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Principles of green oak construction

There is growing interest in green oak framing for a variety of reasons, from satisfaction in hand craftsmanship to the ecological advantages of using a renewable material, now once again available in sufficient quantity.

This Wood Information Sheet (WIS) is an overview of the design and construction principles that specifiers should consider in order to ensure that green oak construction is correctly specified and that clients know what to expect.

The materials used, structural design and construction details are discussed, concluding with a helpful summary checklist of best practice tips for successful green oak buildings.

Signposts to more detailed sources that are listed at the end, including TRADA Technology's book *Green oak in construction* [1], which describes the whole process of green oak construction – the design, framing and enclosing of structures.

Contents

Figure 1: London's Globe Theatre, probably the most famous modern green oak building
Photo: Peter Ross

Key points

- 'Green oak' means European oak and sweet chestnut used before it has seasoned. Initial moisture content will be typically 30% or more.
- Applications include:
  - ancillary buildings where energy conservation rules do not apply
  - reproduction buildings that, nevertheless, must still comply with the building regulations
  - modern designs with either traditional or metal connections.
- Anyone contemplating using this form of construction should be aware of some important characteristics of green oak construction that affect its appearance and weather resistance. These include tendency to distort, crack and occasionally discolour.
- Neither oak nor chestnut require any surface treatment to ensure their durability but unfinished wood will gradually bleach out to grey due to exposure to ultraviolet light.
- Structural design of green oak must assume 'wet' stresses, which are less than allowed for seasoned wood.
- Traditional carpentry joints are commonly specified in green oak buildings.
- Modern metal joints can be more economic and lead to more efficient structures. Corrosion-resistant connectors are needed in situations exposed to moisture because of the effect of acidic extractives in the wood.
- Designers must allow for shrinkage in all aspects of detailing.
- The type and detailing of joints is a key consideration for weatherproofing and airtightness in green oak structures.
- External walls require careful detailing to ensure adequate thermal resistance. This is due to a differential between the oak frames and wall panels.

Background

For many centuries oak framing was the traditional form of construction for buildings throughout the British Isles. Many of these buildings still stand today (*Figure 2*) and some of them are over 800 years old. However, the use of oak framing of this kind began to diminish from the 17th Century onwards for three reasons:

- Architectural taste changed to the Classical style which originated in masonry construction. Any expression of structure in the form of columns was purely stylistic as masonry walls supported the floors and roofs.
- The extensive use of oak for ship building had depleted the old forests to the extent that home-grown oak was in short supply. Consequently the use of lightweight softwood framing, based on Scandinavian practice, became more common.
- Rules that prohibited the use of timber structures were introduced after the Great Fire of London, although these applied only in a number of cities.

Figure 2: Lavenham Guildhall, Suffolk
Photo: Peter Ross

There was renewed interest in oak framed construction in the 19th Century, based largely on the Victorian nostalgia for all things medieval. Oak was used for a wide range of purposes, from cottages to major public and ecclesiastical buildings.

Oak framed construction now extends beyond traditional 'Tudor' style mansions to include visitor centres, theatres, galleries, museums, boathouses and restaurants of modern design. Some of these buildings may use the material in the traditional way, with only carpentry joints and using large sections of timber. In others, large hardwood members are used in a totally modern form, in conjunction with bolted steel connections and steel ties.

Although this combination of materials may be assumed to be modern in form, composite construction is actually not new, as iron connections and tension members were frequently used in timber structures from the 17th Century onwards.

Green oak construction is used in four applications:

- Ancillary buildings. These are traditional designs, usually of domestic scale, eg garages, stables and summerhouses, where the Building Regulations' energy conservation provisions do not apply (*Figure 3*).
- Reproduction buildings. These contemporary examples of traditional designs must nevertheless comply with the full Building Regulations (*Figure 1*).
- Modern framed designs with traditional carpentry joints (*Figure 5*).
- Modern framed designs with metal connections and tension members (*Figure 6*).

The material

Figure 3: Green oak summerhouse
Photo: English Heritage Buildings

'Green' hardwoods

The reference to green oak framing is not strictly limited to oak, but includes any un-dried or 'green' hardwood. The two species most commonly used in the UK for construction of 'green oak' framing are European oak and, to a much lesser extent, sweet chestnut. The heartwoods of both timbers are durable with very similar properties.

Softwoods, in particular larch and Douglas Fir, are also readily available in larger frame sizes and are often used as a cheaper option for structural work. They are however less durable.

Because of the difficulty of air drying any large section of wood, particularly a dense hardwood, these woods have historically been used in an un-dried form. However, this still applies to modern usage of large timber sections, as even modern kiln drying cannot economically reduce the core moisture content effectively of any section thicker than 100mm. Thinner sections can be partially seasoned in the open air.

A major attraction of using these woods is their ecological merit. Although slow growing, the wood is a renewable material and the replanting of native hardwoods is now actively supported by the Government, although harvesting will inevitably be over a much longer time scale than for coniferous wood. The wood can be either home-grown or available from nearby European sources. Sourcing must be legal and in accordance with the EU Timber Regulation (EUTR) [2]. In addition, we strongly recommend that sustainable sources are sought – chain of custody certification schemes are available (such as those maintained by FSC® and PEFC™) to support this process.

Because the wood is naturally durable it does not require treatment with preservative, providing the sapwood is excluded.

As well as being naturally durable, these woods have excellent structural properties, will weather well when exposed externally and have a natural resistance to chemicals or salt in a marine environment. Because they are dense woods, they resist fire in the sense that they are slow burning. Larger sections will protect themselves by charring predictably and this is recognised in the structural codes, which allow for sacrificial timber in the design of structures requiring fire resistance.

Managing expectations

Anyone contemplating using this form of construction should be aware of some important characteristics of green oak construction that need to be considered in the choice and subsequent design. These include tendency to distort, crack and occasionally discolour.

Used ‘green’ with an initial moisture content of 30% or more, typically up to 80–100%, these woods will shrink considerably as they dry ‘in use’. They may also distort somewhat, either bowing or twisting in their length. Careful selection can reduce this risk but it is not always possible to predict how the wood will behave as it seasons. Care must be taken in the design to ensure that any shrinkage or distortion that occurs will not cause damage to other components, or reduce the weather resistance or insulation of an external wall.

Figure 4: Tangential shrinkage causes a fissure between the heart of this sample and its bark

One feature of the shrinkage, which can cause particular concern to the occupants of green oak buildings, is the substantial shakes (deep splits) that can occur in large structural members (see the posts in *Figure 1*). Shakes can extend from close to the centre of a section out to the visible face (*Figure 4*), but the width on the outside face will always be far larger than internally because the shake will taper inwards.

Even large shakes are rarely a structural problem. They may develop on internal members because heating a building can cause rapid drying of the outer faces of large sections while the core remains wet. Shakes can also occur in external members, particularly when one or more faces are exposed to sun, but usually to a lesser extent. In some cases, where the framing of the structure is exposed externally, shakes on the outside faces can be large enough to cause leakage into the building.

Besides shakes, large sections of wood will almost invariably contain some knots and other flaws that may not inhibit the durability or performance of the wood, but which will affect its appearance and need to be accepted as typical of a natural material.

Exceptionally large knots do reduce the strength but this is allowed for in the strength grading.

Keeping up appearances

Both European oak and sweet chestnut have a high extractive content, particularly when the wood is used 'green'. These extractives will appear as a dark brown exudation on exposed faces as a result of exposure to weather. This process can last for some time before the extractives are eventually washed off the face of the wood by rainfall. However, if washed onto other surfaces below, extractives can be difficult to remove, particularly from porous materials. Hence, provide temporary protection on surfaces below exposed oak frames or cladding.

As extractives are acidic, they are very corrosive to mild steel. Any corrosion of exposed ferrous metal will cause dark staining to the adjacent wood surfaces, which may be very difficult to remove. For this reason, all fixings into oak or chestnut used externally or in a humid atmosphere should be of stainless steel or other non-ferrous metal. Hot-dip galvanising can protect larger components such as brackets, plates or bolts but is not adequate for screws or nails, because the installation process may damage the galvanising, or other thin protective coating, leading to corrosion of the metal and consequent staining of the wood.

Neither oak nor chestnut require any surface treatment to ensure their durability but unfinished wood will gradually bleach out to grey due to exposure to ultraviolet light. To ensure that this bleaching is even, avoid projections over frames or external cladding, as these will prevent – or at least slow down – the bleaching process in the shaded area. Projections will also prevent extractives from being washed off the surface of the wood below, resulting in uneven staining.

Adding clear coatings, wax or oils to external faces of the wood will not prevent bleaching in the long term and, even if these products contain ultraviolet light filters, frequent re-application will be necessary to prevent bleaching. To prevent loss of colour, it is necessary to include some pigment in the finish, thereby in fact artificially colouring the wood.

The 'tarring' of any exposed wood frames in Victorian times was largely a fashion, but it did have the advantage of sealing any shakes or splits in the wood, making the frames more waterproof. Substantial splits on externally exposed members may require sealing, and there are several ways that this can be done in an inconspicuous manner.

Exposed oak surfaces can sometimes suffer blackening in the long term. This can be due to excessive wetting, or possibly growth of algae on the surface. There is a high risk of this where frames or cladding are close to heavy foliage, suffer severe run-off of rainwater, or are exposed to splashing off the ground.

Airborne pollution from traffic exhaust emissions or brake dust can also cause discolouration, so it may not be advisable to expose unfinished wood in this environment. There are various clear coatings that can be applied to the wood, both to prevent any surface algae growth and to reduce water absorption and consequent staining but they may need to be re-applied on a regular basis.

Structural design

This sheet mentions only the basic principles of the structural design of heavy frames in green oak. See *Green oak in construction* for comprehensive advice.

WIS 1-17: Structural use of hardwoods [3] includes guidance on design.

Strength grading

WIS 4-7 Timber strength grading and strength classes [4] describes how timber is graded, including hardwoods.

Both European oak and sweet chestnut are strong dense woods. The structural properties of individual sections is determined by visual strength grading using *BS 5756 Visual grading of hardwood. Specification* [5], which takes into account the size and frequency of strength reducing characteristics such as knots and splits, as well as slope of grain.

European oak and sweet chestnut, graded to *BS 5756*, are not included in *BS EN 1912 Structural timber. Strength classes. Assignment of visual grades and species* [6]. However, these are listed in the UK complementary document to EC5, *PD 6693-1-1 Guidance to Eurocode 5* [7].

Although the quality of any piece of timber may satisfy the required structural grading rules, the size and frequency of knots may be visually unacceptable. Where appearance is of particular concern, specify wood that conforms with an appropriate visual grade under *BS EN 975-1 Sawn timber. Appearance grading of hardwoods. Oak and beech* [8], as well as *BS 5756* for structural timbers.

The *BS 5756* rules are not flexible enough for green oak framing companies, so revised rules have been devised and are included in *Green oak in construction*. However, it is unlikely that timber graded to these rules is commercially available, but some framers will carry out their own grading.

If the wood is to be used 'green', structural calculations must be based on allowable 'wet' stresses, which are less than those allowed for dried wood, even if the wood will eventually achieve full strength as it dries. This is covered in *Eurocode 5*.

Figure 5: Traditional carpentry joint in a modern green oak structure
Photo: Peter Clegg/Feilden Clegg Bradley Studios

Figure 6: Modern metal joints in green oak
Photo: Carpenter Oak and Woodland

Joints

A primary decision in the structural design of a green oak frame is whether the design uses traditional carpentry joints such as mortice and tenon, dovetails, or scarfed joints with traditional pegs and wedges (*Figure 5*), or modern joints comprising steel plates and screws, connectors and tie rods (*Figure 6*).

Some recent green oak designs combine the two methods to obtain a more efficient and economic construction, particularly for long spans in larger buildings. Iron components were originally introduced to increase spans and to reduce the weight and size of sections. This rationale still applies to the modern steel components used today. This is because, where traditional carpentry joints are employed, the size of the sections is often determined by the need to accommodate these joints, rather than on the actual spanning properties of the section.

In either type of design, the design of connections must allow for shrinkage of the timber. With traditional carpentry joints, this shrinkage may result in the frame as a whole reducing in size, whereas with steel connections any shrinkage needs to be accommodated within the structural joints themselves because the steel components do not shrink.

When using steel connections, it is preferable to use the wood at a lower moisture content than for traditional carpentry joints. This is best done by limiting the size of the sections. Small sections can be dried more easily and the amount of shrinkage that will occur is therefore reduced. It is often preferable to couple two smaller sections together in pairs, rather than use a single large section for the structure. Paired sections also allow steel brackets or plates to be located between the members where they will be least affected by shrinkage of the sections. Enclosing the steel in this way also provides some fire protection to the metal, and often improves the appearance of the connections.

If steel connections are to be exposed externally, it is important that they be corrosion resistant, particularly in contact with highly tannic woods such as oak or chestnut.

The size and length of individual frame members should be considered. The larger the size of a piece of oak, the higher the comparative cost against the use of two smaller sections, largely because of the reduced availability of larger pieces.

The same limits on available lengths of section may also apply to other components such as cladding, joinery components or decking. Finger jointing and lamination can increase the lengths or dimensions of oak or chestnut, and also allow flaws such as knots and splits to be cut out. However, the wood may require drying prior to gluing.

Construction detailing

Allowing for shrinkage

If the wood is to be used 'green' for any building components, allow for drying shrinkage. For instance, where two fixings are required in the width of cladding boards, provide oversize holes to allow for shrinkage between the screw fixings. It may be necessary to add washers under the screw heads to give sufficient purchase on the wood.

The effect of drying shrinkage between different components is often a problem. For instance, if externally exposed structural columns shrink away from the infill walls between them, gaps may open up in the weatherproof joints and thermal bridges can also be created leading to excessive heat loss and air leakage. These joints can be further compromised by distortion or bowing of the columns rather than shrinkage alone.

Thermal resistance of external walls

There are three ways to detail external walls:

- frame exposed internally (*Figure 7a*)
- frame exposed externally (*Figure 7b*)
- frame aligned with wall panels and exposed on both faces (*Figure 7c*).

As an external wall is always at most risk of leakage at the junctions between wall and exposed frame, it is generally preferable if the wall lies outside the frame (*Figure 7a*), rather than between it. This provides protection to the frame members and also eliminates these vulnerable joints. However, although the frame may still be exposed internally, this may conflict with the required traditional appearance of the frame that is expected to be visible both internally and externally.

An alternative, adopted in less 'traditional' buildings, is to locate the frame outside the external wall (*Figure 7b*) but this does reduce the internal floor area and requires careful detailing where horizontal beams or roof trusses have to penetrate the external wall and of course the frame is then not visible internally.

'Traditional' green oak frames aligned with wall panels (*Figure 7c*) are often chosen for unheated ancillary buildings. In this case, the junction between panels and frames must be detailed to resist the weather. However, where thermal insulation is also required, it is difficult to achieve the required level of insulation or adequate airtightness standards where the structural frames interrupt the external wall, regardless of the type of cladding.

Several green oak building manufacturers have developed framed systems that use either prefabricated insulated panels, or insulated softwood stud framing to meet the current regulations. These systems generally increase the wall insulation well above the required level to compensate for any heat loss through the structural columns or at the junctions between infill wall and column. The junctions between these infill panels or walls and frame members are also designed to allow for shrinkage of the framing while maintaining a weather resistant joint.

Green oak in construction includes advice on infill panel detailing.

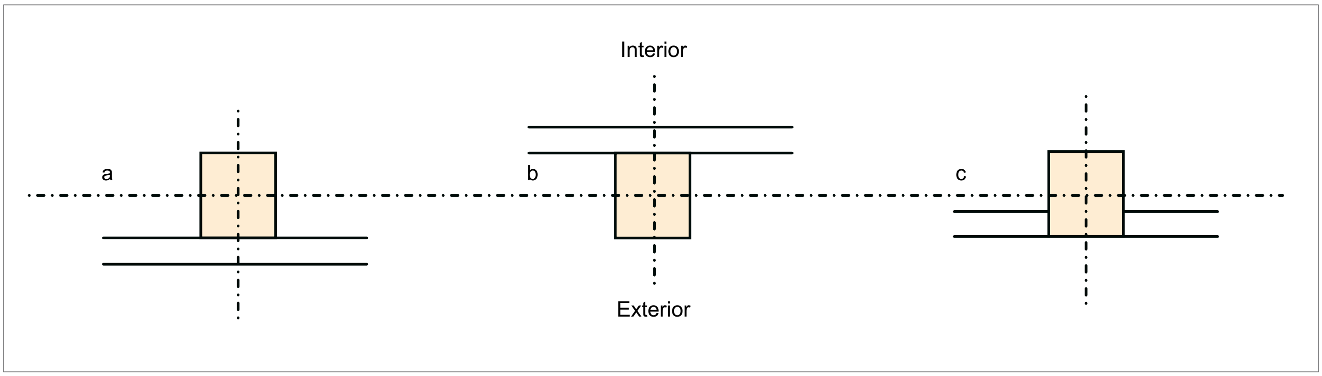

Figure 7: Diagramatic relationship of green oak frames to wall panels

Best practice tips for successful green oak buildings

Besides achieving satisfactory junctions between frames and walling, general good practice principles should be followed in detailing both frames and cladding.

- Provide ventilation around all timber members, where possible, and provide a ventilated cavity behind all external cladding, eg wood boards, tiles or cement render.
- Protect the tops of exposed vertical or horizontal members by flashings or overhangs.
- Provide drip grooves under exposed horizontal members to prevent water tracking back underneath (*Figure 8*).
- Raise the underside of exposed columns well clear of ground level to prevent moisture absorption into end grain (although this may not be possible with traditional column and sole plate design).
- Stop all timber components above splash back level, ie 200–250mm above ground level.
- Avoid creating water traps in any exposed frame connections by providing drainage channels. Steel connections should be designed to allow drainage at junctions.
- Where weatherproof joints are required, use seals that will expand into an increasing gap, eg pre-compressed expanding foam tapes or rubber gaskets, rather than gunned mastic or butyl tapes that cannot expand.
- If glazing into green oak framing, do not put glass directly between any frame members. Glazing should be located outside the face of the frames and held in position by capping sections of 'dried' wood. These should be fixed to the centres of the frame members where they will be least affected by any shrinkage or distortion of the members.
- Glazing of insulated glass units should be of the vent/drain type using rubber or expanding foam gaskets, which can accommodate movement of the wood more easily than mastic or butyl tapes.

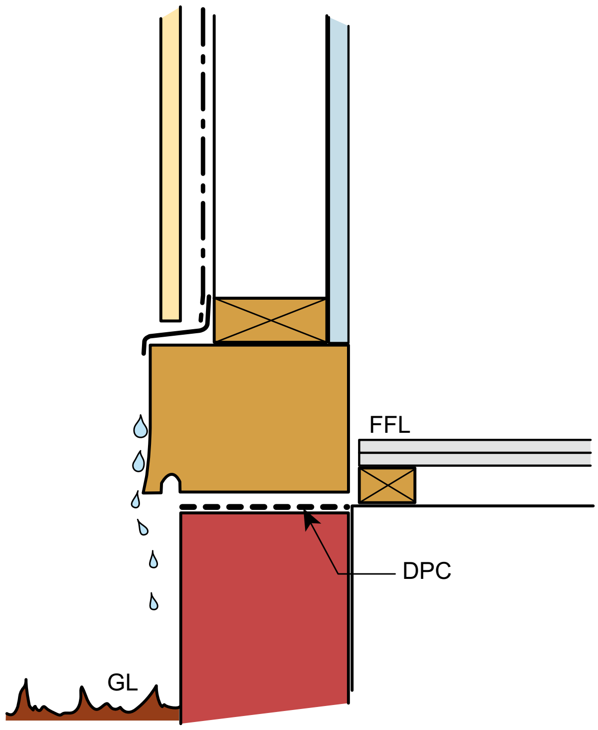

Figure 8: Drip groove to prevent water penetrating under the sole plate

References

1. Ross, P., Mettem, C. & Holloway, A. Green oak in construction, TRADA Technology, 2007
2. Regulation (EU) No 995/2010 of the European Parliament and of the Council of 20th October 2010 laying down the obligations of operators who place timber and timber products on the market (EUTR)
3. WIS 1-17: Structural use of hardwoods, TRADA Technology, 2010
4. WIS 4-7: Timber strength grading and strength classes, TRADA Technology, 2011
5. BS 5756:2007+A1:2011. Visual strength grading of hardwood. Specification, BSI
6. BS EN 1912:2012. Structural Timber. Strength classes. Assignment of visual grades and species, BSI
7. PD 6693-1:2012. Recommendations for the design of timber structures to Eurocode 5: Design of timber structures. Part 1 General – Common rules and rules for buildings British Standards, BSI
8. BS EN 975-1:2009 Sawn timber. Appearance grading of hardwoods. Oak and beech, BSI

Other reading

WIS 2/3-1: Finishes for external timber, TRADA Technology, 2012

WIS 2/3-36: Design of structural timber connections, BM TRADA, 2013

WIS 2/3-60: Specifying timber exposed to weathering, BM TRADA, 2015

WIS 4-14: Moisture in timber, TRADA Technology, 2011

WIS 4-28: Durability by design, TRADA Technology, 2012

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TRADA is a company limited by guarantee and not-for-profit membership-based organisation. TRADA's origins go back over 75 years and its name is synonymous with independence and authority. Its position in the industry is unique with a diverse membership encompassing companies and individuals from around the world and across the entire wood supply chain, from producers, merchants and manufacturers, to architects, engineers and end users.

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