



In January 2013, Institution Director of Engineering and Technical Services, Sarah Fray, heralded a new technical support initiative; a series of articles focussing on specific materials and their use. CEO of the UK Timber Frame Association, Andrew Carpenter, introduces the series...

This new series of technical articles will gradually build to form a *Timber Engineering Notebook*. Written by Chartered structural engineers Milner Associates with contributions from industry specialists, on behalf of the UK Timber Frame Association (UKTFA), the series aims to provide basic technical

information on the use of timber as a structural medium, for the practising structural engineer.

By way of setting the scene, the first paper in the series provides a historical and technical background to natural sawn timber as a structural material. Subsequent papers will cover the range of engineered

timber materials (engineered wood products) and composite wood products commonly available and different types of timber structures in more detail.

It's hoped that as the *Timber Engineering Notebook* series develops, it will become an essential source of technical information for anyone interested in and/or working with timber - and we look forward to providing this high quality, peer-reviewed reference material to members of the Institution.

Timber Engineering Notebook series

No. 1: Timber as a structural material - an introduction

The use of timber as a structural material is not new, in fact dating back many centuries. As time passes, developments in the various types of timber components which are available and their use in different structural forms have occurred; new advanced timber products are now available enabling structural engineers to achieve the performance and efficiency in building forms being demanded in the 21st century.

There are thousands of species of tree from which timber can be obtained, each with different rates of growth, structural properties and degrees of durability. The timber supply chain has responded to nature's variability and now provides repeatable product supply from managed forests. The industry has also created grading processes to deliver reliable technical performance (grades) for these products.

The UK construction industry generally uses the word 'timber' to describe structural products of wood, whereas in North America the word 'lumber' is used. 'Wood' is often used to describe furniture and other non-structural items. Nevertheless, all three terms are commonly used to describe structural products.

Timber is categorised as either 'softwood' or 'hardwood'. Softwood is obtained from coniferous trees and hardwood comes from broad-leaved trees. Softwood and hardwood are botanical terms and do not necessarily refer to the density or hardness of the wood. For example Balsa, which is known to be soft and used for building lightweight models, is a hardwood whereas Douglas Fir is a softwood with good durability and high strength properties.

Softwood is commonly used for timber structures (Figure 1) as it is



IWS AND FLIGHT TIMBER

↑ Figure 1
Softwood timber frame construction using prefabricated floor 'cassettes'

readily available, easily worked, of relatively low cost and its fast rate of growth gives a continuous supply from regenerated forest areas.

Hardwoods are typically used for exposed structures and claddings where durability and particular aesthetic characteristics, such as colour or grain pattern, are required.

Table 1: Historic use of timber and structural forms in buildings

Era	Application	Forms
Medieval	Wall framing	close studding to create loadbearing wall panels square panels with curved braces chevron bracing
	Floor structures	common joists between 'spine' beams 'jetted' floor construction
	Roofs	common rafter roofs purlin-supported roofs arched roofs collar-tied roofs scissor-braced roofs crown-post roofs
	Whole buildings	cruck frames box frames post and stud frames aisled construction
Post Medieval (17th-19th Century)	Wall framing	internal partitions trussed partitions
	Floor structures	common joists with primary 'girder' beams ceiling joists trussed girders
	Roofs	king post trusses with ironwork queen post trusses with ironwork mansard roofs mechanically laminated timber arches
Modern (20th Century onwards)	Roof and floor structures	use of mechanical connectors glued laminated timber beams lattice girders I-joints and open-web joists plywood box beams Belfast trusses 'Fink', 'Pratt' and 'Warren' trusses bowstring girder folded plate roofs
	Whole buildings	arches and rigid frames post and beam construction membrane shells platform-frame construction balloon-frame construction

Table 2: Characteristic strength, stiffness and density properties for typical softwoods from EN 338 Table 1

Grade	Bending strength (N/mm ²)	Mean modulus of elasticity parallel to grain E _{0,mean} (N/mm ²)	Characteristic density (kg/m ³)
C16	16	8000	310
C24	24	11000	350
TR26	27	11000	370

Note: In comparison the density of steel = 7850kg/m³ and approximate density of concrete = 2400kg/m³.

History of use

In the United Kingdom, timber was the principle construction material for buildings in the Medieval period until the 18th century. After the Great Fire of London in 1666, masonry was used increasingly for external and separating walls with structural timber employed for roofs, floors and internal walls.

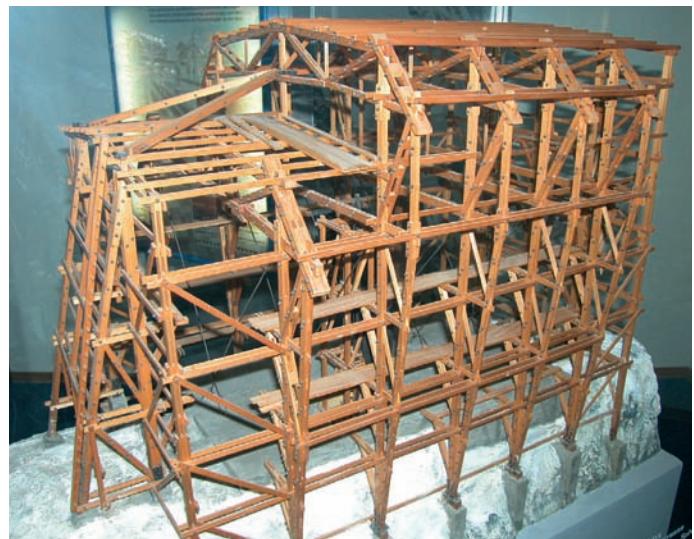
Oak was typically used for timber-framed buildings during the medieval period due to its availability, while softwoods from the Baltic countries and North America were increasingly employed for internal structural timber, floors and roofs within masonry buildings from the 18th century onwards.

With the increasing use of iron in buildings in the 19th century, timber was used in combination with metal for long span and heavily loaded structures. The development of mathematical procedures at this time for the design of structures and structural elements (Figure 2) led to today's approach to engineering timber structures (Figure 3).

Table 1 shows the evolution of the use of timber in buildings. For more information on these historic forms of construction, refer to the 'References and further reading' section.

Why use timber for today's structures?**Energy issues**

As a natural and renewable building material, timber has excellent ecological attributes. It acts as a carbon sink and has low embodied energy. The energy needed to convert trees into wood and hence into structural timber is significantly lower than that required by other structural materials such as steel and concrete. Figure 4 compares the production energy requirements for lightweight concrete block and timber frame walls. This point is further demonstrated by



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Figure 2
Early 20th Century timber post and beam and truss construction subjected to high wind loads. Model of the climatology and research station located at 4000m above sea level at Jungfraujoch, Switzerland

Figure 3
Multi-storey timber frame construction using platform frame methods

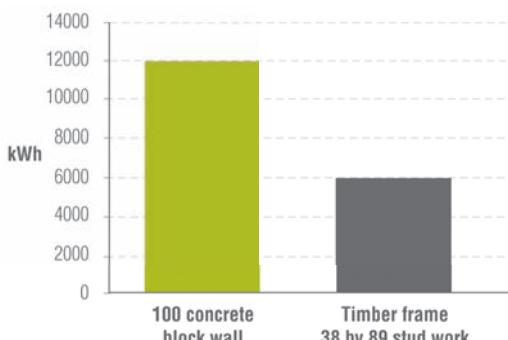


Figure 4
Comparison of production energy requirements for timber frame and lightweight concrete blocks

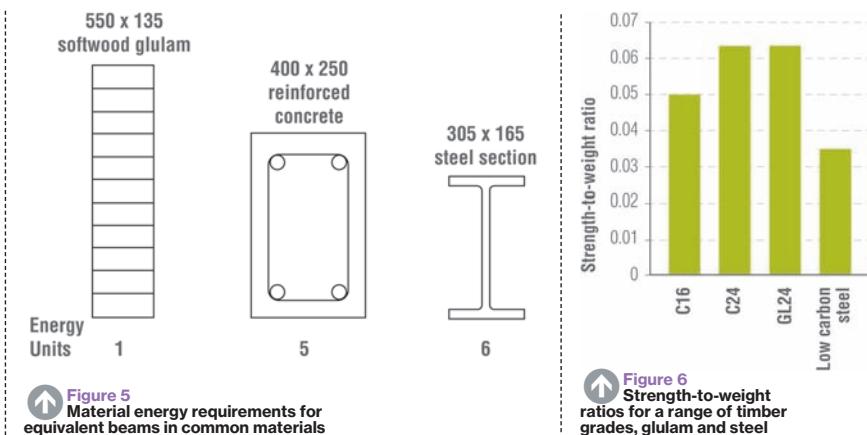


Figure 5
Material energy requirements for equivalent beams in common materials

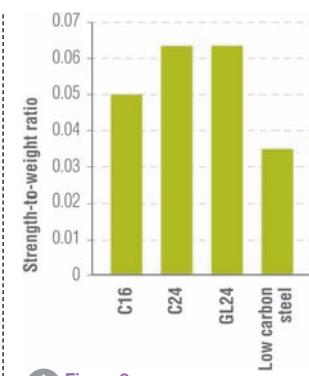


Figure 6
Strength-to-weight ratios for a range of timber grades, glulam and steel

comparing the energy requirements for beams in steel, reinforced concrete and timber, as illustrated in Figure 5.

Depending on species, timber can also have good durability characteristics and good insulating properties against heat and both airborne and impact sound.

Strength issues

Timber has a very high strength-to-weight ratio. This is illustrated as a comparison between steel and timber in Figure 6.

Commercial considerations

When compared to other structural materials, softwood timber has a low density (Table 2). This means it can offer lightweight structural solutions resulting in benefits such as reduced foundation loads and ease of lifting prefabricated elements during transportation and assembly.

Prefabrication

Many modern buildings are prefabricated in elements off site. As a result there is generally a requirement for less site labour and a reduced programme time for work on site (Figure 7).



Figure 7
Prefabricated timber frame wall panels during erection

Prefabrication in a factory gives the opportunity for quality control and avoids the vagaries of the weather and site conditions.

Other benefits of timber

- material can be easily shaped and modified - waste material can be recycled
- it can be easily connected using nails, screws, dowels, bolts and connectors - under controlled conditions of temperature and humidity adhesives may be used to glue timber elements together
- timber (and timber components) is lightweight and easy to handle in manufacture, transport and construction

Strength of timber

The strength of timber comes from the natural properties of the wood and the way the tree grows (Figure 8). Standard timber joists are sawn from the trunk of a tree. The trunk is composed of cells aligned axially along the trunk, which are long in relation to their width. Timber joists and beams sawn from the trunk of the tree have these cells parallel to their length and this provides both the axial and flexural strength. The compression and tension strength of timber parallel to the grain is much greater than that perpendicular to the grain, due to the natural characteristics of these cell structures.

The strength of sawn timber is a function of species, density, size and form of member, moisture content and duration of applied loading, together with strength-reducing characteristics such as slope of grain, knots, fissures and wane. Strength grading methods have been devised to classify timber using either visual strength grading or machine strength grading methods.

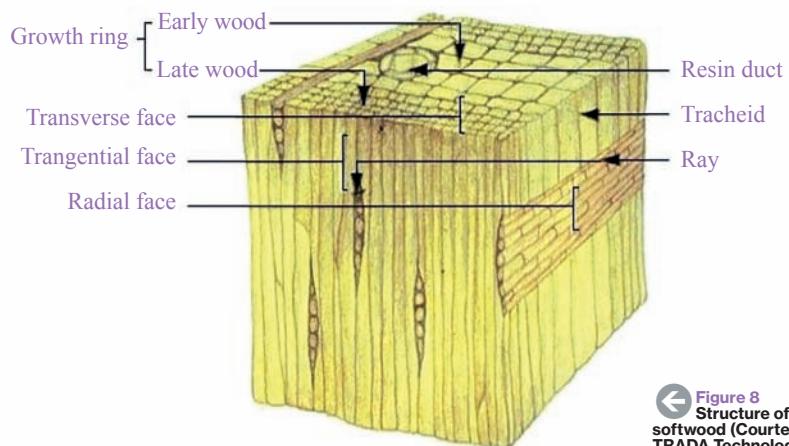


Figure 8
Structure of softwood (Courtesy of TRADA Technology Ltd)



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Figure 9
Open web floor joists using TR26 timber for flanges

Timbers of similar strength properties are grouped together into a series of strength classes which are defined in BS EN 338:2009. This simplifies the design and specification process by enabling designs to be based on defined strength class limits without the need to identify and source a particular species and grade combination. Strength classes are defined as softwoods prefixed 'C' (coniferous) and hardwoods prefixed 'D' (deciduous). The values for commonly available softwood grades are indicated in [Table 2](#) (note that the TR26 grade is a UK grade typically for truss rafter roofs and open web floor joists derived from C27 material – [Figure 9](#)).

Size of timber

Softwood timber sections tend to be produced in a range of standard sizes and lengths called 'customary sizes'. These are listed in BS EN 336: 2003 and its UK National Annex.

More information on common softwood timber joist sizes is given in the Institution's Technical Guidance Note 18 (Level 1) *Design of timber floor joists*.

For products that require thicknesses above 75mm, the use of multiple sections or engineered wood products (EWPs) are often used, as the appropriate installation moisture content of timber sections above 75mm thickness is difficult to achieve. [Table 3](#) provides an indication of the section size limits for timber. Note: engineered wood products, composite wood products and wood-based board materials will be described in more detail in future articles in this series.

Table 3: Section size limits for timber products

	Thickness up to 75mm	Thickness above 75mm
Depths up to 250mm	Sawn timber products	Multiple thicknesses or EWPs
Depths above 250mm	EWPs	
Lengths more than 5.4m	Finger jointed softwood or EWPs	Multiple thicknesses or EWPs

Moisture content of timber

Water in a tree immediately after felling lies within the walls and voids of the cells previously described. When the timber dries, water is then lost from within the cell voids and there is no dimensional change as the moisture content reduces (m/c is the weight of water to oven dried timber) until the 'fibre saturation point' (approximately 25% m/c) is reached when water begins to be lost from the cell walls. Dimensional change, otherwise known as shrinkage, then commences. Likewise when timber attracts moisture it will swell until fibre saturation is reached.

Typical moisture contents (by weight) of timber in service are in the range 7-12% for internal heated areas, 10-18% for internal unheated areas and 12-26% for exposed UK timbers. The typical moisture content of timber freshly felled is at least 100% but varies depending on what time of year the tree is felled. BS EN 1995-1-1 defines timber in service with a moisture content of 12% or less as being in Service Class 1, 20% or less in Service Class 2 and above 20% as Service Class 3.

The moisture content of timber can affect the strength and stiffness properties and generally, timber strength increases with decreasing moisture content values. Design strengths given in BS EN 338:2009 refer to the characteristic strength of timber at a moisture content consistent with Service Classes 1 and 2 conditions. Above 20% moisture content (Service Class 3) timber is classed as wet and stresses are reduced with increasing moisture content up to 30%.

The dimensional change in timber perpendicular to the grain direction is commonly taken as 1% change in dimension for every 4% change in moisture content. For practical purposes shrinkage parallel to the grain is small enough to be ignored.

Creep of timber

An important characteristic of timber which affects its serviceability performance is 'creep'. When first loaded, timber deforms elastically but over a period of time, additional deformation occurs.

The degree of creep deformation will increase with increasing moisture content of the timber and with loading applied for longer durations. E.g. the deflection of a sawn timber joist in Service Class 2 could increase due to creep by as much as 80% of the initial deflection.

More information on the creep deformation modification factor k_{def} is given in the Institution's Technical Guidance Note 18 (Level 1) *Design of timber floor joists*.

Durability of timber

Timber materials will have varying degrees of natural durability and this depends on the species. Decay of timber will generally occur where the moisture content is above 22% for a prolonged period of time, for example where defects in the building design or poor maintenance allow moisture to build up to this level.

The durability of timber is classified against fungal decay or insect attack as indicated in [Table 4](#) (taken from ground contact trials in accordance with BS EN 350-1:1994).

Where durability against the risk of decay or insect attack is required for a non-durable species, chemical preservative treatments may be applied. Preservatives are often used as a second line 'insurance' against design or construction failures that could lead to moisture contents above 22%.

Table 4: Classes of natural durability of heartwood* to fungal attack

Durability class	Description	Examples
1	Very durable	Greenheart, Iroko
2	Durable	European Oak, Western Red Cedar (N.America)
3	Moderately durable	Douglas Fir, European Larch
4	Slightly durable	Scots Pine, Norway Spruce, Fir, European Whitewood
5	Not durable	Beech, Birch

*All sapwood should be considered as belonging to durability class 5 (not durable). Note: Details of timber's heartwood and sapwood zones are shown in Figure 10

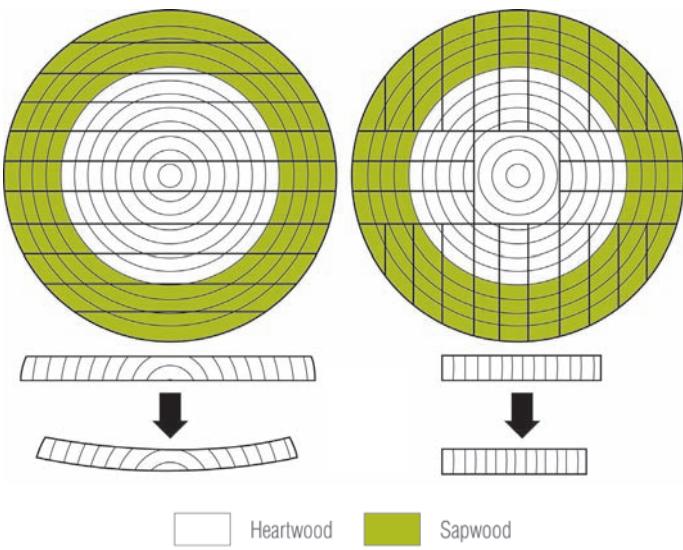


Figure 10
Sawn timber from the tree indicating sapwood and heartwood zones and the shape which may occur in drying. Logs sawn through-and-through (left) give wide boards but these tend to 'cup' on drying (bottom left). 'Quarter-sawn' logs (right) give narrower sections but these are less likely to distort during the drying process and in use (bottom right). However, quarter sawn logs are less readily available and attract a cost premium

Examples where preservative treatment of timber in accordance with BS 8417 is required (taken from NHBC Standards Appendix 2.3A) are:

- Roof timbers in areas where house longhorn beetle (*Hylotrupes bajulus L*) is prevalent (refer to Building Regulations Approved Document A Table 1)
- Flat roof joists and tiling battens exposed to risk of condensation
- Soleplates above damp proof course level
- External wall studs

Alternatively, the structural engineer may adopt a specific timber species for a particular project where natural durability is required, such as exposed timber columns, bridges and water-containing structures.

However, the majority of timber structures adopt timber materials that are assumed not to be durable and therefore, it is the design of the structure itself which plays the most important part, to ensure that the

timber is not susceptible to high moisture contents in service, giving rise to the potential for decay.

Resistance of timber to fire

Wood is a combustible material and when it ignites there can be a rapid spread of flame across its surface. However, the build-up of carbon on the surface (in the form of charred wood) limits the oxygen supply to the underlying wood and acts as an insulator, so the wood below the charred level is relatively cool and retains its structural integrity.

Solid timber of large cross section can therefore be designed in accordance with BS EN 1995-1-2:2004 without additional fire protection by considering the properties of the depleted section below the charred timber. Alternatively, fire-resistant linings such as plasterboard, can be used to protect the timber.

The ignitability and surface spread of flame of exposed timber surfaces can be reduced by surface coating or impregnating chemical treatments.

More information on timber in relation to its fire performance during construction and in service will be described in future articles.

Relevant codes of practice

BS EN 336:2003 Structural timber – sizes, permitted deviations

BS EN 338:2009 Structural timber - strength classes

BS EN 350-1&2:1994 Durability of wood and wood-based products – Natural durability of solid wood

BS EN 1995-1-1 Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings

UK National Annex to Eurocode 5: BS EN 1995-1-1: Design of timber structures – Part 1-1: General – Common rules and rules for buildings

BS EN 1995-1-2:2004 Eurocode 5: Design of timber structures – Part 1-2: General – Structural fire design

UK National Annex to Eurocode 5: BS EN 1995-1-2:2004: Design of timber structures – Part 1-2: General – Structural fire design

BS 8417:2011 Preservation of timber – Code of practice

Definitions

Deciduous – trees that lose all of their leaves for part of the year.

Evergreen – trees where green foliage is present all year round.

Knots - imperfections in natural wood/base of a side branch.

Fissures - splits parallel with grain as a result of drying/shrinkage.

Wane – a rounded edge of a timber section.

Heartwood – inner zone of wood in a growing tree that has ceased to contain living cells or conduct sap.

Sapwood – outer zone of wood in a growing tree that contains living cells and conducts sap.

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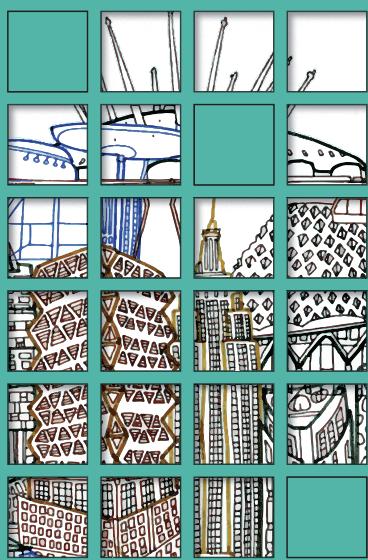
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The UK Timber Frame Association (UKTFA) represents over 85% of the UK's timber structural frame supply industry and is a trade organisation that provides business and technical support to the industry. The Association provides peer reviewed outputs on subjects related to the timber industry such as health and safety, fabric and technical performance, fire safety, promotion and training. These documents and other information are available at www.uktfa.com

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