles and other timber marine structures.

Insect damage may occur in standing trees, logs, and undried (unseasoned) or dried (seasoned) timber. Although damage is difficult to control in the standing tree, insect damage can be eliminated to a great extent by proper control methods. Insect holes are generally classified as pinholes, grub holes, and powder post holes. Because of their irregular burrows, powder post larvae may destroy most of a piece's interior while only small holes appear on the surface, and the strength of the piece may be reduced virtually to zero. In practical usage, limitation is imposed on the number and intensity of such insect holes available in a piece of timber as spelt out in strength grading of timbers for structural application.

Chemical treatment

Timber is often treated with chemicals to enhance its fire performance or decay resistance in service. Each set of treatment chemicals and processes has a unique effect on the mechanical properties of the treated timber. Fire-retardant treatments and preservative treatment methods may reduce the mechanical properties of timber due to the treatment process and the type of chemical being used.

Although preservative treatments and treatment methods could reduce the mechanical properties of timber, any initial loss in strength from treatment must be balanced against the progressive loss of strength from decay when untreated timber is placed in wet conditions.

The effects of preservative treatments on mechanical properties are directly related to timber quality, size, and various processing factors. Oil-type preservatives cause no appreciable strength loss because they do not chemically react with timber cell wall components.

Waterborne preservative treatments can reduce the mechanical properties of timber. Treatment standards include specific processing intended to prevent or limit strength reductions resulting from the chemicals and the waterborne preservative treatment process.

Mechanical properties of timber

Many of the mechanical properties of timber were derived from extensive sampling and analysis procedures . These properties are represented as the average mechanical properties of the species. But these average values are not safe for engineering calculations because variability is not included. Variability, or variation in properties, is common to all materials. Because timber is a biological material and the tree is subject to many constantly changing influences (such as moisture uptake, soil conditions,

and growing space), knots, slope of grain, mechanical properties vary considerably. In par with general practice worldwide, the mechanical properties are reduced by using statistical method as well as reduction due to its visual grade to a form known as the basic properties. These basic properties are the ones published for the public, especially engineers, to use.

The usual mechanical properties needed for engineering design include Modulus of Rupture (MOR) in bending, Modulus of Elasticity (MOE) in bending, compressive stress parallel to grain, compressive stress perpendicular to grain, shear stress parallel to grain, tensile stress parallel to the grain and hardness. Other measurements include the work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain.

Mechanical properties	Description	Usage
Modulus of rupture	The maximum load-carrying capacity of a member in bending. It is relative to the maximum moment imposed on the specimen. Modulus of Rupture can be considered as a criterion of strength, but it is not the true stress even though the unit is in Megapascal (MPa) or N/mm^2.	Beam, suspended floor, deck, joists, purlins, columns in bending, roof truss components and other components in bending.
Modulus of elasticity	The stiffness of timber is measured by Modulus of Elasticity. It is the elastic property of timber that encompasses the ability of timber to withstand load in bending while deflecting within the elastic limit.	Beam, suspended floor, deck, joists, purlins, columns in bending, roof truss components and other components in bending.
Compressive strength parallel to grain	Maximum stress in compression parallel-to-grain that is sustained by a specimen.	Column, roof truss component and other components in compression parallel to the grain.
Compressive stress perpendicular to grain	Reported as stress at proportional limit. There is no clearly defined ultimate stress for this property.	Railway sleepers, oil rig mud mat, ship's land to sea transfer surface, any component with force acting perpendicular to the grain
Shear stress parallel to grain	Ability to resist internal slipping of one part upon another along the grain. Values presented are average strength in radial and tangential shear planes.	Beam, suspended floor, joists, timber joints that involve shear stress and other components that receive shear loading
Tensile stress parallel to grain	Maximum tensile stress sustained in direction parallel to grain. In the absence of sufficient tension test data the MOR can be considered to be a low or conservative estimate of tensile strength for clear specimens.	Roof truss chord and web that are under tension, bottom flange of timber I-beam, and any other components that receive tensile load parallel to the grain.
Tensile stress perpendicular to grain	Resistance of wood against force acting across the grain that can cause the grain to split.	Any component that has the tendency to split due to tension perpendicular to the grain such as the curved member of a glulam structure.
Hardness	Resistance to indentation using a modified Janka hardness test, measured by the load required to embed a 11.28-mm (0.444-in.) steel ball to a half of its diameter.	Flooring (parquet, floor strip) that is non-suspended, and to judge the wear and tear of a species due to traction.

The Malaysian Standard MS 544: 2001 categorised the national species into seven Strength Groups, designated as SG1 to SG 7. The grouping was done based on the mechanical properties of the species whereby SG1 contains mostly of high mechanical properties as well as high density. The group SG 7 contains the weakest species having the lowest values of mechanical properties as well as density. Nevertheless, due to timber's variability there exists some overlapping of the mechanical properties among the strength groups. The strength grouping also separates between the durable and non-durable species for each group. The species shown in the strength grouping are considered to be the usual commercial species popularly traded in the market.

But it is wise to know that there also exists the lesser-known species that are grouped together as "mixed-hardwood", also known as "chap-char", and sold at cheaper price even though some of the

species possess high strength comparable to the higher strength groups. Please note that some of the species in the strength grouping are considered "non-commercial" because of its scarcity.

A website that is dedicated to this strength grouping containing the details of each species as well as a Design Toolbox for simple structural members can be reached at timbertech.frim.gov.my.

Strength grouping (MS 544)

S.G.1	S.G.2	S.G.3	S.G.4	S.G.5	S.G.6	S.G.7
Naturally durable						
Balau	Belian	Bekak	Giam	Teak		
Bitls	Mata ulat	Delek	Malabera	Tembusu		
Chengal	Kekatong	Keranji	Merbau			
Penaga			Resak			
Requiring treatment						
	Dedaru	Agoho	Berangan	Alan bunga	Bayur	Ara
	Kempas	Balau, red	Dedali	Babai	Damar Minyak	Batai
	Merbatu	Kelat	Derum	Balek angin bopeng	Durian	Geronggang
	Mertas	Kembang semangkok	Kapur	Bintangor	Jelutong	Laran
		Kulim	Kasai	Brazil nut	Jenitri	Pelajau
		Pauh kijang	Keruntum	Gerutu	Jongkong	Pulai
		Penyau	Mempening	Kayu kundur	Kasah	Sesendok
		Perah	Meransi	Kedondong	Machang	Terentang
		Petaling	Meranti bakau	Keledang	Medang	
		Ranggu	Merawan	Keruing	Melantai/Kawang	
		Durian batu	Merpauh	Ketapang	Meranti, light red	
		Tualang	Nyalin	Kungkur	Meranti, yellow	
			Perupok	Melunak	Mersawa	
			Punah	Mempisang		
			Rengas	Mengkulang		
			Simpoh	Meranti. dark red		
				Meranti, white		
				Nyatoh		
				Penarahan		
				Petai		
				Ramin		
				Rubberwood		
				Sengkuang		
				Sepetir		

Fastenings

The strength and stability of any structure depend heavily on the fastenings that hold its parts together. One prime advantage of timber as a structural material is the ease with which timber structural parts can be joined together with a wide variety of fastenings-nails, screws, bolts, lag screws and metal connectors of various types. For utmost rigidity, strength, and service, each type of fastening requires joint designs adapted to the strength properties of timber along and across the grain and to dimensional changes that may occur with changes in moisture content.

Nails

Nails are the most common mechanical fastenings used in timber construction. There are many types, sizes, and forms of nails (Figure 5). Nails resist withdrawal loads, lateral loads, or a combination of the

two. Both withdrawal and lateral resistance are affected by the timber, the nail, and the condition of use. In general, however, any variation in these factors has a more pronounced effect on withdrawal resistance than on lateral resistance. The serviceability of joints with nails laterally loaded does not depend greatly on withdrawal resistance unless large joint distortion is tolerable. Nails can be used for gusset plate connection at the apex of glulam or solid timber roof structure, and for the connection of plywood and solid timber frame for box beams etc.

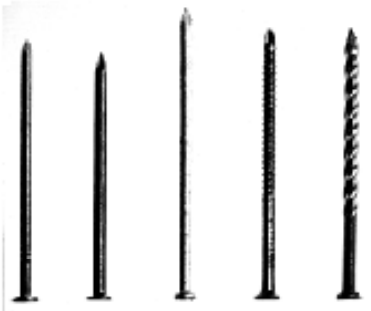


Figure 5 Various types of nails: (left to right) bright smooth wire nail, cement coated, inc coated, annularly threaded, helically threaded, helically threaded and barbed

Timber screws

The common types of timber screws have flat, oval, or round-heads. The flat-head screw is most commonly used if a flush surface is desired. Oval-head and roundhead screws are used for appearance, and roundhead screws are used when counter-sinking is objectionable. The principal parts of a screw are the head, shank, thread, and core. The root diameter for most sizes of screws averages about two-thirds the shank diameter. Timber screws are usually made of steel, brass, other metals, or alloys, and may have specific finishes such as nickel, blued, chromium, or cadmium. They are classified according to material, type, finish, shape of head, and diameter or gauge of the shank. Current trends in fastenings for timber also include tapping screws. Tapping screws have threads the full length of the shank and may have some advantage for certain specific uses.

As an alternative to nails, timber screws can also be used for gusset plate connection at the apex of glulam or solid timber roof structure, connection of floor boards to joists, connection of plywood or composite panels to wall studs, and for the connection of plywood and solid timber frame for box beams etc.

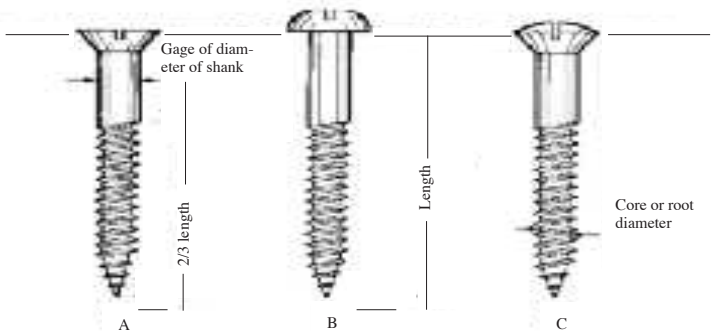


Figure 6 Typical timber screws

Lag screws

Lag screws are commonly used because of their convenience, particularly where it would be difficult to fasten a bolt or where a nut on the surface would be objectionable. Commonly available lag screws range from about 5.1 to 25.4 mm in diameter and from 25.4 to 406 in length. Lag screws have a hexagonal-shaped head and are tightened by a wrench (as opposed to timber screws, which have a slotted-head and are tightened by a screw driver).

Lag screws are normally used to provide high holding capability per screw without the need to provide nut on the other end. Lag screws need predrilled holes before being installed. Lag screws can used to connect solid or glulam beams together to provide a compound beam. Due to their relatively large size, lag screws are not suitable for thin components than are susceptible to crack along the grain but rather for joining of large size components together that need higher stress to be transferred or distributed.

Connectors

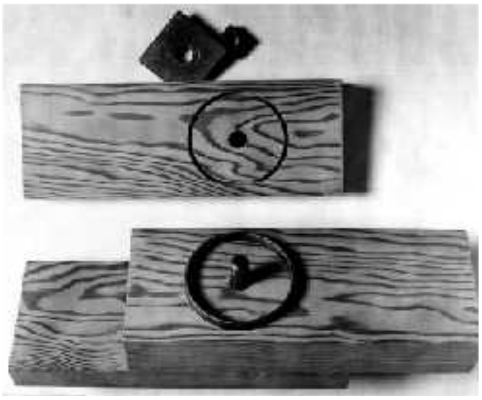


Figure 7 Joint with split ring connector showing connector, precut groove, bolt, washer, and nut

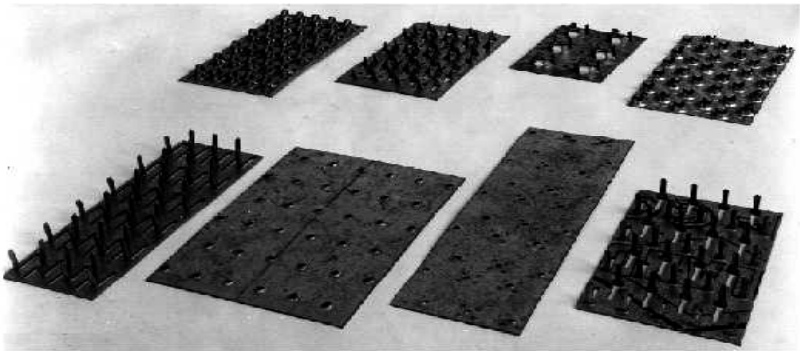


Figure 8 Metal plate connector

Timber-based composites and engineered timber products

The term "Engineered Timber/Wood" is being used to describe any timber material such as boards (or planks), strands, particles, fibers or veneers that are adhesive-bonded together to form composite materials. The need to produce composites is due to several factors:

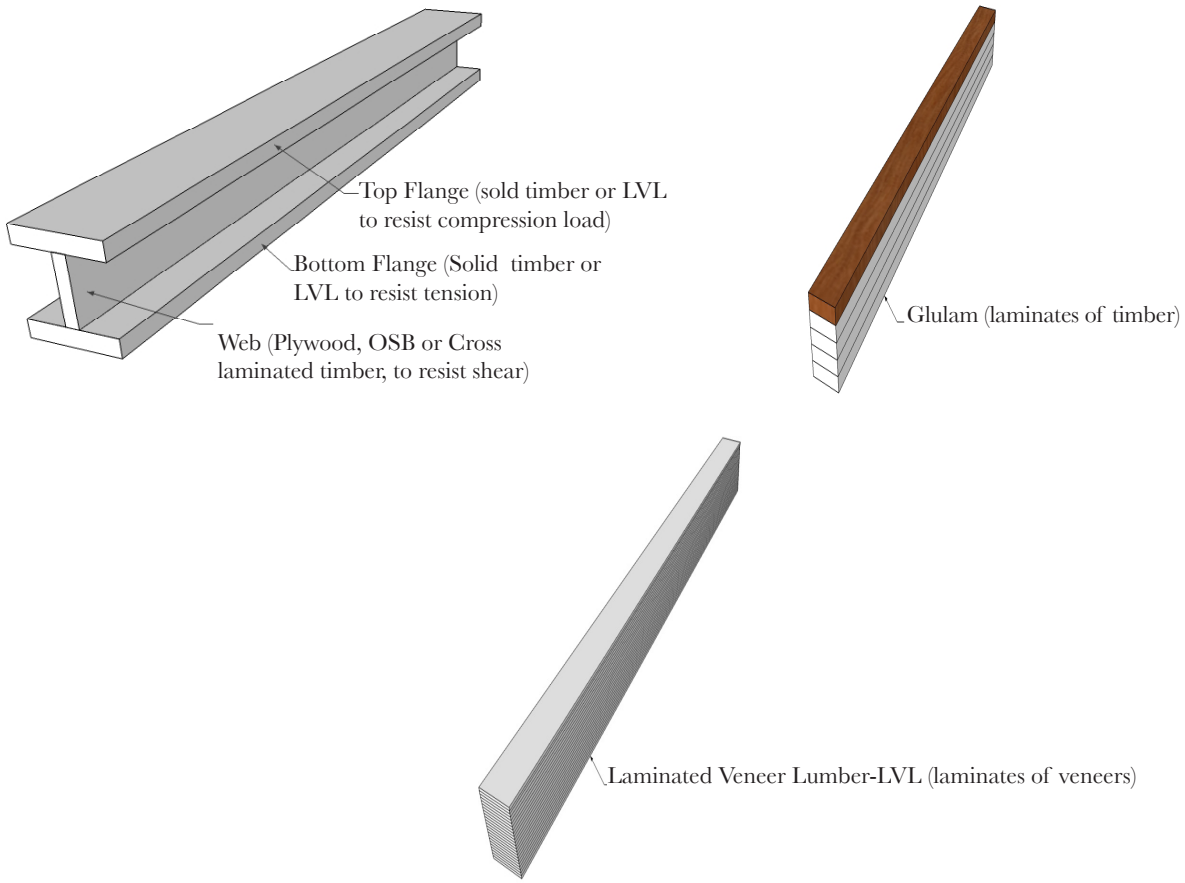
1) the scarcity of solid timber in large diameter
2) to facilitate the use of plantation timbers and non-popular species which are generally smaller in diameter and high in internal stresses, and
3) to produce components that cover larger surface area (such as structural plywood for stressed skin panels, structural panel for load bearing wall etc.), members of larger dimensions and curved structural members that cannot possibly be achieved using solid timber.

These composites are engineered to design specifications to meet national or international standards This product mix ranges from fiberboard to laminated beams and components. Composites are used for a number of structural and non-structural applications in product lines ranging from panels for interior covering purposes to panels for exterior uses and in furniture and support structures in many different types of buildings. Engineered products can also be made into I-beams or laminated veneer lumber (LVL) as alternative to solid timber beams. LVLs are also being used as roof truss components.

Classification of engineered timber products

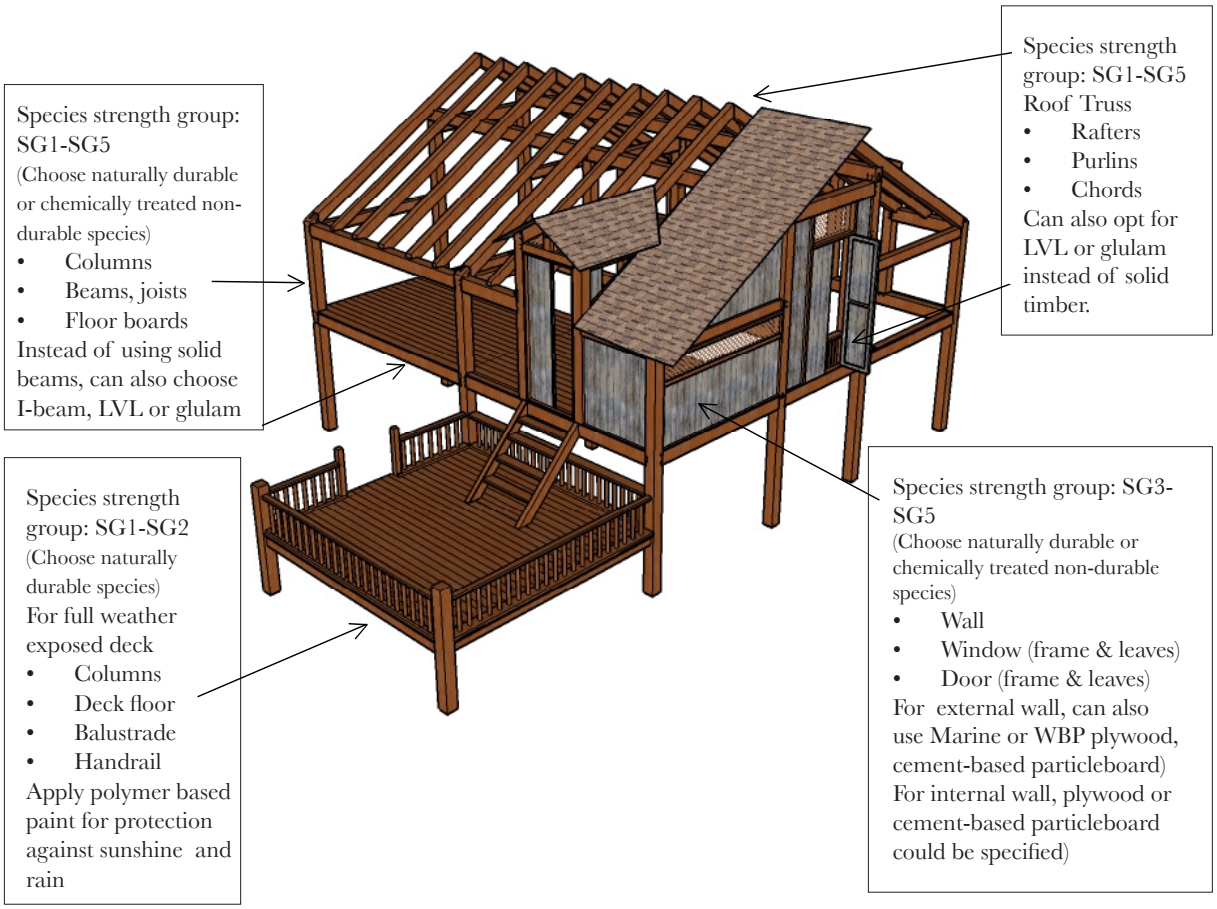
Type	Product name
Veneer-based material	Structural plywood Marine plywood Phenolic film overlay plywood Laminated veneer lumber (LVL)
Laminated timber	Glued laminated beams (Glulam) Laminated (engineered) floor materials
Composite material	Particleboard Oriented strand-board (OSB)
Components	I-beams Stressed-skin panels
Timber–non-timber composites	Timber fiber–plastic composites Timber fiber–agricultural fiber composites

Some engineered timber components



Recommended use of timber products for building

Recommended use of timber products for building



Note: The moisture content of all timber must be below 19%

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