Introduction
There are limitations on the maximum cross-sectional size and lengths of sawn timber that can be used as a structural component due to the availability of log sizes and the presence of naturally occurring defects in the timber (see Timber Engineering Notebook No. 1). These defects can be cut out and the timber reconstituted using engineered wood techniques such as finger jointing (Figure 1) to create longer lengths of timber of an assured strength grade, or laminating to form a homogeneous timber section. Combinations of timber or laminated sections with different materials such as wood-based boards or metal elements are used to create ‘engineered wood products’ (EWPs) whose maximum size is limited only by manufacturing, handling and transportation constraints.

In addition to engineered wood products, there are reconstituted board products which comprise smaller wood-based strands and fibres re-formed into panel products. These have structural applications but are also used extensively in the furniture-making and packaging industries. Types of timber structural systems and their applications are also introduced in this Notebook.

Engineered wood products
EWPs including glued laminated timber, finger joints, plywood, stressed skin panels, mechanically and adhesive bonded web beams and connected and nail plated trusses, have been in existence for at least 40 years.

Recently, there have been significant developments in the range of EWPs for structural applications with materials such as laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), prefabricated I-beams, metal web joists and ‘massive’ or cross-laminated timber (CLT) becoming more widely available.

These EWPs are typically manufactured by adhesively laminating together smaller softwood sections or laminates (e.g. glulam and CLT) or veneers or strands of timber (e.g. LVL, LSL and PSL).

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The varying performance of EWPs is influenced by the size of wood component used in the product. At one end of the spectrum smaller sections of timber are laminated and finger jointed to form sections of glulam, whilst at the other end, reconstituted board products such as oriented strand boards (OSBs) and medium density fibre boards (MDFs) use small wood strands or fibres bonded together (Table 1).
Thin webbed joists (I joists)
I joists (Figure 2) are an EWP manufactured with flanges made from softwood or LVL with glued thin webs generally made from OSB, fibreboard or plywood. I joists can be used to resist either flexural or axial loads or a combination of both (Figure 3).

Metal web or open web joist
Open web joists are shallow parallel-chord trusses manufactured using similar techniques to that used for trussed rafters comprising a member with flanges (or chords) usually made from softwood and with metal or timber strutting to form the webs (Figure 4).

The chords (and webs where timber webs are used) are generally planed softwood graded in accordance with BS EN 14081-1. The strength class of the timber is usually C27 in accordance with BS EN 338:2009 or TR26 (whose characteristic strength values are equal to that of C27 but whose characteristic stiffness values are taken from BS5268-2:2002). The depth of the chords is generally 47mm and their widths range from 72mm to 145mm. Metal webs are typically profiled, nominal 1mm galvanised light gauge steel with a zinc coating specification of Z275.

Open web joists are principally used as a roof or floor joist element. They are often preferred to I-joists as they allow a combined services and structural zone.

Plywood
Plywood is a flat panel made by bonding together, under pressure, a number of thin layers of veneers (or plies). Plywood was the first type of EWP to be widely available. The structural properties and strength of plywood depend mainly on the number, thickness, species and orientation of the plies.

The structural grade plywood that are commonly used in the UK construction industry are:
- American construction and industrial plywood
- Canadian softwood plywood
- Finnish birch-faced, birch and conifer plywood. Birch plywood gives a good fair-faced finish and is readily persuaded into curved profiles
- Swedish softwood plywood

Plywoods are typically used for roof and floor decking applications and for wall sheathing boards.

Plywood for structural applications should be specified as “having exterior glue bond to BS EN 314-2 and veneers in compliance with BS EN 636:2003” This replaces the previous definition for the plywood of WBP exterior grade where ‘WBP’ describes the properties of the adhesive and ‘exterior grade’ describes the durability of the outer veneers.

The characteristic strength and stiffness values for plywood for use in structural design are contained in BS EN 12369-2:2004.

Laminated veneer lumber
Laminated veneer lumber (LVL) is a structural member manufactured by bonding together thin vertical softwood veneers with their grain parallel to the longitudinal axis of the section, under heat and pressure. In some cases cross grain veneers are incorporated to improve dimensional stability.

LVL is often used for high load applications to resist either flexural or axial loads or a combination of both. It can provide both panels and beam/column elements.

The requirements for LVL are contained in product standard BS EN 14374:2004.
Laminated strand lumber
Laminated strand lumber (LSL) is a structural member made by cutting long thin strands approximately 300mm long and 0.8mm - 1.3mm thick directly from de-barked logs. The strands are blended, coated with adhesive and oriented so that they are essentially parallel to the longitudinal axis of the section before being reformed by steam-injection pressing into a solid section. LSL is used in similar applications to LVL.

Parallel strand lumber
Parallel strand lumber (PSL) is a structural member made by cutting long thin strands (typically 3.2mm thick, 20mm wide and up to 3.0m long) from timber veneers. The strands are oriented so that they are essentially parallel to the longitudinal axis of the section before being coated with adhesive and fed into a continuous press and microwave-cured. PSL is used in similar applications to LVL.

LSL and PSL have recently become less widely available in the UK due to a preference for LVL and supply chain considerations.

Glued laminated timber
Glued laminated timber (glulam) is a structural member made by gluing together a number of graded timber laminations with their grain parallel to the longitudinal axis of the section. Members can be straight or curved, horizontally or vertically laminated and can be used to create a variety of structural forms (Figure 5).

Laminations are typically 25mm or 45mm thick but smaller laminations may be necessary where tightly curved or vertically laminated sections are required.

The requirements for the manufacture of glulam are contained in product standard BS EN 14080:2013.

Cross laminated timber
Cross laminated timber (CLT) is a structural timber product with a minimum of three cross-bonded layers of timber, of thickness 6mm to 45mm, strength graded to BS EN 14081-1:2005 and glued together in a press which applies pressure over the entire surface area of the panel.

CLT panels typically have an odd number of layers (3,5,7,9) which may be of differing thicknesses but which are arranged symmetrically around the middle layer with adjacent layers having their grain direction at right angles to one another (Figure 6).

The structural benefits of CLT over conventional softwood wall framing and joisted floor constructions, include:

- large axial and flexural load-bearing capacity when used as a wall or slab
- high in-plane shear strength when used as a shear wall
- fire resistance characteristics for exposed applications
- superior acoustic properties

Due to its arrangement as a panel rather than a framed construction comprising discrete loadbearing elements, CLT also distributes concentrated loads as line loads at foundation level.

A variant of CLT developed in Germany in the 1970s is Brettstapel or ‘massive timber’, which is the term commonly used for solid timber construction that does not generally use glue or nails. Fabricated from softwood timber posts connected with hardwood timber dowels, the system works by using dowels with a moisture content lower than that of the posts. Over time, the dowels expand to achieve moisture equilibrium, thus ‘locking’ the posts together and creating a structural load-bearing panel system.

CLT should be designed using the principles given in BS EN 1995-1-1 and -1-2 together with data from the manufacturer of the product.

Table 2 illustrates the properties of a variety of EWP.

Reconstituted wood-based board products
Reconstituted board products are typically manufactured by combining smaller wood strands or fibres with adhesive.

There is a structural penalty when timber is modified from a sawn product to small strands and fibres used in board products, as the effects of creep increase as the amount of glue used to join the smaller wood elements increases.

The design of reconstituted timber board materials takes the resulting reduced performances into account by the use of relatively low values for the factor $k_{mod}$ in BS EN 1995-1-1 Table 3.1 for OSB, particleboards and fibreboards.

Oriented strand board
 Oriented strand board (OSB) is a multilayer board made from strands of wood sliced from small diameter timber logs and bonded together with an exterior grade adhesive, under heat and pressure. OSB is manufactured in various grades with improving resistance to the effects of moisture. The minimum grade that should be used for...
### Table 3: Summary of timber, engineered wood and board products and their structural applications

<table>
<thead>
<tr>
<th>Product</th>
<th>Application</th>
<th>Common sizes</th>
</tr>
</thead>
</table>
| **Sawn timber**                      | Small structural framing, studs and joists, general carcassing, door panels, joinery | Length: up to 5.4m  
Width: 25-75mm  
Depth: up to 250mm |
| **Finger-jointed softwood**          | Floor and roof joists, ceilings, loadbearing studs, cladding support, prefabricated multi-span ‘cassette floors’, laminations for glulam members | Length: up to 20m  
Width: 38-75mm  
Depth: up to 250mm |
| **Glulam**                           | Large structural elements, beams, columns, trusses, bridges, portal frames, post and beam structures | No theoretical limits to size length or shape.  
Common size range: 60 to 250mm wide by 180mm to >1000mm deep |
| **‘Massive’ or cross laminated timber (CLT)** | Floor slabs, roofs, beams, columns, load bearing walls, shear walls | Length: up to 20m  
Thickness: 50-300mm  
Width: up to 4800mm |
| **Laminated veneer lumber (LVL)**    | Beams, columns, trusses, portal frames, post and beam structures, structural decking, I-joint flanges, stressed skin panels | Length: up to 20m  
Width: 19-200mm  
Depth: 200mm up to 2500mm |
| **Laminated strand lumber (LSL)**    | Beams, columns, post and beam structures                                    | Length: up to 20m  
Width: 30-90mm  
Depth: 90mm to >1000mm |
| **Parallel strand lumber (PSL)**     | Beams, columns, post and beam structures                                     | Length: up to 20m  
Width: 45-200mm  
Depth: 200mm to >1000mm |
| **Particleboards**                   | Flooring, ceiling and panel infill                                           | Board materials typically available in 1220mm x 2440mm sheets and thickness ranges from 9 to 25mm |
| **Oriented strand board (OSB) & plywood** | Structural sheathing and decking                                             |                                                                              |
| **Metal web or open-web joists**     | Floor and roof joists, ceilings, prefabricated ‘cassette floors’             | Length: up to 20m  
Width: 72-147mm  
Depth: 200-400mm |
| **I joists**                         | Floor and roof joists, formwork, ceilings, loadbearing studs, cladding support, prefabricated ‘cassette floors’ | Length: up to 20m  
Width: 38-97mm  
Depth: 200-500mm |
| **Box beams, thin flange beams e.g. stressed skin panels** | Beams, roofs, columns                                                      | No theoretical limits to size length or component sizes |
Particleboard and fibre composites
There are a number of different board materials made from particle and fibre composites including fibreboards, tempered hardboard, cement-bonded particleboard and wood chipboard. The most common for structural applications is chipboard, which is made from small particles of wood and binder.

Chipboards are classified as grades P1-P7 in BS EN 312:2003 depending on their intended use. The minimum grade that should be used for structural applications is P5 which is a moisture-resistant grade.

The characteristic strength and stiffness values for OSB, particleboards and fibreboards for use in structural design are contained in BS EN 12369-1:2001.

Table 3 shows the range of timber and EWPs available, together with their typical applications.

Advantages of EWPs as structural materials
Use of waste timber
Timber can be recycled and turned into strands and fibres and reconstituted into an engineered wood product.

Enhanced strength and stiffness
By building up a structural section from a number of smaller elements it is possible to reduce the variability inherent in natural timber, thereby improving the strength and stiffness of the composite section.

This is illustrated in Figure 7 which shows the mean and 5th percentile modulus of elasticity parallel to the grain associated with a range of softwoods, hardwoods and structural timber composites. The figure shows that composites have better stiffness properties than the natural sawn sections from which they are composed.

Increased size and scope of application
Engineered timber structures incorporate factory produced components where the constraints on length and section may be determined only by manufacturing, handling and transportation considerations rather than the constraints set by the size of log available. It is therefore possible to extend the range of timber engineering possibilities to large span and tall structures.

Reduced moisture content
The production requirements for certain EWPs may call for low moisture content e.g. gluing, which can result in lower movement upon drying out in service. However, in some cases (e.g. OSBs) the moisture content of the product following manufacture is lower than will be experienced during the construction phase, which can lead to problems due to dimensional changes of the product in humid environments.

Dimensional consistency
Engineered wood products disperse the natural defects inherent in solid timber and are manufactured to controlled tolerances. As a result, their dimensional consistency is significantly improved. This can be beneficial where tight tolerances may be required e.g. at connections. More regular joist depths also result in flatter floor structures than would be possible with sawn timber joists; thus avoiding some of the problems that can be associated with small variations in joist depth such as ‘nail squeak’.

Ease of installing services and ease of handling
Service runs for mechanical and electrical infrastructure can easily be installed through open-web joists and, to a lesser extent, through I joists.

I joists and open web joists in particular are lighter in weight than equivalent solid timber sections and are therefore easier to handle.

Figure 7
Comparison of modulus of elasticity (E) and associated variation with various timber grades and structural timber composites

Figure 8
Scunthorpe Sports Academy: example of glulam gridshell roof

Types of timber structures
Structural methods have been developed, incorporating EWPs, to provide timber structures which achieve a particular function with satisfying aesthetic form and performance e.g. timber gridshells and stressed skin panel roofs (Figure 8).

Portal frames and beam and post structures
Large open plan structures can be created by using portal frames and beam and post structures constructed from engineered wood products.

Platform frame construction
Methods of construction such as platform frame construction enable the construction of multi-storey timber frame structures for buildings which have a cellular arrangement of rooms and where internal loadbearing walls can be utilised.
### Table 3: Types of timber structural systems and their applications

<table>
<thead>
<tr>
<th>System</th>
<th>Application</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform frame construction</td>
<td>Residential, care homes, hotels, student accommodation</td>
<td>Commonly used for cellular-plan buildings with internal load-bearing walls. Up to 7 storeys possible, however requirements for preventing building overturning may govern</td>
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<tr>
<td>(softwood construction)</td>
<td></td>
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<tr>
<td>Glulam or LVL beam and post</td>
<td>Schools, atria, commercial, supermarkets</td>
<td>Used to create 'open' framed areas but require separate bracing systems for stability. No theoretical limits on span or number of storeys</td>
</tr>
<tr>
<td>frames</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glulam or LVL portal frames</td>
<td>Halls, industrial buildings, arenas, distribution centres</td>
<td>Usually single storey. Large open spaces with spans of more than 30m possible. The size of the portal frames is usually only limited by transportation</td>
</tr>
<tr>
<td>Cross laminated timber (CLT)</td>
<td>Multi-storey residential, schools, academies, auditoria, exhibition spaces, places of worship,</td>
<td>Platform and balloon-frame construction. Tall single storey wall panels possible and structures up to 10 storeys tall have been constructed. Large panels need careful consideration in terms of transportation and handling</td>
</tr>
<tr>
<td>or 'Brettstapel' (massive</td>
<td></td>
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<tr>
<td>timber)</td>
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<tr>
<td>Structural insulated panels</td>
<td>Residential, care homes, hotels, student accommodation; infill panels to steel and concrete frames; roof panels for ‘room-in-the-roof’ construction</td>
<td>External envelope wall panels within platform frame or frame infill construction. Up to 4 storeys possible for load-bearing applications. Good thermal performance. Roof spans may be limited by shear and creep deflections of core materials</td>
</tr>
<tr>
<td>(SIPs)</td>
<td></td>
<td></td>
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<tr>
<td>Special structures</td>
<td>Gridshells, arches, domes, bridges</td>
<td>Project specific solutions which typically span 10-50m, though there are examples of 150m span gridshells</td>
</tr>
<tr>
<td>Engineered trusses</td>
<td>‘Feature trusses’ using glulam or oak, industrial, commercial and institutional</td>
<td>Spans between 10 to 50m</td>
</tr>
<tr>
<td>Trussed rafters</td>
<td>Roofs for residential buildings, care homes, hotels, masonry, steel and concrete structures</td>
<td>Typically up to 12m but for special designs spans of up 30m are practicable</td>
</tr>
<tr>
<td>Stressed skin panel roofs and</td>
<td>Swimming pools, infill panels to steel frames, civic buildings</td>
<td>Roof spans up to 20m; floor spans up to 12m</td>
</tr>
<tr>
<td>floors</td>
<td></td>
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</tbody>
</table>

**Trussed rafters**

The modern trussed rafter roof is an engineered timber structure that has evolved in form over the past 40 years, but most commonly adopts the use of softwood timber tension and compression members connected in a single plane by punched metal plate fasteners, manufactured from galvanised mild steel.

**Structural insulated panels**

Other structural systems such as structural insulated panels (SIPs) are composite members which use a core of rigid insulation, not only to provide a u-value for a building’s thermal envelope, but also to form a longitudinal shear connection between plywood or OSB face layers; thus enabling it to act as a structural panel.

"Timber can be recycled and turned into strands and fibres"
Design

Eurocode 5 has provided opportunities for UK designers to use timber for new applications that should give economic solutions, particularly as the code makes provision for the use of new materials, such as engineered wood products and new efficient jointing techniques. The code encourages engineers to gain a greater understanding of timber which will lead to more efficient and innovative designs for engineered timber structures.

Structural forms and detailing, together with examples of calculations for structural timber to Eurocode 5, will be discussed in future articles.

Limitations

In addition to the structural strength and stiffness aspects of timber engineering, there are other considerations which affect 'whole-building' performance and must be considered. These include:

- Timber shrinkage and differential movement
- Design for robustness
- Architectural detailing including detailing for durability
- Fire during construction and service
- Workmanship and maintenance

As with structural form/detailing etc., these topics will be explored in more depth, later in the series.

References and further reading

- TRADA (2011) Wood Information Sheet: 2/3-23 Introduction to wood-based panel products High Wycombe: TRADA

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