(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

American Forest and Paper Association (1987) Permanent Wood Foundation System Design, Fabrication and Installation Manual. Washington, DC: AF&PA.

American Forest and Paper Association (1996) Load and Resistance Factor Design Manual for Engineered Wood Construction. Washington, DC: AF&PA.

American Forest and Paper Association (1997) National Design Specification for Wood Construction. Washington, DC: AF&PA.

American Forest and Paper Association (1997) Supplement National Design Specification for Wood Construction. Washington, DC: AF&PA.

American Institute of Timber Construction (1994) Timber Construction Manual., 4th edn. Englewood, CO: AITC.

Canadian Wood Council (1991) Wood Reference Handbook. Ottawa, Canada: CWC.

Canadian Wood Council (1993) Wood Building Technology. Ottawa, Canada: CWC.

Faherty K and Williamson T (1989) Wood Engineering and Construction Handbook. New York, NY: McGraw-Hill.

Forest Products Laboratory (1999) Wood Handbook. Wood as an Engineering Material. Madison, WI: Forest Products Society.

Goldstein E (1999) Timber Construction for Architects and Builders. New York, NY: McGraw-Hill.

Hoyle R and Woeste F (1989) Wood Technology in the Design of Structures., 5th edn. Ames, IA: Iowa State University Press.

National Frame Builders Association (2001) Post-Frame Building Design Manual. Lawrence, KS: NFBA.

National Institute of Standards and Technology (1999) American Softwood Lumber Standard DOC PS 20-99. Gaithersburg, MD: NIST.

Sherwood G and Stroh R (1989) *Wood-Frame House Construction*. USDA Forest Service Agriculture Handbook 73. Washington, DC: US Superintendent of Documents.

Smulski S (ed.) (1997). Engineered Wood Products. A Guide for Specifiers, Designers and Users. Madison, WI: PFS Research Foundation.

Williamson T (ed.) (2002) APA Engineered Wood Handbook. New York, NY: McGraw-Hill.

Wood Truss Council of America (1997) Metal Plate Connected Wood Truss Handbook. Madison, WI: WTCA.

Lumber Production, Properties and Uses

F G Wagner, University of Idaho, Moscow, ID, USA

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 allows lumber end trimming during manufacture. Logs may be as small as 10 cm in diameter, or they may be greater than 1 m in diameter.

Logs are purchased by weight or by log scale. If logs are purchased by weight, log trucks are weighed both loaded and empty to calculate the weight of the logs. Mathematical formulae are often used to convert weight to cubic or lumber volume.

Log scale is an estimate of the volume of lumber that is expected to be sawn from the logs. If logs are purchased by log scale, an experienced individual measures the diameter and length of logs, calculates gross lumber volume based on a scale stick or portable computer, and subtracts scale volume for defects that may reduce the volume of lumber sawn from the logs.

Logs are usually delivered to sawmills on log trucks or railcars. They are unloaded with large specially designed lift trucks or overhead cranes, and they are placed on a log yard. Logs are often sorted on the yard based upon species, species group, and diameter of the logs. It is important that enough logs be stored on the log yard to supply the sawmill during interruptions in log deliveries. Log deliveries may be interrupted because of wet weather, lags in log purchases, equipment breakdowns, or a number of other factors. Therefore, logs are sometimes stored for a year or more before they are sawn into lumber. If logs are stored for an extended period of time during warm weather (above 10°C), they must be protected from stain fungi, decay fungi, insects, and drying (*see* **Solid Wood Processing**: Protection of Wood against Biodeterioration. **Wood Formation and Properties**: Biological Deterioration of Wood). Protection is often accomplished by spraying the logs with water. The wet log surfaces provide an anaerobic environment in which most fungi and insects cannot survive, and it prevents drying of the logs. Environmental–government agencies often require that water sprayed on logs be captured at the sawmill site and reused. This prevents chemicals leached from the wood and bark of the logs from entering streams and other estuaries. If these chemicals enter streams and estuaries at high levels, they may be toxic to fish and other marine life.

Lumber Production

Stored logs are eventually transported to the sawmill by lift trucks or overhead cranes. Logs may then be moved by conveyor to a debarker where bark is detached from the logs. Debarkers are usually electrically powered machines that scrape or rub bark from the logs. Bark often contains soil and small rocks that become embedded during log harvest or storage. Thus, removing bark from logs helps prevent dulling of cutting tools in the sawmill. Removing bark from logs also separates bark from the outer portion of logs that often becomes pulp chips during the sawmill process. Bark and sawdust from the sawing processes are often burned to provide energy for lumber drying.

Either before or after the logs are debarked, multisegment logs and tree-length logs are crosscut (bucked) to lumber lengths plus trim allowance. Logs that were bucked to lumber lengths during the harvest process bypass this step. In large sawmills, logs are transported to the log-bucking station via conveyor where they are bucked to length with large circular saws or chainsaws powered by electric motors. At small sawmills, logs may be bucked to length with manually operated gasoline-powered chainsaws.

Logs are next processed by a machine called a headrig. A headrig is the first machine in a sawmill where longitudinal cuts are sawn or chipped on the log (*see* **Solid Wood Processing**: Machining). Every sawmill has one or more headrigs. Many different types of headrig are used worldwide, but most utilize one or more band saws, circular saws, and/or chipping heads to make longitudinal cuts. Logs may be completely sawn into lumber or timbers at the headrig, or they may be sawn into some combination of lumber, timbers, and cants. Cants are logs with one or more sawn or chipped faces. Some lumber may be produced with two sawn wide faces and wane (absence of wood) at the narrow faces (flitches). Flitches may be edged at an edger in the sawmill where the wane is sawn or chipped away. In the case of some hardwoods, flitches may also be sold to other manufacturers for further processing.

The speed of processing at headrigs is quite variable. At some small sawmills, only a few logs may be sawn on the headrig each hour. These are usually headrigs with many manual functions. At modern high-speed small-log sawmills, as many as 25 logs per minute may be processed. These are usually headrigs with scanners and computers that automatically determine the log size and shape, make sawing decisions, and perform many of the sawing functions. Many headrigs have chipping canters that chip a flat face on the side of logs. If the headrig does not have a chipping canter, flat faces are produced with the headrig saws, and the portion removed (slabs) is chipped at another location. Chips (small rectangular pieces of wood) produced at the headrig and at other machine centers in the sawmill are usually sold to pulp companies.

Various sawing methods may be used at headrigs and resaws. Sawn faces may be parallel to the log taper (follow the slope of the outside of the log from the small end to the large end of the log). This sawing method is termed 'taper sawing.' Logs may also be sawn parallel to the centerline of the log, which is termed split taper sawing. In addition, three different sawing patterns may be used. Logs may be completely sawn into lumber on the headrig with all saw lines parallel (live-sawing pattern). Alternatively, lumber and cants may be sawn on a headrig, and the cants may be transported to a resaw where sawn faces are made perpendicular to the sawn faces made at the headrig (cant-sawing pattern). A grade-sawing pattern is also sometimes used where the sawyer makes sawing decisions based upon defects in the log. In grade sawing, the sawyer attempts to improve the grade of the sawn lumber by first sawing the worst face. The log is then rotated to the best face, and the sawyer saws additional lumber from that face until grade declines. The sawyer then rotates the log 90° and continues to saw until the log is completely sawn into lumber.

If cants are produced at the headrig, they are further sawn into lumber at a resaw. Resaws often have multiple circular or band saws, and they may saw cants into lumber in one pass. Lumber produced at a headrig or resaw containing excess wane (absence of wood for any reason but usually due to sawing to the outside of the log) may be edged at an edger. An edger is a machine with saws or chipping heads that produce acceptably square narrow faces on each piece. Lumber is usually fed through an edger lengthwise. Typically some wane may be left on lumber if the amount of wane is not expected to lower the grade. Resaws and edgers may be operated manually, or they may be operated by scanning and computer systems. Chips are produced from the edges of wide faces.

At many sawmills, lumber trimsaws are used to trim one or both ends of lumber. Ends are trimmed to make the ends more square, to make the lumber consistent lengths for further processing, and to remove excess wane or other defects at one or both ends. Trimsaws typically have multiple circular saws that are set at specified distances apart. Lumber usually moves through trimsaws sidewise, and the appropriate saw is lowered to crosscut the lumber to length. Trimsaws may be operated manually, or they may be operated by scanning and computer systems. Short trim ends produced at the trimsaw may be chipped and sold to pulp companies.

Sawmill Performance

The principal measures of sawmill performance are lumber production and lumber recovery. Profitability of a sawmill is closely linked to lumber production. Because some costs at a sawmill are fixed (buildings, machines, and labor), higher lumber production results in lower fixed cost per unit of lumber. Many sawmills set goals or standards of production for a shift, day, week, month, or year. Sometimes bonuses are paid to sawmill workers if production standards are met or exceeded.

Lumber recovery is a measure of the proportion of lumber produced to the volume of logs processed. Lumber recovery is extremely important to the profitability of a sawmill because approximately 75% of the total manufacturing cost of lumber is the cost of logs. Therefore, even small improvements in recovery can greatly reduce manufacturing costs. Lumber recovery may be expressed in terms of percent cubic recovery, volume of lumber to cubic volume or weight of logs, or volume of lumber to log scale. When sawmill recovery is high, 50% or more of the log will become lumber. The rest of the log will become green sawdust and bark, which is often burned to produce energy for dry kilns, chips which are usually sold to pulp manufactures, and dry sawdust and planer shavings which are often sold to particleboard manufactures or burned to produce energy for the kilns. At most sawmills, 100% of the log is utilized.

One method of maintaining high lumber recovery is to have a quality-control program at the sawmill. Sawmill recovery is usually highest when log diameter is large, logs are straight with little taper, saw kerf (width of cut made by saws) is narrow, sawing variation (thick and thin lumber) is low, lumber products are wide and thick, equipment is well maintained, sawing decisions are good, and lumber is carefully dried to the correct moisture content. Therefore quality-control programs often collect and analyze data related to each of these factors. Measurements are taken on a regular basis within the sawmill, and statistics are used to determine whether established standards are being met and manufacturing processes are in control.

Lumber Drying

After trimming, lumber is sorted for thickness, width, and length to accommodate lumber drying and finishing. Lumber may be sorted manually by individuals who pull lumber from a slowly moving chain (green chain) and stack the lumber in an appropriate compartment. Lumber may also be sorted automatically by a large machine that drops lumber into compartments or slings according to thickness, width, and length. In these machines, sort decisions are often based upon limit switches placed along the length of the machine, or they may be based upon a scanning and computer system at the trimsaw.

Lumber may be sold in a rough-green condition, finished (planed) and sold in a dressed-green condition, dried and sold in a rough-dry condition, or dried, finished, and sold in a dry-dressed condition. Hardwood lumber is often sold in the rough-green or rough-dry conditions, and softwood lumber is often sold in the dressed-green or dressed-dry conditions. If lumber is dried at the sawmill, it is dried in an air-drying yard or in a dry kiln (*see* **Solid Wood Processing**: Drying). In the case of hardwoods, lumber may also be partially air-dried and then kiln-dried. Lumber is dried to reduce weight for shipping, to make the wood more dimensionally stable, and to comply with grade standards.

To prepare lumber for drying, it is usually stacked in layers with narrow pieces of lumber (stickers) placed perpendicular to the length of the lumber. This separates each layer of lumber in a stack, and allows air to flow through the stack and dry the lumber. Stacking may be done manually, or it may be done by machine. Softwood structural lumber is typically dried to 15% or 19% moisture content, and hardwood furniture lumber may be dried to 6–8% moisture content.

Lumber dried in an air-drying yard may take several months to reach desired moisture content. However, lumber may sometimes be dried in a dry kiln in as little as a few hours. A dry kiln is a chamber where temperature and relative humidity are closely monitored. Dry kilns are heated with steam or direct-combustion systems. As previously mentioned, heat is often produced by burning bark and sawdust. The heat provides energy for evaporation of water from the wood. Regulation of relative humidity helps control the rate of drying. It is important to control the rate of drying because some types of lumber may be damaged if dried too fast. Regulation of relative humidity within the kiln is achieved by opening vents to exhaust water vapor and reduce relative humidity and by spraying water or steam into the kiln to increase relative humidity. Temperatures within commercial dry kilns may be as high as 125°C.

After drying, lumber may be graded and packaged for sale. It may also be finished (planed) to a smooth surface, graded, and packaged for sale (*see* **Solid Wood Processing**: Machining). Lumber is often planed on four faces, and sometimes a pattern is machined into one or more faces. Lumber planers are usually composed of a lumber feed mechanism and planer heads with planning knives. As lumber is transported through a planer, the planing knives remove a small amount of wood on each planed surface. This provides a smooth surface, and it reduces variation in thickness and width.

Lumber Grading, Properties, and Uses

Lumber is then graded to separate lumber according to the level of quality needed for its intended use. Softwood structural lumber (lumber used for framing buildings) is usually graded based upon visual defects that detract from strength, stiffness, and utility. Structural lumber is graded on both faces for the presence of knots, excess wane, warp (deviation from straight), and other defects. It may also be machine stress-rated by passing each piece of lumber through a machine that bends the lumber flat-wise and measures resistance to bending. Almost all species of softwood trees are manufactured into structural lumber. However, where high strength and stiffness are needed, such as in roof trusses, those softwood species with high density (e.g., Douglas-fir: *Pseudotsuga menziesii*) are often preferred. Dry-dressed softwood structural lumber is typically 38–100 mm thick and 100–300 mm wide. Structural lumber thicker than 125 mm is often defined as timbers. Structural lumber and timbers often range in length from 2.4 to 6.1 m. However, longer lengths are sometimes produced.

Appearance-grade lumber (lumber used for trim and other nonstructural applications in building construction) is usually graded for appearance of the best face and for utility. Appearance lumber is graded on the best face, because often the best face is the only face that will be seen when the lumber is in service. This type of lumber may be painted or finished with a transparent material. Some defects that reduce the grade of appearance lumber are knots, stain, streaks, warp, and other defects. Since high strength is not required, low-density softwood species (e.g., Ponderosa pine (*Pinus ponderosa*) and spruce (*Picea* sp.)) are often preferred for appearance lumber. Dry-dressed appearance-grade lumber is often 19 mm thick and 100–300 mm wide. Lengths often range from 2.4 to 6.1 m.

Factory and shop lumber (lumber used for furniture and millwork) is graded based upon the proportion and size of clear area on the worst face of the lumber. This lumber is often sold to furniture or millwork plants where it will be sawn into parts for furniture, windows, doors, and other applications. Many species of hardwood logs are sawn into factory lumber for furniture production. However, the most popular species groups are white oak and red oak (*Quercus* spp.). Furniture manufacturers often prefer lumber produced from species with high strength and stiffness, attractive appearance, and good machining properties. Lower grades of hardwood factory lumber are sometimes used to manufacture pallets. Pallets are support structures used to ship numerous manufactured products. Rough (undressed)-dry hardwood factory lumber often ranges from 25 to 50 mm thick and may be almost any width 100 mm or greater. Lengths are usually from 2.4 to 4.9 m.

Softwood shop lumber is often used to manufacture furniture or millwork for wood doors and windows. As with hardwood factory lumber, softwood furniture and millwork lumber are often sawn into clear parts. Therefore, the size and proportion of clear-lumber area are important to the grade. Softwood furniture and millwork producers often prefer species with low density and good machining properties (e.g., Ponderosa pine and radiata pine (*Pinus radiata*)). Dry-dressed softwood shop lumber is usually 19 or 29 mm thick and 100–300 mm wide. Lengths often range from 2.4 to 6.1 m.

All types of lumber are graded by experienced sawmill employees who follow grade standards established by grade agencies. These grade standards specify the size, spacing, and/or volume of defects for each size and grade of lumber. Softwood structural lumber and softwood appearance lumber are stamped showing the grade, moisture content, supervising grade agency, and sawmill number. Supervising grade agencies provide training to sawmill graders, and inspect random packages of lumber for conformance to grade standards. They may also settle grade disputes between the sawmill and lumber customers. Hardwood factory lumber and softwood shop lumber usually do not carry a grade stamp. Rather, whole packages of lumber containing the same grade, species, and size are packaged and sold to experienced manufacturers of furniture, millwork, windows, doors, and other products.

Following grading, lumber is packaged and shipped to customers via truck, rail, barge, or ship. If lumber is to be transported over long distances and there is a chance that dry-lumber packages will encounter rain, the packages may be wrapped with a water-resistant covering. In other cases, packages are simply banded with steel bands and shipped without a covering.

See also: **Solid Wood Processing**: Drying; Machining; Protection of Wood against Biodeterioration. **Solid Wood Products**: Construction; Logs, Poles, Piles, Sleepers (Crossties); Structural Use of Wood. **Wood Formation and Properties**: Biological Deterioration of Wood; Formation and Structure of Wood.

Further Reading

Haygreen JG and Bowyer JL (1996) Lumber. In: *Forest Products and Wood Science*, 3rd edn, pp. 303–330. Ames, IA: Iowa State University Press.

Simpson WT (1991) *Dry Kiln Operators Manual*. Madison, WI: Forest Products Society.

Steele PH (1984) *Factors Determining Lumber Recovery in Sawmilling*. Madison, WI: USDA Forest Products Laboratory.

Williston EM (1981) *Small Log Sawmills: Profitable Product Selection, Process Design and Operation*. San Francisco, CA: Miller Freeman.

Williston EM (1988) *Lumber Manufacturing: The Design and Operation of Sawmills and Planer Mills*. San Francisco, CA: Miller Freeman.

Construction; Logs, Poles, Piles, Sleepers (Crossties)

J A Youngquist, Verona, WI, USA
R Youngs, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

Published by Elsevier Ltd., 2004

Introduction

The material in this article is adapted from the Forest Products Laboratory *Wood Handbook*, which is especially concerned with use of wood as an engineering material in the USA. However, the use of wood in log or timber form is common worldwide and the same principles apply. Such applications were among the first uses of wood by primitive people, because the material was available and could be used without further processing, except to cut to size. It was used to make homes, buildings of many types, and fortifications, as well as weapons and means of transport. The concepts developed through experience were carried on and improved over thousands of years, appearing today in homes, barns, bridges, and other structures of many kinds. Use of timber as sleepers (crossties) made possible the development of railroads in many parts of the world and continues as a major element in transportation systems. Poles for electric power transmission lines have developed with the industry and provide essential structures as electricity is generated and distributed to the far corners of the world.

Wood in the form of timbers and poles for construction has been an essential element in the development of civilization and continues in that role today.