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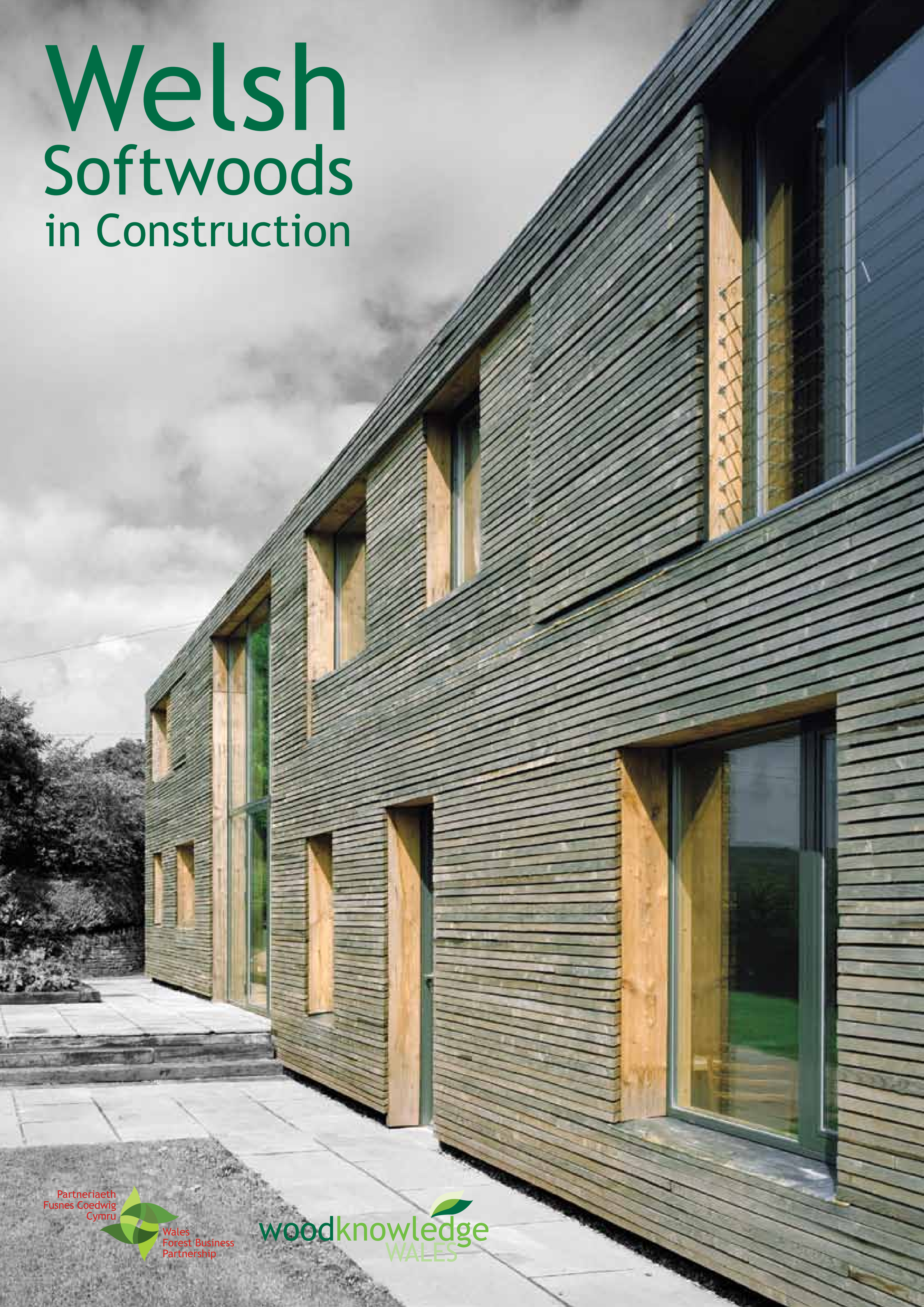
Welsh Softwoods in Construction



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Contents

1. Executive summary

- Foresters agree that Wales has one of the most favourable environments in Europe for growing conifers such as Sitka spruce, Douglas fir, larch and other minor species although this is not common knowledge even within Wales.

- Edinburgh Napier University and Forest Research carried out a study of UK grown Sitka spruce publishing the first full analysis of its performance and material properties in 2011, therefore statements regarding its usefulness in construction previous to that date were based at best on limited data and at worst on subjective or normative judgements.

- Welsh grown Sitka spruce is already strength graded to C16 and with new grading technology mixed strength grades of C16 and C24 would be possible in Wales.

- Douglas fir and larch grown in Wales can already be visually strength graded to C24, however Douglas fir needs to be over 20,000mm in cross section.

- There will be large volumes of larch available in Wales because of the Phytophthora ramorum epidemic. Larch is a very useful construction timber. Napier University and Woodknowledge Wales are about to start a study of this species with the intention of delivering new machine strength grading settings for summer 2014.

- There is an opportunity of a few years' duration to use very large quantities of larch in construction.

- At least eight timber wall construction methods are available in Wales which are capable of utilising Welsh grown softwoods in designs that deliver high thermal performance.

- Two wall construction methods, open panel and twin-wall can be utilised immediately for mass housing by mainstream Welsh timber engineering firms using Welsh-grown strength graded Sitka spruce or larch from BSW Timber Ltd at Newbridge on Wye and Pontrilas Sawmill near Hereford.

- Mid-rise structures in open panel and twin-wall are immediately deliverable by Welsh firms using homegrown softwoods.

- High thermal performance using low energy construction is deliverable immediately using all of the systems described within this document.

- Costs of systems vary widely. However the cheapest open panel and twin-wall methods are already mainstream; they can be manufactured using homegrown softwoods and can deliver high thermal performance.

- Developments and innovations are inevitable and will follow on from wood science currently being carried out, glulam and closed panel systems will both have an impact on construction in Wales.

- 50,000 cubic metres per annum of Welsh strength graded softwoods are produced at BSW Timber's site at Newbridge on Wye, Powys. This site services most of Wales within a 100 mile radius.

South elevation of Britain's first Dowellam structure using homegrown timber

2. Introduction and background

This research was undertaken by Woodknowledge Wales to identify the range of timber construction systems or techniques that are available for use in Wales and to identify the extent to which Welsh-grown softwoods could be utilised in their production. Some content (particularly the thermal performance data) was created for a similar but more locally focused report written by BRE Wales for the Conwy Rural Partnership. The authors freely exchanged information in order to avoid duplication of effort and to cross check the evidence used in the report.

This report was peer reviewed by researchers from Edinburgh Napier University and BRE Wales and has been extensively distributed for comments from stakeholders during the process of writing and editing.

Timber construction has seen a resurgence of popularity during recent years as developers strive to deliver the increasing energy performance standards demanded by Building Regulation revisions. Aspirational domestic building projects featured in TV programs such as 'Grand Designs' have brought timber construction to the public's attention, raising the profile of timber framing against systems using materials with higher embodied energy.

Timber frames can be designed to accommodate significant thicknesses of insulation within a supporting structure to allow low U values to be delivered. However this is contingent on choice of insulant; for instance use of blown-in cellulose fibre demands significant wall thicknesses and consequently larger building footprints. For individual dwellings this may not present a problem but wall thickness influences density of large developments of detached houses; volume house builders already facing financial challenges may not adopt methods which decrease housing density. Therefore thick-walled timber construction may be better suited to terraced housing or multi-storey apartments.

However, timber construction may also permit increased productivity through prefabrication within controlled factory environments independent of site conditions. Mechanisation, production line working and improved working conditions can reduce waste and increase work rates by using modern methods of construction (MMC); combining efficient design, factory assembly, just in time delivery and rapid erection of structures. However, timber frame manufacturers in Wales face a challenging economic climate at present and are wary about making significant investment in new manufacturing processes (Aldridge, 2013).

Foresters agree that Wales has one of the most favourable environments in Europe for growing conifers, although this is not common knowledge even within Wales. Up to one million cubic metres of softwood logs are harvested from sustainably managed plantations in Wales every year, however only a small proportion of this renewable resource is used in the Welsh construction industry. Furthermore, as older generation sawmills capable of converting many species and sizes of sawlogs were decommissioned across Wales, a great deal of the empirical knowledge regarding the Welsh conifer resource was lost.

For several decades, large diameter softwood logs such as Douglas fir (Wales grows some of the largest Douglas fir in Europe) have generally been sold into specialist high value markets outside of Wales. Large baulks of this species destined for structural applications are processed by Somerscales Ltd in Lincolnshire and East Brothers near Salisbury but there are no longer any Welsh sawmills regularly converting large diameter Welsh grown Douglas fir. This is only one of several conifer species demonstrating the significant unrealised potential that Wales possesses to sustainably grow high yield softwoods to service a construction industry based on intelligent design and utilisation of Welsh forests.

Several other conifer species ideal for use in sustainable construction are grown in Wales, but knowledge of their material properties is often limited. Coastal redwoods were introduced to Wales in 1858 but have only just recently been utilised in construction. At over 2,000 m^3 per hectare, the redwood grove at Leighton near Welshpool is one of the most highly stocked stands in Europe (Williams, 2013). High yield softwoods such as these can supply sustainable, high grade construction materials whilst sequestrating CO_2 at higher rates than native broadleaved forests. It is the conifer plantation forests growing softwood species that will provide the renewable materials for a future low carbon built environment.

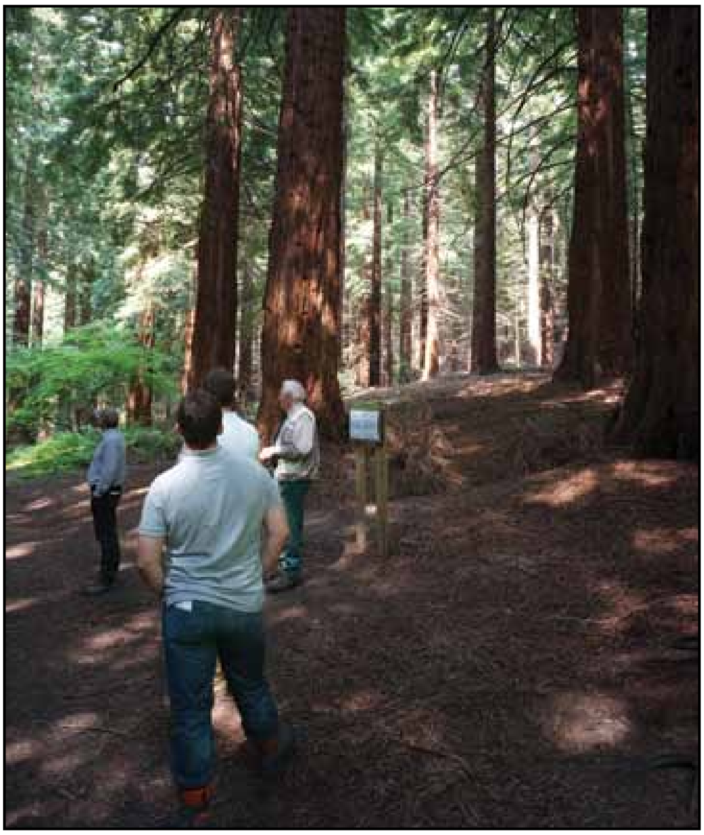


Figure 1: Leighton redwood grove is the most densely stocked timber stand in Europe

Conservative attitudes on the part of UK sawmillers have until recently limited the marketing of structural softwoods. Many timber frame companies also take conservative stances and either regard homegrown softwoods with suspicion or simply prefer to continue manufacturing with the product they know best; imported softwood. Badly informed or ideological negative commentary directed at homegrown softwoods has reinforced the notion that they are unsuitable for construction.

Much Welsh softwood nowadays is used for pallet wood and fencing. Because the latter market is less technically challenging and particularly profitable for sawmills there has been a reluctance to breech the construction market. Until the economic crisis of 2008, the strong pound drove Britain's dependence on imported structural softwoods but the recent downturn and weak pound have driven an increase in production of homegrown structural softwoods, mostly in C16 grade. Also, because the British market is saturated with non-strength graded homegrown sawnwood products some UK sawmillers are now trying to capture part of the imported construction grade timber market. Currently, most construction timber is imported from Scandinavian or Baltic sources where timber may already have travelled significant distances to processors and then onward to docks for subsequent shipment. In comparison, homegrown softwoods used within Wales can offer reduced 'timber miles' and embodied impact.

BSW Timber at Newbridge on Wye produce strength graded Welsh softwoods at a central location in Mid Wales capable of servicing most of Wales without travelling outside a 100 miles radius. A virtuous circle of growing, processing and constructing with Welsh grown softwoods is currently being created. Increased uptake of homegrown timber in Welsh construction is seen as desirable by foresters, architects, institutions, NGOs and both local and national governments. Long term, joined up thinking will be essential to ensure long term success. There is a need to better understand the supply chain from forest to manufacturer. Proactive forest design is necessary not only to more efficiently match supply and demand but also to help future proof forests against pests, pathogens and climate change.

2.1 Strength grading of softwoods grown in Wales

Softwoods are strength graded using C markings which relate directly to the characteristic bending strengths of each species. The C grades range from C14 up to the strongest, which is C50. These grades allow timber engineers to calculate load bearing characteristics of structural timber elements. Individual conifer trees or stands grown in Wales demonstrate a wide range of material properties; both stiffness (modulus of elasticity) and density vary widely and correlate with strength grades from C14 to C50 although only a few samples within given populations demonstrate the highest bending strengths. However it appears that selected material from certain conifer species in Wales, such as larch, might be capable of being graded over C24. The data will be available by summer 2014 when a major study of UK grown Japanese larch is due to be completed.

UK strength grades are generated using data from timber specimens sourced across all of Britain and calculations take into account the wide variability of material properties. Therefore strength grades are based on statistical procedures which derive minimum values (called the 5th percentile) to create permissible strength values. At present strength grading can be performed visually by qualified individuals or by passing sawn timber through specialised testing equipment installed at sawmills.

Researchers in Wales have been conducting tests with a hand held acoustic grading tool, the 'Brookhuis MTG', in order to gain a better understanding of the stiffness of Welsh softwoods. At present the MTG is of limited commercial value as machine settings are not available for this particular tool; however settings for UK grown larch and possibly other species should become available in 2014.

Figure 2: The Brookhuis MTG hand held acoustic grading tool

High volume, multisensory scanning technology which measures several material properties in order to strength grade softwoods more efficiently is replacing old generation mechanical graders which rely on passing timber through rollers to allow direct measurements of deflection under load. Using the new grading technology, at least one UK mill has started mixed grading runs and homegrown C24 spruce is now available. One of the larger timber engineering firms in south Wales has changed timber procurement policy this year in favour of British grown spruce and no production problems have been reported.

It has been widely assumed and stated that British grown softwoods 'are not of sufficient quality' for construction but recent research has shown this not to be the case; spruce, pine, larch and Douglas fir may all be graded to higher C strength classes than previously thought possible. It is only in recent years that Edinburgh Napier University and Forest Research carried out a study of Sitka spruce culminating in the first full analysis of its performance and material properties (Moore, 2011). Therefore statements regarding its usefulness in construction previously were based at best on limited data and at worst on subjective or normative judgements.

There is a growing consensus amongst UK wood scientists that selected British softwoods are not only fit for purpose in regard to construction but some can be 'world class' timber. Certainly the latest research suggests that Douglas fir has great potential in UK construction (Bawcombe, 2012).This species is also a likely contender to replace larch in plantations affected by the Phytophthora ramorum epidemic. It is often sold well below international market prices in Britain because of the continuing influence of old perceptions. Use of the word 'quality' may be misleading when attempting to describe homegrown softwoods. Definitions of softwood qualities need to be reinforced with scientific data. It is necessary to understand a range of relevant material properties of timber in order to make objective judgements as to whether particular timbers may be fit for purpose in any given application. Because of the wide variation of mechanical properties encountered in home grown softwoods, generalised statements are unhelpful.

There is not a widespread culture of selection in the British forest processing industries from forest to timber merchant; neither best grades of softwood sawlogs nor sawnwood are routinely picked out for higher value adding applications. In Scandinavia and North America softwoods are generally separated out into many different grades; until we in Britain do the same, better grade softwoods will continue to be sold with and at the same price as lower grade material.

BSW Timber Group's Newbridge on Wye sawmill is the only mill in Wales currently machine strength grading softwoods, producing up to 50,000m^3 of C16 home-grown softwood every year (MacCleod, 2013). At the moment this comprises mostly Sitka spruce with a small proportion of Japanese larch. Historically, selected Welsh larch was used in high value specialist applications such as boatbuilding and premium prices are still obtained for boatskin larch sawlogs; at over £600/m^3 sawn boatskin larch is nearly as valuable as sawn green oak. Nevertheless the desirability of run of the mill larch for mainstream markets other than fencing has significantly decreased since the early 1970s as sawmills geared up to process the increasing volumes of Sitka spruce coming on stream since WW2.

However, the recent Phytophthora epidemic spreading across western Britain's larch forests has led to the need to find applications for the high volume of diseased larch about to come to market. Material properties are presently assumed to be unaffected by the disease and the new larch study will specifically test for reduction of stiffness in diseased timber. Larch timber could be highly suitable for construction applications such as cladding, post and beam, glulam, engineered trusses or simple open panel. There is a one-off opportunity to capitalise on the unfortunate circumstances associated with its new found availability and affordability. One million m^3 of standing diseased larch is currently available in Wales and as extraction of this material accelerates, graded larch may be substituted for part of the graded spruce output. Woodknowledge Wales is working with Edinburgh Napier University and Forestry Commission Scotland to obtain new machine grading settings for larch in order to allow production of higher strength grade C24 material.

It may be possible to grade selected batches of larch up to C30 in Wales but this is dependent on installation of new grading technology at BSW, Newbridge on Wye. Availability of new settings data for larch will influence BSW's management decisions regarding replacement of their present grading line at the Newbridge plant (Brownlie, 2013). New settings data may also allow commercial use of the Brookhuis MTG hand held grading tool, which could be useful to small timber producers wishing to add value to Welsh softwoods by strength grading them for use in bespoke construction projects or to produce small runs of engineered beams, trusses or massive wood panels.

Figure 3: Homegrown coastal redwood being processed at a specialist sawmill in Mid Wales

2.2 Welsh timber for cladding

When considering wall finishes for timber construction in Wales, timber cladding can be a viable locally sourced option. Needing no strength grading, timber cladding is an ideal value added product for smaller sawmills. Japanese larch cladding could be produced in large quantities in sawmills across Wales because of the massive volumes of diseased larch timber currently available. However larch cladding needs careful detailing because of its tendency to move after fixing. The extractives in larch heartwood make it moderately durable so no chemical treatment is necessary to lengthen its working life. BSW Timber currently produce several types of profiled larch cladding.

Figure 4: Homegrown western red cedar cladding on a house in Mid Wales

Other minor species such as Western red cedar and coastal redwood make relatively durable and extremely stable cladding options; these species are only cut by smaller specialist mills with higher unit costs than the modern high volume mills. The corrosive nature of the extractives present in all of the aforementioned species means that only non-ferrous fastenings should be used when fixing. Douglas fir heartwood tends to be less durable than larch, cedar or coastal redwood but its stability and availability make it a good option for projects which are well designed and detailed on walls where severe wetting is unlikely. Welsh grown hardwoods such as oak and sweet chestnut can be used for bespoke projects but low availability of homegrown sawlogs and high unit costs may limit uptake of this option. Well designed homegrown timber rain screens can last for many decades and offer low embodied energy alternatives to brick, tile or rendered façade.

2.3 Types of timber construction system/ elements

Creating a clear taxonomy of timber construction systems is problematical. Perhaps the simplest generic descriptions of the more common timber construction types are open panel, closed panel, post and beam (which may use either solid wood or glulam elements), massive wood panels (including cross laminated timber and Brettstapel/Dowellam), volumetric, and engineered beams, joists or trusses (including I-joists and open web beams). In practice, systems or elements have undergone considerable historical evolution. Systems, components or techniques may be combined e.g. a building might use Brettstapel walls, solid wood joist floors and open web beams for the roof. Some specific elements can be clearly defined and others may be specialised derivatives of generic types. Thus twin-wall construction is a derivative of open panel; however, engineered open web joists can be used vertically to create similar separated-stud high thermal efficiency walls.

There is some confusion in naming systems; in Scotland twin-wall construction is called dual wall. SIPs or structural insulated panels are a derivative of the closed panel concept and although they are not currently manufactured in Wales, they offer significant potential. Their high thermal performance combined with structural capability makes them very useful in combination with systems using homegrown timber, although ‘green’ architects tend to shy away from them because they use polymer based foam insulants. Some companies have used combinations of different timber construction systems and have branded them as complete, unique added value systems; examples are Modcell, Wise Wall, Ty Unnos and the New Welsh House. A prototype low cost, high thermal performance dwelling roofed with solar panels has been built near Cardigan. This design is being marketed under the brand ‘Ty Solar’.

This report does not aim to rank or prioritise systems, components, or techniques; it endeavours to identify key benefits or limitations. Examples using Welsh timber are cited and objective judgements are made as to whether there is scope to incorporate Welsh timber. All systems are suitable for low rise and domestic developments although some may be suitable for building to eight storeys, the current limit prescribed by UK Building Regulations. Further research is necessary to better understand material properties of Welsh softwoods in order to optimise their utilisation in construction.

2.4 Thermal performance of timber frame constructions

It is possible to specify any of the construction systems discussed below to deliver any given required, realistic thermal performance or U value. Thermal performance will be dictated by the type and thickness of insulation material prescribed within each construction system. High resistivity products, such as polymer based insulation materials, will deliver improved U values with relatively smaller thicknesses of insulation, whereas wool and cellulose insulants require thicker wall cross-sections to deliver equivalent performance.

This may lead to practical or economic rather than technical limitations to the use of some types of insulation within some timber frame systems. Recycled cellulose fibre insulation made from newspaper is already available in Wales. Researchers in Wales and Scotland are interested in using wood shavings or other wood particles from timber processors as feedstock for wood fibre insulant production. This work is ongoing and the first batches of suitably treated wood fibre insulants are scheduled to be produced by early 2014. Architects and specifiers may choose insulants to suit clients’ or their own environmental aspirations and these decisions have significant influence on wall thickness. Overall airtightness and thermal bridging performance of any timber frame building will largely be dictated by attention to design, detailing and quality control during both manufacture and erection on site. However specific design and detailing features are beyond the scope of this study and are therefore not discussed.

In summary, with the correct design detailing and material specifications, it should be possible to utilise any of the construction methodologies described in this report to deliver project specific thermal performance criteria and comply with UK Building Regulation requirements.

2.5 Construction standards in Wales

In addition to meeting the requirements of the Building Regulations, new houses built in Wales are required to achieve a Level 3 rating under the Code for Sustainable Homes and obtain a minimum of 1 credit under issue Ene1 – 'Dwelling Emission Rate'. This requires dwellings to deliver an 8% improvement over Part L 2010 Building Regulations. The Code also ensures that wider sustainability impacts are considered during construction, including the environmental impact of the materials and products used, the ecological value of construction sites selected and wider health and wellbeing considerations for occupants, including daylight availability and other factors. None of these requirements essentially restrict the type or form of construction that can be utilised, since to some extent the factors under consideration can be traded off against one another to deliver the overall Code rating. However, some construction products and systems will inherently offer benefit towards assessments through their environmental credentials, so these are often sought by designers and specifiers to facilitate the Code assessment process. These include timber systems and natural insulation products.

3. A taxonomy of timber wall systems

This section describes a range of generic types of timber construction systems currently manufactured in Wales. There are many variations and derivations of these systems and similarities exist between them because of the evolutionary nature of timber construction techniques. Where generic techniques have been adapted and evolved into value added branded 'systems', these are also discussed along with their applicability to Welsh construction.

3.1 Post and beam

Post and beam construction is possibly one of the oldest types of timber building techniques and historical vernacular examples, particularly using local oak, are common across Wales. All timber construction using orthogonal arrangements of timber elements are derived from the post and beam method, which has been utilised for millennia. Since posts and beams create the load bearing structure, there are many potential options for creating wall infill elements. Composite matrices can be cast between or outside posts and external load bearing or non-load bearing insulating envelopes can be fabricated in order to retain the revealed structure as an aesthetic detail. Post and beam structures can also be enclosed within hygroscopic composite walls formed using temporary shuttering, the embedding material lending durability and protection to the timber structure whilst creating clean orthogonal buildings. Some research on this topic using earth, clay, lime and hemp has been carried out at the Centre for Alternative Technology and Bath University.

Post and beam construction can allow design flexibility, since the arrangement and size of the structural elements are not limited by dimensions of standard sawnwood. Solid wood post and beam structures tend to use timber from specialist bespoke sawmills capable of supplying unusual, often 'oversized' timber beams of lengths limited only by availability of suitable logs. The simplicity of this method lends itself to utilisation in minimalistic contemporary design.

3DCAD design software is capable of generating the data needed by modern CNC (Computer Numerical Control) machinery to produce complex shapes such as compound curves drawn within parametric software. Therefore it is now possible to readily create post and beam structures incorporating complex curved elements. Post and beam construction is a scale-able technique, it can be utilised by a range of manufacturers from microbusinesses using hand tools to sophisticated factory installations equipped with the latest CNC joinery production lines.

Both solid wood and glulam are suitable for post and beam structures. However, large section solid wood suffers from movement and distortion in service, therefore careful design is necessary to allow dimensional change to occur without detriment to structures. Glulam may be specified where stability and predictability are desirable and although it is available in standard sizes, bespoke glulam manufacturers offer options for shaped structural elements, such as simple arches, catenary arch, boomerang and straight tapered. Lengths are only limited by logistical considerations. Glulam is now being manufactured using Welsh-grown softwoods by Clifford Jones Timber (Ruthin) and at least two other Welsh firms are seriously interested in producing glulam from homegrown timber. Glulam manufacturers Buckland Timber in Devon have expressed an interest in using Welsh softwoods in their products (Nicholson, 2013); this may give another option for sourcing 'homegrown' glulam. New grading settings for larch and other high stiffness timbers may now catalyse volume production of high strength structural glulam in Wales and England for the first time.

Figure 5: Treglown Court in Cardiff; glulam post and beam with SIPs (image: courtesy of Stride Treglown)

Completed in 2010 and designed by Stride Treglown architects, Treglown Court in Cardiff utilised a glulam post and beam structure, its design aided by use of modern parametric 3DCAD software. The glulam was manufactured by Wood Newton of Sutton in Ashfield using imported softwood; they also made the stressed skin structural insulated panels used for the walls, floor and roof. The building cost £1,664/m^2 and was awarded a BREEAM Excellent rating (Constructing Excellence).

Treglown Court demonstrates how modern methods of construction and use of timber can deliver highly efficient, sophisticated structures at reasonable cost. Many proprietary solutions are available for connections in post and beam construction. These include steel dowels, bolts, split-rings, shear plates, steel gusset plates and combinations of these connectors. Bespoke connectors can be readily fabricated for complex junctions.

There are few technical barriers to the utilisation of Welsh softwoods in this type of construction. Glulam is now being manufactured in Wales and as understanding of material properties of Welsh softwoods progresses, so technical applications and innovations using this knowledge will develop.

Figure 6: Treglown Court glulam structure being erected (image: courtesy of Stride Treglown)

There has been a significant revival of traditional oak post and beam construction across Wales aimed at the aspirational 'self build' market mainly using imported French oak. Specialist companies such as Welsh Oak Frame near Newtown and Castle Ring Oak Frame of Evenjobb manufacture bespoke buildings using a mixture of traditional and contemporary techniques. Small timber framing companies specialising in solid wood post and beam construction are ideal candidates to utilise locally grown structural softwoods, especially Douglas fir or larch.

Hence, with the availability of significant quantities of larch now coming to market, this traditional form of construction could find increased use in construction projects. Homegrown Douglas fir is regularly used in post and beam construction in France and is also offered instead of oak as a lower cost option by Oakwrights of Hereford.

Figure 7: Douglas fir posts and beams being prepared in a local workshop in France

There are several individual examples of Douglas fir and larch post and beam projects in Wales but the technique has not yet gained the widespread acceptance it enjoyed historically. Figure 8 shows a massive section Douglas fir post and beam house under construction near Welshpool. A separate low thermal bridging twin-wall envelope working in a non-structural capacity was used to contain insulation and run services outside the main frame. Non-structural twin stud frames used to create insulating envelopes are sometimes called 'Larsen Trusses'. In order to obtain the thermal performance demanded for modern buildings, SIPs may also offer opportunities to create insulated envelopes around post and beam structures. Closed panels (which may or may not need to be load bearing) could also have potential to create contemporary variants of the post and beam method.

Figure 8: Local Douglas fir post and beam structure with low thermal bridging twin-wall envelope

Post & beam	Thickness, mm	Conductivity, W/mK	Layer bridging
Plasterboard	15	0.210	
220mm timber stud frame with cellulose insulation	220	0.035	Bridged by timber studs
Timber counter battens with fibre batt insulation	70	0.039	Bridged by timber battens
OSB	18	0.130	
Ventilated cavity	25	R=0.13	Bridged by timber battens
External façade (timber cladding)	20	0.180	
Overall wall thickness		**368mm**	
Overall U value		**0.154 W/m²K**	

Table 1: Example of wall thickness compared with U value for possible post and beam construction

One evolution of the post and beam concept is the development of engineered 'box beams' to substitute solid timber beams. The benefit of the box beam is that it provides a hollow, high strength to weight ratio structural element that may be fabricated using either machined solid wood components or structural panels such as plywood. Long span beams can be manufactured using a combination of structural softwood chords and braces with side panels formed in plywood. It is possible to make box beams using only softwood elements but this can require precise profiling and selection of the lamellae in order to create interlocking elements capable of being reliably glued and clamped together. In instances where the weight of the beams is not an issue, (i.e. would offer no advantage), glulam beams are likely to be a cheaper, more simply engineered solution. The 'Ty Unnos' system described below is a Welsh branded application of the box beam.

3.2 Engineered box beam system – Ty Unnos

Ty Unnos takes its name from the historical practice of building a house within 24 hours on common land in Wales. The system was developed to utilise homegrown softwood in a variety of building types. It consists of three principal components:

- A hollow box beam made from graded softwood.
- A ladder truss made from visually selected falling boards.
- Wooden or steel connectors.

The components can be arranged as portal frames or use the racking strength of the sheathing panels, which are made up from ladder trusses and sheet material (OSB or Plywood). These same panels can provide wall, floor and roof sections. The ladder trusses and hollow beams allow use of blown cellulose insulation.

The box beam system has been approved by a European Technical Assessment (ETA). The box beam components could be finger jointed or box beams connected by bonded-in rods to create long beams. The internal wooden connectors are claimed to be stronger and cheaper than standard metal connectors or traditional timber joints (presumably compared with conventional post and beam construction).

Ty Unnos has been used in two ways:

- Ty Unnos Modular is a fully certified volumetric system offered by Elements Europe, where buildings leave the factory fully finished and fitted.
- The Ty Unnos component system which takes the prefabricated sections to site. The pre-insulated box beam frame is assembled and in-filled with the open ladder truss panels, which are then internally sheathed and insulated. This method has been successfully used by Kenton Jones of Welshpool on a number of projects.

As with other prefabricated systems, a principal goal with Ty Unnos is to achieve high levels of air tightness, minimise waste and the time taken to complete a weathertight unit. The system lends itself to bespoke internal design as it does not rely on partition walls as structural components. A number of Ty Unnos Toolkits have been produced by Cardiff based engineers Burroughs.

A typical build up could be:
Internal finish
Service void
OSB
Ty Unnos box beams, ladder beams & cellulose insulation
OSB
Counter batten
Breather membrane
Service void
External cladding

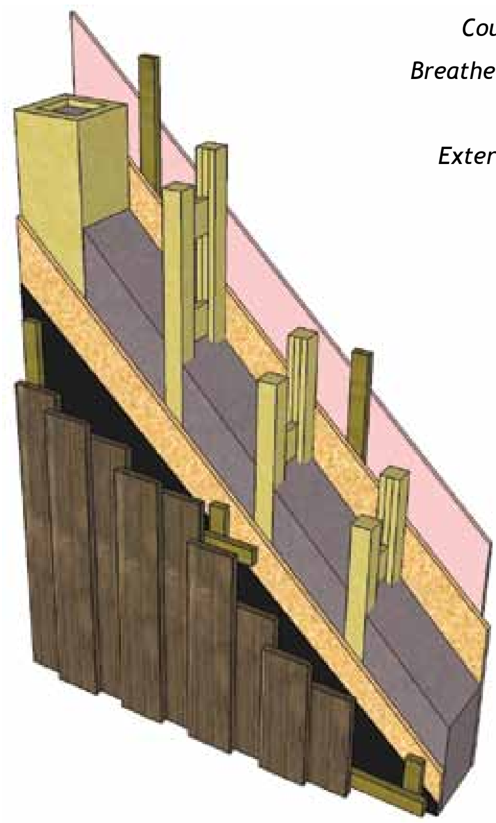


Figure 9: Schema of Ty Unnos construction system

The Ty Unnos system is currently a niche product and mainstream timber frame manufacturers will not necessarily be familiar with it. Engineered timber box beams have a performance advantage over glulam beams of the same weight. However because timber box beams are not made in volume in the UK and only limited volume in Germany it may be difficult to manufacture them competitively in Wales. To achieve spans longer than 5.4 metres, it is currently necessary to use specialist sawmillers cutting selected logs in order to source the long planks needed for the box beam elements. Architects may choose Ty Unnos in order to express a revealed structure in bespoke design led projects, but presently volume house builders may find it difficult to justify its use when compared with using simple, strength graded Welsh construction softwood in conventional open panel or twin-wall structures.

Figure 10: Ty Unnos portal frames erected at Blaengors, Carmarthenshire (image: courtesy of Coed Cymru)

Ty Unnos box beams	Thickness, mm	Conductivity, W/mK	Layer bridging
Plasterboard	15	0.210	
OSB	9	0.130	
270mm box beam frame with cellulose insulation	270	0.035	Bridged by timber beams and studs
OSB	9	0.130	
Ventilated cavity	25	R=0.13	Bridged by timber battens
External façade (timber cladding)	20	0.130	
Overall wall thickness		**348mm**	
Overall U value		**0.154 W/m²K**	

Table 2: Example of wall thickness compared with U value for Ty Unnos construction

3.3 Open panel or platform construction

Open panel systems are by far the most common approach to construction of timber frame housing in the UK. There are many varieties and derivatives of the open panel concept. Open panel timber frames utilise vertical load bearing timber posts or 'studs' that are assembled into walls, which are erected one storey or floor at a time. Each storey becomes the platform on which the next storey is erected; therefore this method is sometimes called platform construction. The system is derived from American 'balloon' framing but by separating floors with horizontal timber members sometimes called 'wallplates', firebreaks are introduced which reduce flame spread within the vertical voids between studs in the walls.

Layers of different materials may be built onto the exterior and interior or placed between the stud work of open panel frames, making them very versatile and suitable for a wide range of buildings; from single storey dwellings to medium rise apartments or office blocks. Oriented strand board (OSB) is commonly used as the exterior sheathing, which holds the insulation in place and imparts racking capacity to the walls, creating shear walls that are able to withstand lateral loading such as wind.

Open panel construction can be undertaken on site but this is now considered to be inefficient and wasteful. Cassettes are more commonly made in factories equipped with optimising cross cut saws and assembled on production lines varying from simple benches to mechanised lines with stations for different operations. Panels are delivered to site partly complete and can be offloaded and erected immediately when transported on suitably crane-equipped lorries. Panel sizes can be varied to meet required building dimensions and design features, while complex forms or features can be built using post and beam construction tied into the panelised modules. Where increased load bearing is necessary, 'cripple walls' or adjacent studs nailed together within panels can be created to strengthen window apertures or carry components such as glulam or steel beams.

A typical domestic application timber open panel wall utilises 140mm insulated studs and 9mm OSB racking boards with an exterior cladding, this is often masonry but timber provides a lower energy embodied solution. Frame depths of up to 220mm may be adopted to accommodate increased thicknesses of insulation and 18mm OSB will increase racking resistance. Extra insulation can be installed between counter battens fixed to the outside of the panel to further increase thermal performance.

A typical build up could be:
Internal finish
Service void and battens if needed
OSB racking board
Vapour barrier
Timber stud with insulation
Counter batten, additional insulation if needed
External cladding

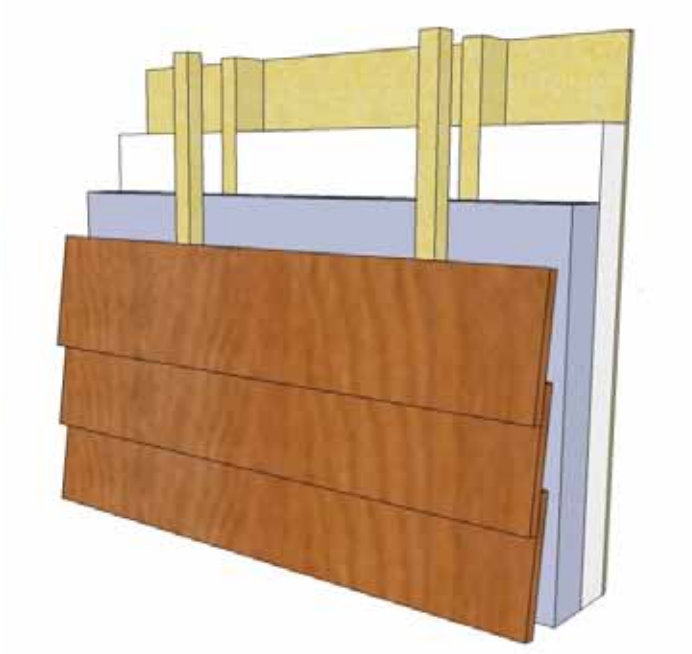


Figure 11: Typical open panel timber frame construction with timber cladding

Open panel timber frame is manufactured extensively across Wales. As of September 2013 only Fforest Timber Engineering of Swansea regularly utilise homegrown Sitka spruce in their open panel frames. This company recently manufactured an exemplar open panel house for a 'Grand Designs' project using Japanese larch from Wentwood forest. Acoustic strength testing carried out by Woodknowledge Wales (verified by BRE Timber Research Department) confirmed that the timber met required standards; C16 strength class for 90mm deep profiles and C24 for 225mm profiles. Fforest Timber Engineering have reported no technical problems either using the homegrown larch or their regular batches of homegrown spruce procured from BSW Timber.

Williams Homes, manufacturers of open panel timber frames at their factory in Bala, have expressed the aspiration to use only homegrown softwoods in their timber frame projects. This company have a wide experience of utilising homegrown timbers on individual projects and now wish to extend this across their whole range. Holbrook Timber Frame of Bridgend and Ecoframes of Welshpool have in the past used homegrown spruce in open panel manufacture.

Figure 12: Welsh larch assembled as partly complete open panels at Fforest Timber Engineering

Figure 13: 225mm deep C24 larch from Wentwood forest at Fforest Timber Engineering

3.3.1 Mainstream adoption of larger scale open panel timber frame

Fire regulations restricting the height of open panel timber framed buildings were lifted in 1991 allowing construction up to eight storeys without any additional fire resistance requirements than for three storey buildings (Lewis, 2005). The 'TF2000' project, carried out by BRE at Cardington, showed that this type of timber frame maintained structural integrity by compartmentalisation, despite application of severe mechanical damage and full scale fire tests. This research allowed development of multi storey buildings such as the student accommodation at Swansea University. Designed by Architype and completed in 2004 for Tai Cartrefi, this was one of Europe's tallest timber frame residential buildings at the time. This type of open panel construction is technically feasible using strength graded homegrown softwoods; high strength grade larch would be particularly appropriate in this application.

Figure 14: Six storey open panel student housing at Swansea University (image: courtesy of Architype)

Open panel	Thickness, mm	Conductivity, W/mK	Layer bridging
Plasterboard	15	0.210	
220mm timber stud frame with cellulose insulation	220	0.035	Bridged by timber studs
Timber counter battens with fibre batt insulation	70	0.039	Bridged by timber battens
OSB	18	0.130	
Ventilated cavity	25	R=0.13	Bridged by timber battens
External façade (timber cladding)	20	0.180	
Overall wall thickness		**368mm**	
Overall U value		**0.154 W/m²K**	

Table 3: Example of wall thickness compared with U value for open panel construction

3.3.2 Open panel using I beams

Typical timber studwork can be replaced by engineered I beams that fill the thickness of the panel between sheathing layers providing load bearing capacity and rigidity. I beams are available up to 360mm wide and can be a convenient solution for accommodating large depths of insulation between the vertical I beams obviating the need for counter battens or extra insulation layers to be added.

The OSB web in I beams limits thermal bridging somewhat but is not as efficient as the twin-wall systems described later in this section.

However, I beams are not currently made in Wales. Although high strength Welsh larch is available that could be suitable for chords in engineered joists, the economic viability of producing I beams in Wales is questionable and would certainly need to be researched further to establish any commercial potential. OSB is not manufactured in Wales either and the nearest British manufacturer of I beams is James Jones in Scotland. I beams are distributed in Wales by Pasquill (amongst others), who have sites in Buckley and Newport.

Nevertheless this method of construction has some merits; I beams are more uniform, predictable and lighter than solid wood joists, quicker construction may be possible along with easier installation of services through the thin OSB webs. Wood or cellulose fibre insulants could be locally sourced. Homegrown cladding could be utilised externally and internal partition walls could be created using homegrown softwoods.

A typical build up could be:

Internal finish

Insulation between I beams

OSB

Battens

External finish

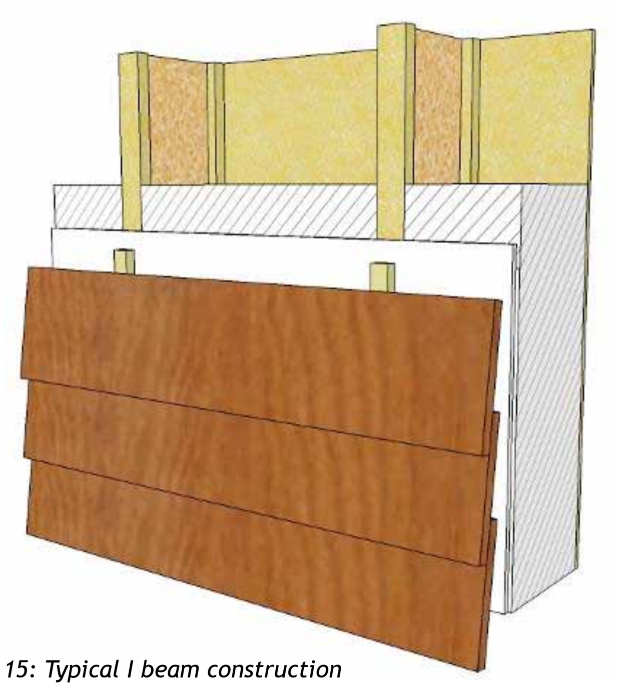


Figure 15: Typical I beam construction

3.4 Wall cassettes using engineered web beams

Open web trussed beams using diagonal galvanised steel webs to join parallel softwood chords are manufactured across Wales and marketed under trade names such as Easi-Joist, Eco-joist and Posi-joist. Most manufacturers use imported softwood but a few Welsh SMEs such as Fforest Timber Engineering (Swansea) and Williams Homes (Bala) have started using, or are about to start using, strength graded Welsh-grown softwoods in open web joist systems. Open web joists make ideal lightweight floor trusses, which readily carry services through the gaps between steel webs.

They may also be used as vertical load bearing members in wall panels, effectively acting as a twin wall system. Deep section wall panels capable of being filled with blown-in insulants such as cellulose fibre can be created, with thermal performance adjusted according to depth of wall section. Racking panels can be varied according to requirements, with OSB being an obvious choice when cost is the major consideration.

Vertical open web joists as a low thermal bridging wall solution were developed by Williams Homes and Wolf Systems for use in the Loughborough Dogs Trust building which achieved a BREEAM 'outstanding' rating (Williams, 2013). SEED Homes (Pembridge, Herefordshire) originally developed a wall cassette utilising vertical open web joists supplied by Fforest Timber Engineering (Swansea). Sheathing/racking panels are created through the American practice of nailing tongue and groove boards diagonally in opposite directions either side of the vertical elements, also forming the void that can be filled with cellulose fibre insulation. Welsh-grown Sitka spruce supplied by BSW Timber at Newbridge on Wye is used throughout the wall module.

This system is also manufactured in Wales carrying the 'New Welsh House' brand. Many joinery companies across Wales have access to homegrown softwoods and facilities for creating tongue and groove profiled boards suitable for sheathing. Researchers have expressed reservations in relation to condensation occurrence on the galvanised steel of the webs but there is no data currently available on this topic.

Engineered web beams and joists are discussed in greater depth in section 7.

A typical build up could be:

Internal finish

Internal tongue and groove sheathing

Vertical engineered web joists with insulation

External tongue and groove sheathing

Counter battens

External finish

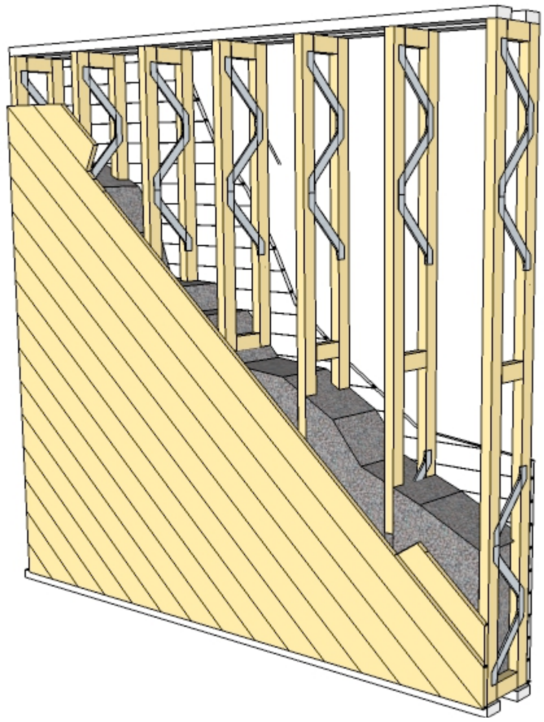


Figure 16: Typical engineered web beam as vertical structural elements in wall cassette

3.5 Open panel twin-wall construction

The twin-wall timber frame concept delivers very low U values by minimising thermal bridging within a simply manufactured system. Two separate open panel walls are joined by just enough cross braces to ensure structural integrity. Each wall acts as a load bearing open panel timber frame, but smaller timber cross sections may be utilised than in a standard open timber frame construction since loads can be shared between the inner and outer skins. The inner and outer studs can be placed at varying distances apart using gussets or noggins according to the thermal performance required and the insulation material specified.

Therefore, the thickness of insulation between external and internal sheathing can be adjusted to achieve desired U values. Solid noggins held with nail-plates, OSB or plywood gussets may all be used to join the separate vertical elements. Figure 17 shows a variant by Williams Homes utilising OSB gussets; they intend to brand their twin wall houses 'Ty Gwrydd'.

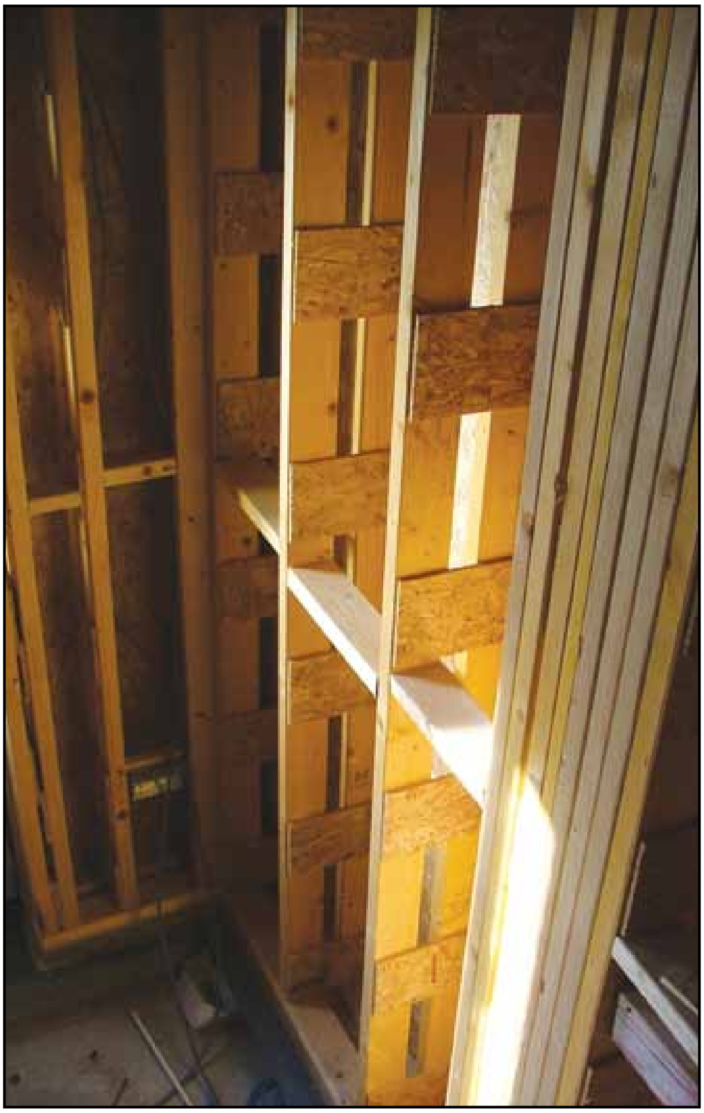


Figure 17: Twin-wall construction with OSB gussets prior to filling with insulant (image: courtesy of Williams Homes)

Figure 18: The 'Ty Solar' prototype house at Cilgerran

The 'Ty Solar' low energy houses developed by Western Solar Ltd at Cilgerran are intended to be constructed using a twin-wall system (Figure 18).

Cross-tying requirements can be minimised according to location and wind loadings thus avoiding unnecessary repeated thermal bridging between opposite studs. A further advantage of this construction method is that while the roof remains supported on the external skin of the wall, the intermediate floor can be supported on the inner skin, thus allowing continuity of insulation up the external wall, minimising a significant potential thermal bridging point.

It is inevitable that the twin-wall system will carry a slight cost uplift compared to traditional open panel timber framing, since manufacturers have to construct two separate, fully structural frames per wall. One manufacturer suggests this uplift is likely to be in the region of 10%, another has calculated that an extra cost of only £1,100 may be sufficient for a three bedroomed house (Williams O. , 2013) Twin-wall panels could potentially be made by any timber frame company capable of manufacturing open panel timber frames.

Holbrook Timber Frame (Bridgend) and Fforest Timber Engineering (Swansea) have already constructed buildings using twin-wall panels and the latter firm is now using homegrown spruce. There are no technical challenges to utilising homegrown spruce in this system and there is great potential to use Welsh grown larch from diseased plantations. Homegrown structural CLS larch is significantly stiffer and more durable than spruce but is currently offered at the same price by BSW Timber. Some distortion is possible when using homegrown timber but Simon Orrells of Framewise in Presteigne considers this not to be a problem when studs are constrained within twin-wall construction. Framewise have started production of twin-wall closed panels using homegrown spruce under the brand 'Wise Wall T' (Orrells, 2013), Figure 19, shows a typical build up.

Labour input required for twin-wall construction compared to standard open timber frames is somewhat higher. Both Holbrook Timber Frame and Fforest Timber Engineering reported no cost savings in prefabricating twin-wall panels off site. They cite increased transport costs of the higher volume panels outweighing any cost advantage. However although it appears to be more efficient to transport pre-cut, marked timber components for assembly and erection on site for these companies, Williams Homes assemble complete twin-wall cassettes in their factory for delivery to site.

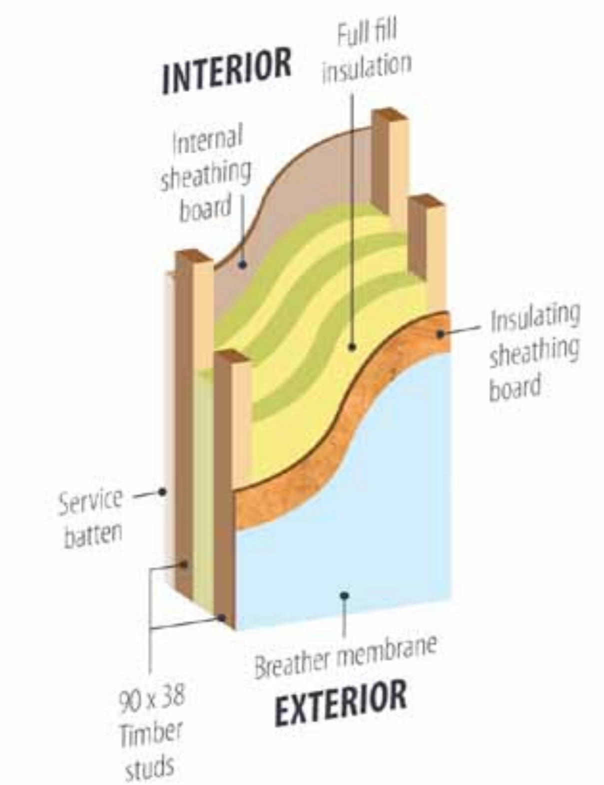


Figure 19: Typical twin-wall layout in the 'Wise Wall T' system by Framewise (image: courtesy of Framewise)

Twin-Wall	Thickness, mm	Conductivity, W/mK	Layer bridging
Plasterboard	15	0.210	
OSB	18	0.130	
89mm stud frame with cellulose insulation	89	0.035	Bridged by timber studs
Cellulose insulation between stud walls	70	0.035	
89mm stud frame with cellulose insulation	89	0.035	Bridged by timber studs
OSB	18	0.130	
Ventilated cavity	25	R=0.13	Bridged by timber battens
External façade (timber cladding)	20	0.130	
Overall wall thickness		**344mm**	
Overall U value		**0.153 W/m²K**	

Table 4: Example of wall thickness compared with U value for twin-wall construction

3.6 Closed panel construction

Closed panel systems have evolved from open panel systems. Panels can be prefabricated off site and a variety of insulation, services and finishes can be applied in factory conditions, reducing on site construction time and reducing waste. Rapid erection of weathertight cassettes on site allows immediate access to follow on trades.

The material build up can be similar to open panel systems. Traditionally on site practices tend to be less disciplined and of lower quality than factory processes but despite the advantages and the typically enhanced level of build quality that closed panels offer compared to on site timber frame construction, Welsh companies are reluctant to embrace closed panel timber frame manufacture at present.

Figure 20: Typical closed panel (example from Latvia)

The closed panel manufacturing process requires significant investment in machinery such as butterfly tables which allow panels to be turned over in order to finish both sides and overhead cranes to transport materials to work stations or to remove completed panels (see Figure 21). Depending on wall make-up, it may be necessary to close panels with a membrane or board to contain the insulation for transport and to provide temporary weatherproofing, adding cost. Panels are ideally transported and manoeuvred upright to avoid potential damage. Connecting closed panels together on site is more difficult than with open panels because being nearly complete at the time of erection, there is no access within the frame so this can lead to additional costs.

Closed panel manufacture is common in parts of central Europe but higher investment in the fabric of buildings is the norm there. Latvian manufacturers abound but their customer base tends to be wealthy, aspirational and located in Norway and Sweden. Developers in Britain tend to be extremely cost conscious and possibly more hesitant to invest in the fabric of their buildings, furthermore British main contractors tend towards adversarial behaviour in order to drive down costs along their supply chains.

While this situation continues timber frame manufacturers (who tend to be subcontractors) are reticent to upgrade their manufacturing facilities and then place themselves at the mercy of contractors. James Sweet of C4Ci consultants believes that open panel manufacturers in Britain face a dilemma; the days of making open panels may be numbered according to him and other commentators. However there is insufficient confidence on the part of many timber frame manufacturers or demand shown by their customers for them to risk investment in closed panel manufacture.

Therefore although there may be no technical obstacles for closed panel manufacture in Wales using homegrown timber, it is only likely to be undertaken on a small scale until British construction procurement processes change. There is one exception; Framewise of Presteigne have already installed butterfly tables and cranes (Orrells, 2013) but they appear to be the only timber frame firm in Wales able to offer volume manufacture of closed panel systems. Their 'Wise Wall T' system is a closed panel version of the twin-wall system described earlier.

Figure 21: Closed panel production line in Latvia with overhead crane and butterfly tables

Figure 22: Larch House in Ebbw Vale used closed panel construction and larch cladding

Closed panel	Thickness, mm	Conductivity, W/mK	Layer bridging
Plasterboard	15	0.210	
220mm timber stud frame with cellulose insulation	220	0.035	Bridged by timber studs
Timber counter battens with fibre batt insulation	70	0.039	Bridged by timber battens
OSB	18	0.130	
Ventilated cavity	25	R=0.13	Bridged by timber battens
External façade (timber cladding)	20	0.180	
Overall wall thickness		**368mm**	
Overall U value		**0.154 W/m²K**	

Table 5: Example of wall thickness compared with U value for closed panel construction

Closed panels can be made now in Wales using homegrown timber. Although this method has only been taken up by one mainstream open panel manufacturer in Wales, demonstration projects have shown the potential for closed panel production here. Wales could learn from Latvia, another small nation seeking new economic opportunities. Recognising the need to add more value to their exported timber, the Latvian government has encouraged inward investment to catalyse a new timber construction industry specialising in high thermal performance standard closed panels and other building systems which are exported to the wealthy Nordic countries.

Figure 23: A bespoke 6m. long closed panel made using Welsh Douglas fir and western red cedar

Latvian closed panels and volumetric buildings have also been exported to England. This begs the question; what would it take to convert Welsh timber processing firms to manufacturing building systems such as closed panel? Woodknowledge Wales is currently working with leading low carbon housing developers, ZEDfactory, to set up a Welsh supply chain for projects in England and results from this collaboration will inform the manufacturing conversion process from open to closed panel (ZEDfactory, 2013). The 'Zero Bills' demonstration unit at Ecobuild 2013 was manufactured in Wales; the next step will be to catalyse Welsh timber engineering firms to create a suitable closed panel system using Welsh softwoods. Welsh conifer forests provide the renewable resource from which a sustainable construction supply chain can be developed, allowing opportunities for Welsh timber frame companies to 'export' low carbon, engineered solutions such as closed panels to wealthy areas of England.

Figure 24: Woodknowledge Wales and Welsh SMEs contributed to this ZEDfactory 'Zero Bills' demonstration unit at 'Ecobuild'.

3.6.1 Glulam and straw bale closed panel; the Modcell system

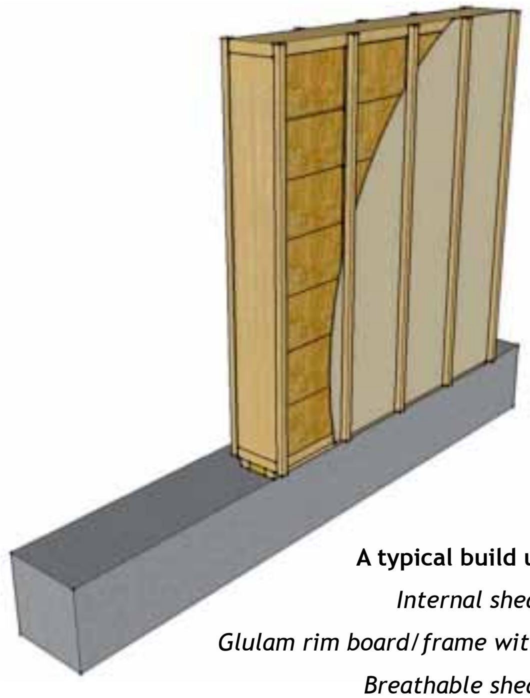
Although straw bale construction is considered here as an offsite pre-fabricated closed panel system available from Modcell, it is of course also possible to construct straw bale buildings on site. The straw is most commonly used as infill (non-load bearing) insulation with timber frame structures which can be timber clad or externally rendered. As they are generally enclosed by the bales, the timber frames can utilise a wide range of solid timber elements from roundwood to glulam. Render protects the straw from decay, improves its fire resistance and its stiffness. The straw is highly susceptible to moisture, which can be detrimental to its performance. It is therefore necessary to protect the straw from significant moisture ingress during the construction process and also to ensure long term preventative maintenance is carried out. Where driving rain might saturate rendered walls for extended periods, timber rain screens using Welsh grown refractory softwoods afford better protection to the straw insulation.

This moisture susceptibility gives a strong argument for prefabricated systems which offer year round construction reliability with reduced risk of water damage and in the case of lime render, more reliable finishes since setting times can be weather dependent. Prefabrication in factories tends to be quicker and results in reduced wastage. Nevertheless, on site straw bale wall fabrication may offer a viable and very economical solution to individual self-builders, as generally only simple carpentry or woodworking skills are needed. Construction techniques can be easily learned and cheap softwoods can be utilised.

White Design have pioneered the commercial manufacture of Modcell large scale straw bale construction panels and have also developed the concept of the local 'flying factory'. The company works with local farmers to procure straw and to locate agricultural barns which are rented to provide space in which to prefabricate the panels. Modcell aims to set up flying factories within twenty miles of the construction site. Panels can be made in varying sizes and types; Modcell traditional, Modcell Core and Modcell Core +. Fully closed, sealed panels can be delivered to site and are lifted into position using a telescopic loader or crane.

The Modcell system was designed by White Design in conjunction with researchers at Bath University. This construction system uses large structural glulam frames one storey high and between 400-480mm deep which are in-filled with straw bales and then sheathed or lime rendered. Services can be hidden behind sheathing, flush mounted within render or surface mounted.

Modcell buildings can be built up to three storeys high and currently imported glulam is used as panel rim boards. During 2013, Clifford Jones Timber Ltd commenced manufacture of glulam beams at their Ruthin site in North Wales. Therefore glulam for Modcell cassettes using larch, Douglas fir or spruce could be procured within Wales for the first time. There may also be an opportunity to use glulam manufactured in S.W. England using Welsh-grown softwoods.



A typical build up could be:

Internal sheathing board

Glulam rim board/frame with straw bale

Breathable sheathing board

Battens

Timber rain screen not shown

Figure 25: Simple sketch of a typical Modcell Core cassette (image: courtesy of Modcell)

Modcell straw bale	Thickness, mm	Conductivity, W/mK	Layer bridging
Plasterboard	12.5	0.210	
OSB	15	0.130	
Straw bale insulation within timber studs	400	0.060	Bridged by timber studs
Timbervent board	12	0.100	
Woodfibre board	40	0.039	
Render	10	1.000	
Overall wall thickness		**490mm**	
Overall U value		**0.128 W/m²K**	

Table 6: Example of wall thickness compared with U value for Modcell construction

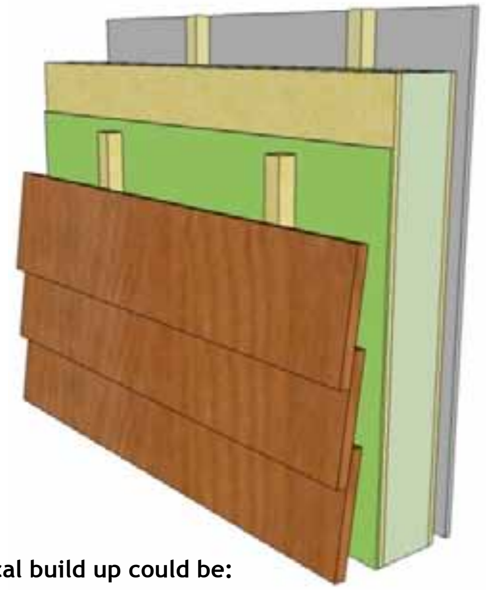
Figure 26: A Modcell cassette being fabricated in a 'flying factory' (image: courtesy of Craig White)

Straw is available in east Wales although cost is heavily weather dependent as farmers use it for cattle fodder following poor hay harvests. However, there may be scope to utilise baled bracken which is available across much of Wales. Bracken encroachment on farms and commons is now considered to be a major problem therefore regular harvesting for use in construction could be perceived as environmentally beneficial by reducing bracken spread, storing CO_2 and by substituting for higher energy embodied insulants. The principal cost of baled bracken would be dependent on agricultural contracting rates but is anyway cheaper than straw. More research would be needed to establish thermal performance of baled bracken if this concept is to be developed.

3.6.2 Structural insulated Panels (SIPs)

Structural Insulated Panels (SIPs) can be considered a variant of closed panel; they are manufactured off site and are capable of taking internal and/or external finishes in the factory. A SIP typically comprises rigid polyurethane or polystyrene insulation material sandwiched between two OSB boards carrying external counter battening with timber cladding. Other rigid insulants might be used and could incorporate locally sourced wood fibre although more research would be needed to quantify the potential for inclusion of other materials. Plywood or other wood based racking panels could be utilised for sheathing the rigid insulation. SIPs can be delivered to site as prefabricated panels and have enough structural capacity to be used as load bearing components.

I joists can be cast into panels to increase structural performance and counter battens can be attached to one or both sides of panels to take internal finishes or external cladding. SIPs are not manufactured in Wales although Eco-mods at Newtown use SIPs manufactured by Kingspan Insulation Ltd in Herefordshire to create volumetric buildings. There is limited potential to incorporate homegrown timber within SIPs, however counter battens and cladding could utilise locally sourced softwoods; plywood and OSB are not currently made in Wales



A typical build up could be:

Internal finish

Service void and battens

SIP (OSB/insulation/OSB)

Membrane

Battens

External timber cladding

Figure 27: Typical SIP wall construction

Bespoke SIPs are made in Britain by Cowley Timberwork in Lincolnshire. There are no technical barriers preventing manufacture in Wales. Some architects who espouse strong 'eco' or 'green' ideals are uncomfortable about utilising SIPs because they include high embodied energy polymer insulation materials. However SIPs can deliver high thermal performance without increased wall thickness and can be manufactured in curved modules. Ty Pren at Trallong near Brecon was designed by architects Feilden Fowles to follow the concept of the traditional Welsh longhouse. The design uses modern building technology to create a highly energy efficient building which needs active heating for only two months per year. SIPs were used with locally sourced external larch cladding (see Figure 28). Large volumes of larch cladding will be available as the Phytophthora epidemic progresses through Japanese larch plantations in Wales.

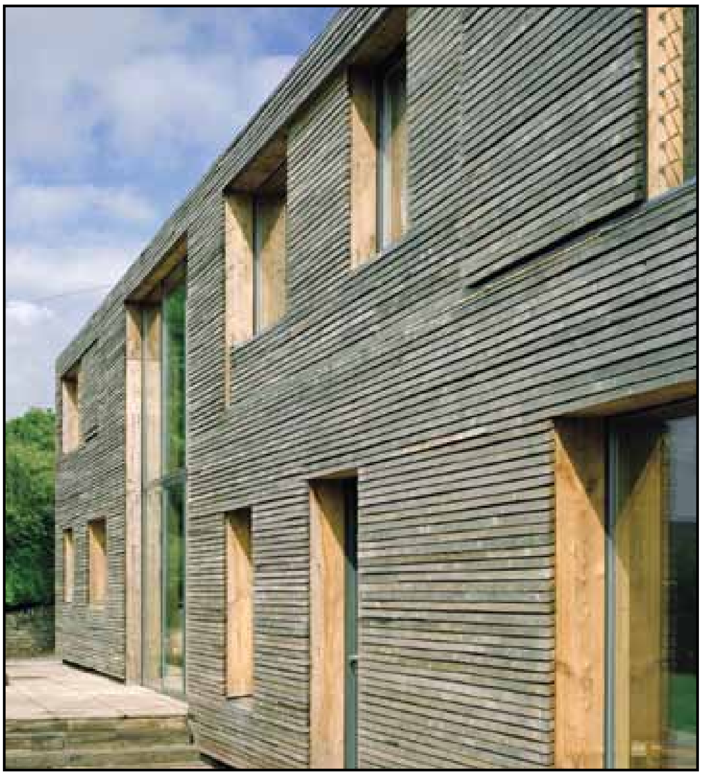


Figure 28: Ty Pren 'longhouse' uses SIPs with larch cladding (image: courtesy of D. Grandorge, Feilden Fowles)

3.7 Solid wood panels

3.7.1 Brettstapel/Dowellam

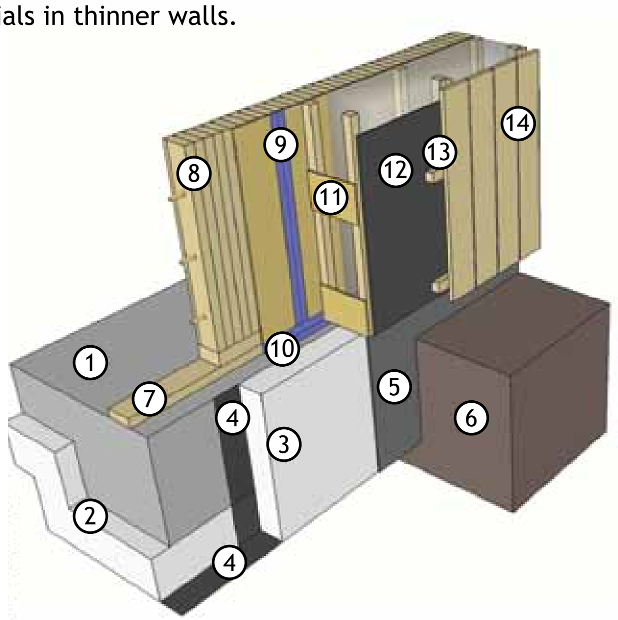
Often referred to by its original German terminology, 'Brettstapel' translates as stacked boards. This solid wood panel system comprises parallel softwood lamellae joined together with nails or super dry hardwood dowels. The dowels absorb moisture from the higher moisture content lamellae, then expand and lock the lamellae together into structural panels.

Brettstapel floor panels are capable of spanning greater distances than other solid wood panels of similar thickness and are therefore also particularly suitable for cantilevered structures. Brettstapel walls have up to twice the load bearing capacity of other solid wood shear walls (Smith, 2013). Brettstapel may be produced in a range of grades, e.g. using low value falling boards for 'industrial' grades or high value softwoods such as Douglas fir for exposed 'architectural grade' panels.

The use of relatively small cross section lamellae in this way to create high strength structural panels opens up a wide range of Welsh softwood species to higher grade applications. Panels can be produced in small workshops with simple equipment making it an ideal 'scale-able' construction technique for SMEs in Wales.

Brettstapel construction is particularly favoured by architects and clients with environmental aspirations as it can be used to create low embodied energy solid panels capable of replacing masonry or concrete but possessing improved environmental credentials; increased use of sustainably sourced wood within solid wood panels stores carbon within structures.

Brettstapel has also been shown to have beneficial hygroscopic properties within buildings, buffering fluxes in relative humidity and maintaining comfortable conditions for occupants. Brettstapel can be an expensive option that may only be viable for prestige construction, although nailed Brettstapel panels have been incorporated into social housing schemes in Scotland. This type of construction needs a thicker wall to achieve the same U values that may be obtained using other timber frame systems with equivalent insulation materials in thinner walls.



1 structual concrete slab
2 250mm rigid insulation wrapping around slab (Jablite)
3 150mm rigid insulation upstand (Sto system)
4 waterproofing layer (Sto system)
5 reinforced render applied to rigid insulation (Sto render system)
6 ground
7 timber sole plate
8 140mm brettstapel dowelled massive timber panel
9 18mm OSB racking board acting as airtightness layer, with taped joints
10 OSB sealed to concrete slab with airtightness tape
11 300mm larsen truss at 600 centres filled with Warmcel recycled cellulose insulation
12 Bitroc sheathing board with taped joints
13 black UV resistant breather membrane
14 vertical board on board timber cladding on horizontal battens and vertical counterbattens: UK grown Douglas fir, treated with OSMO

Figure 29: Dowellam wall construction at Coed y Brenin (image: courtesy of Architype)

Figure 30: The seven storey Brettstapel e3 apartment block in Berlin (image: courtesy of Bernd Borchardt and Kaden + Klingbeil)

At seven storeys, the e3 apartment block in Berlin (Figure 30,) is the tallest Brettstapel building in the world. Designed by architects Kaden + Klingbeil, the structure also incorporated structural glulam post and beam elements. Brettstapel could be used to build similar structures in Wales, few technical or regulatory barriers exist; using Brettstapel for the floor diaphragms in this type of structure is structurally efficient, suits modern methods of construction and can directly replace concrete. Closed panels could be used to infill shear walls between glulam post and beam.

In Wales, Brettstapel is more often being called 'Dowellam' as a more descriptive way of referring to the construction process. An example of a Dowellam building in Wales is the 2013 extension to the Coed y Brenin Visitor Centre near Dolgellau, designed for the Forestry Commission Wales (now Natural Resources Wales) by architects 'Architype'. This was the first ever UK Dowellam structure to use locally sourced Douglas fir and spruce. Larsen trusses, a type of lightweight vertical two stud framing element, were used to create the exterior insulated envelope, which was filled with cellulose fibre insulation.

The system was manufactured in the Williams Homes' factory at Bala less than twenty miles away from the site. The building also used locally grown Douglas fir extensively for cladding, decking, balconies, handrails and other features. This building is a paradigm for the utilisation of locally grown Welsh softwoods in a sophisticated structure and it clearly demonstrates the potential of Welsh-grown softwoods in the built environment.

Figure 31: Interior of Coed y Brenin extension showing Dowellam wall

Dowellam	Thickness, mm	Conductivity, W/mK	Layer bridging
Dowellam timber	120	0.130	
OSB	18	0.130	
Cellulose insulation with timber studs	255	0.035	Bridged by timber studs
Plywood sheathing	12	0.130	
Ventilated cavity	25	R=0.13	Bridged by timber battens
External façade (timber cladding)	20	0.130	
Overall wall thickness		**450mm**	
Overall U value		**0.154 W/m²K**	

Table 7: Example of wall thickness compared with U value for Dowellam construction

Figure 32: Exterior of Coed y Brenin extension; local softwoods were extensively used

3.8 Non-framed wood construction

3.8.1 Durisol woodfibre blocks

Woodcrete is a hygroscopic material using up to 80% recycled wood fibre that can either be cast on site using conventional formwork or, as is the case with Durisol, made as blocks in factories. Woodcrete has been produced in large volumes across the world, for instance in the old Soviet Union. It is currently produced in Australia under the proprietary name Timbercrete. Durisol is a proprietary system using recycled wood, cement and pulverised fuel ash (PFA) to produce blocks in a factory in Crumlin, Caerphilly, under license.

The blocks can be cast with integral insulation and then air cured. Interlocking hollow blocks can be stacked without the use of a bonding agent and once in place steel reinforcement bars can be positioned within the voids, which are then filled with concrete. The recycled wood content is treated during processing to be inert so it will not burn or rot. The system is claimed to have excellent acoustic performance. Finishes and insulation can be fixed with coarse wood screws or by using the ‘dot and dab’ method. Blocks can be chased out by traditional masonry techniques to accommodate conduits and wiring. The typical build up illustrated (Figure 33) assumes a rendered external finish.

However there is potential to fix battens and a ventilated external timber cladding such as homegrown Japanese larch onto this type of woodcrete wall. There is no technical barrier to the incorporation of homegrown wood strands in woodcrete.

A typical build up could be:

Internal finishes

Durisol woodcrete blocks with integral insulation and concrete

External finishes

Figure 33: Typical Durisol woodcrete wall

Construction using the Durisol blocks is said to be simplified (compared to traditional blockwork construction) since the blocks are specifically shaped to stack easily with one another and require no additional bonding agent. Site labour requirements will be relatively high, since by its nature it is a site based construction method. Although according to the manufacturer, the product offers labour time savings of 20% compared with traditional brick and block masonry construction, thereby permitting following trades to progress sooner. In addition the system requires relatively low skilled labour to construct as blocks can be easily cut by hand and waste returned to the factory for recycling.

Durisol woodfibre blocks	Thickness, mm	Conductivity, W/mK	Layer bridging
Plasterboard	15	0.210	
Unventilated cavity	25	R=0.18	Bridged by timber battens
Durisol woodfibre	40	0.083	
Durisol woodfibre with Rockwool insulation	165	0.034	Bridged by Durisol woodfibre
Durisol woodfibre with concrete	120	2.300	Bridged by Durisol woodfibre
Durisol woodfibre	40	0.083	
Render	10	1.000	
Overall wall thickness		**415mm**	
Overall U value		**0.179 W/m²K**	

Table 8: Example of wall thickness compared with U value for Durisol construction

4. Embodied impacts of various timber frame solutions

As legislation and future decarbonisation of the electrical grid reduces the operational CO_2 emissions from buildings, the embodied CO_2 of the structure itself will make an increased contribution to the sustainability of a building. Some timber components e.g. board products, may have higher embodied impacts from manufacture than others. Also, an important feature of biogenic materials (i.e. that take in CO_2 when they grow) is their ability to effectively store carbon during their lifetime within durable structures.

It is difficult to account for the benefit offered by this carbon storage, since the end of life destiny of the materials cannot be predicted. If timber (or other plant based materials, including straw bale and cellulose insulation) is decomposed or burnt at their end of life, the stored CO_2 will be released back into the environment. If they can be further reused or recycled, the carbon may continue to be stored for longer.

The principles of sustainability encourage that materials should be used as efficiently as possible. However, it could be argued that by encouraging the use of sustainably managed timber in construction (i.e. from forests where trees are replanted at the same rate at which they are removed) as a means of storing CO_2 long term within the building stock will further entrap CO_2 in a virtuous cycle. In reality, this will require proactive recovery mechanisms in the future for timber when it reaches its end of life, so as to continue to divert the CO_2 from entering the atmosphere.

Yet arguably, even if the timber was subsequently used as biomass fuel after its use in construction, if its use displaced other more carbon intensive fossil fuels it will have provided a net benefit.

In order to provide some distinction between the systems discussed, a separate embodied impact assessment for the timber frames was also carried out using BRE's Environmental Profiling tools. This was not intended to be an exhaustive assessment, but considered the energy usage associated with the manufacture of the timber and insulation raw materials and the carbon storage these products may offer in light of typical end of use practices across the UK after 60 years. The assessment did not analyse the manufacturing or transport activities for the systems as a whole and is only being considered in the context of optimising the timber resource.

In order to do this, typical wall make-ups of each construction type were derived to give a U value of 0.154 W/m^2K (±0.001 W/m^2K). The same insulation material was assumed in each case, with a thermal conductivity (λ) of 0.035 W/mK. If required, an additional layer of timber counter battening with fibre batt insulation of λ = 0.038 W/mK was assumed in order to achieve this overall U value within the limitations of frame cross sections to accommodate insulation. The wall composition was then normalised to a 1m^2 area functional unit, with the wall thickness dictated by the requirements of the U value. The Modcell closed panel straw bale system has also been included here to compare the impact of the quantities of timber used, although it would obviously utilise straw bale insulation (λ = ~0.060 W/mK) throughout.

This therefore provided relative quantities of the various timber and insulation components required to give a set thermal performance of 0.154 W/m²K. Table 9 shows the embodied energy and embodied carbon equivalent (i.e. including other greenhouse gases) for the components of each of the timber frame systems, excluding the external finish (assumed to be the same in all cases) but including any plasterboard, as some systems (e.g. Dowellam) are more likely to retain an exposed finish. The manufacturing and construction processes are also not included here. In the last column, the more negative the number the more carbon storage is offered hence use of solid wood Dowellam panels stores the most carbon.

System	Embodied energy, MJ/m²	Embodied Carbon equivalent, $kgCO_2eq/m^2$
220mm stud frame (assume same timber for post & beam, open & closed panel)	556	-22
Twin-wall	487	-17
Ty Unnos	481	-25
Dowellam	681	-82
Modcell closed panel	521	-45

Table 9: Embodied energy and embodied carbon impacts of timber wall systems

5. Thermal performance of wall systems

In the previous exercise to assess environmental impacts, a relatively low target U value was used to standardise the systems being adopted; lower than currently required by Part L of the building regulations performance standards and also lower than many current construction projects across the UK. However, this was necessary in order to standardise the U values across all systems, since Ty Unnos in particular would achieve this virtually as standard with no additional internal or external insulation layers required. It is also likely that U values at or below 0.15 W/m²K will become more common as developers strive to achieve ever increasing thermal performance standards as Building Regulations evolve. In particular, any developers considering building to the Passivihaus standard (a very low energy standard that originated in Germany and is gaining popularity worldwide) would certainly be aiming for wall U values at or below this level.

This section therefore examines how the wall systems considered may achieve given target U values and how the wall cross sections may vary, in particular with the utilisation of different types of insulation. Wall cross sections may be important to developers of multiple dwellings who wish to optimise site massing (i.e. achieve the highest number of dwellings possible on a given site) to deliver the highest possible return and offer affordability for buyers. Wall thickness also influences the cost of materials required, as thicker wall profiles require higher volumes of frame materials and a larger footprint of platforms/foundations and roof coverings. However, higher performing or narrower insulation products may also carry a cost uplift.

5.1 Assumptions for this exercise

Two target U values were selected and typical wall constructions for each system input into U value calculations to determine the required thickness of insulation to achieve these values (or as close to these values as practical) and the subsequent wall thickness. The U values chosen were 0.15 W/m²K to correspond to the other examples in this study and a slightly more lenient U value of 0.21 W/m²K, as industry experience suggests that this is the U value to which many mainstream house builders are currently constructing. Some systems, namely Modcell and Durisol, have set thickness parameters that specifically influence the U value achieved. These have been included as intermediate U value specifications in Table 10, as clients would no doubt select a slightly improved U value compared to their desired target rather than try to adapt the standard product specification to hit an exact U value.

In the first instance, the aim has been to derive these U values using natural insulation materials; in this case blown cellulose was assumed, as this would likely be the default insulation in Ty Unnos and twin-wall systems and is a Welsh manufactured product. Actually, a key driver in the development of each of these systems was the ability to utilise such insulation. Alternative products shown to be available across Wales, such as sheep's wool and stone wool, will have similar thermal conductivity values to cellulose so would deliver similar U values and wall cross sections. If specific manufactured products would otherwise use an alternative insulation material, this is noted in Table 10.

When striving for very low U values, a common criticism of natural insulation materials is that the wall thicknesses become too large. Therefore, for comparative purposes, equivalent U values were calculated instead using polyurethane (PU) insulation to show how the relative wall thicknesses would vary although it should be noted that such products are not manufactured in Wales at present. This is included in the white/grey (right hand) cells of Table 10. However, it should be noted that this has not been considered for all systems for the following reasons:

- As mentioned above, the Ty Unnos system specifically uses blown cellulose insulation within the engineered box beams of the construction. PU would likely only be considered as additional externally applied if very low U values were targeted (<0.15 W/m^2K).
- The key feature of twin-wall construction is that the two load bearing walls can be spaced at varying distances apart to allow for wider depths of insulation, with a view to accommodating natural, higher conductivity insulation materials. The specification indicated in Table 10 is likely the narrowest specification that would be considered viable. Otherwise, there is little advantage over simply using a standard open or closed panel timber frame. As such, twin-wall would not be considered with lower conductivity insulation materials such as PU.
- The Modcell system is specifically designed to utilise straw bale insulation, hence the use of alternative insulation products has not been considered.

While the timber frame systems have been assumed to have a timber clad external finish for this exercise, the Modcell and Durisol systems are more commonly used with a render external finish, hence render has been assumed for these systems. It would however be technically feasible to utilise timber cladding, although this would likely increase the depth of the resulting walls further. The external finish chosen would not be expected to significantly alter the U value achieved.

5.2 Discussion of relative wall thicknesses

The most obvious outcome from Table 10 is that somewhat narrower wall constructions can be delivered through use of lower conductivity, polymer based insulation materials than with the natural and fibre based materials produced in Wales. Wall thicknesses are reduced by 11-24%, depending on the type of wall construction considered. Hence in developments where wall thickness is a critical factor it is necessary to utilise such insulation products to keep wall cross sections to a relative minimum, thus reducing the impact of this indicator. However if utilisation of local products is a key priority, it is the natural or cellulose fibre based insulation materials that will be chosen.

At the lower target U value of 0.15 W/m^2K, the narrowest wall cross sections are achieved by the Ty Unnos and twin-wall timber frame systems. These wall thicknesses are the best that can be offered with natural or cellulose fibre insulants. Standard open or closed timber frame constructions approach 400mm at this U value, but specifications could be varied to deliver appropriate solutions. By comparison, the Durisol, Modcell and Dowellam wall systems all exceed 400mm wall thicknesses, which may not be deemed acceptable for some densely massed development sites.

Clearly if higher U values are targeted, the overall wall thickness of the applicable construction systems will become less problematic, as less insulation is generally required, leading to narrower wall cross sections.

Wall/frame type	Insulation thickness within frame system (A) mm	Material A	Addtional insulation internal or external to frame (B) mm	Material B	Total wall U value W/m²K	Overall wall cross section, mm	Equivalent 'A' with polyurethane insulation	Equivalent 'B' with PU	Total wall U value, W/m²K	Overall wall cross section, mm
Target U values of ~ 0.15 W/m²K										
Twin-wall	2 x 89	Cellulose	70	Cellulose	0.153	344	Intended for natural insulants rather than PU			
Ty Unnos	270	Cellulose	-	-	0.154	348	Intended for natural insulants rather than PU			
Post & beam, open or closed timber frame	220	Cellulose	70	Fibre batt	0.154	373	140	65	0.152	283
Dowellam	255	Cellulose	-	-	0.154	450	195	-	0.153	390
Intermediate U values, dictated by fixed dimensions of the product										
Modcell core	400	Straw bale	-	-	0.13*	490	Intended for straw bale rather than PU			
Modcell traditional	400	Straw bale	-	-	0.19*	543	Intended for straw bale rather than PU			
Durisol woodfibre block	165	Stone wool	-	-	0.179*	415	165	-	0.147#	415
Higher target U values of ~ 0.21 W/m²K										
Open or closed panel timber frame	140	Cellulose	60	Fibre batt	0.211	278	140	15	0.212	233
Dowellam	160	Cellulose	-	-	0.212	355	120	-	0.213	315

Table 10: Relative thicknesses for various wall constructions, according to the insulation material used

** These U values are dictated by the straw bale panel sizes themselves and are therefore intermediate to the higher and lower U values set for the other systems in this example. Users would therefore inevitably accept an improved U value over their target (data from manufacturer's literature).*

 # Durisol's standard insulant would be stone wool, which would deliver an intermediate U value relative to the target U values identified in this exercise. To deliver a U value of ~0.15 W/m²K, the manufacturer suggested using PU (or other polymer based) insulation within the woodfibre blocks instead.

5.3 Indicator: Relative thermal performance versus wall thickness

Since the impact of wall thickness may be relatively small for construction projects in rural areas, this indicator has been assessed based on the following wall thickness intervals at a target (maximum) U value of 0.15 W/m^{2}K:

- < 350mm = 1
- 350 - 400mm = 2
- > 400mm = 3

System	Ranking based on relative thermal impacts
Twin-wall timber frame	1
Ty Unnos timber frame	1
Post & beam, open or closed panel timber frame	2
Durisol recycled wood blocks	3
Modcell closed panel straw bale	3
Dowellam timber frame	3

Table 11: Ranking of wall systems based on relative wall thickness/thermal impact

6. Discussion regarding identified timber wall systems

The evidence set out in preceding sections clearly demonstrates that homegrown timber can be used in at least five different wall construction methodologies capable of delivering thermal performance approaching or equal to that demanded to achieve Passivhaus standards. Choice of method will then be determined by:

- Cost per square metre
- Desired insulant
- Wall thickness/site massing
- Ease of procurement
- Desired number of storeys
- Desired aesthetic detailing, e.g. revealed post and beam or Dowellam
- Desired special properties e.g. humidity buffering with Dowellam
- Structural detailing e.g. wide span ceilings/floors or large cantilevered areas

The most straightforward and accessible methods for building with homegrown softwoods to achieve good thermal performance for low energy buildings would appear to be open panel and twin-wall timber frame systems; both types of wall construction can use strength graded timber straight from the sawmill with no further processing required. Many timber frame firms across Wales are already capable of delivering both systems; at least four have used homegrown softwoods in open panel construction and three have used homegrown softwoods in twin-wall construction, one firm offers closed panel twin-wall. **These systems are available right now from mainstream suppliers in Wales.**

It is also now within our grasp to build mid-rise structures similar to the seven storey e3 Brettstapel with glulam building in Berlin but this is contingent upon continuing development of glulam manufacture in Wales. Mid-rise structures can already be delivered in Wales using homegrown softwoods in open panel or twin-wall construction and these would be much cheaper options than Dowellam with glulam. New machine grading settings allowing larch to be strength graded to C24 or over will aid optimisation of homegrown timber in multi-storey construction. Mid-rise buildings using new massive timber systems may be achievable within one to two years. **Mid-rise structures to eight storeys using homegrown timber in open panel construction are technically feasible using mainstream Welsh suppliers now.**

Volume production of glulam has already commenced at Clifford Jones Timber at their Ruthin site. Glulam can be made from Welsh grown softwoods, requires only basic machining before gluing and is a commodity product with pricing influenced strongly by global supply and demand, much like sawnwood. Consequently glulam is widely regarded as an economically viable low embodied energy substitute for steel and concrete in structures.

New machine grader settings are needed to optimise use of homegrown softwoods in glulam but this data is expected to be available by summer 2014. Glulam can be used in post and beam construction and Modcell cassettes. **Volume production of glulam with correct certification from a mainstream Welsh supplier is expected to be deliverable in 2014.**

Dowellam solid wood panel construction using homegrown softwoods has already been delivered in the new Coed y Brenin visitor centre extension completed in summer 2013. This is the first Dowellam structure to be built in Britain using locally grown softwoods. Because Dowellam is a laminated solid wood structural panel it is by its nature expensive. Nevertheless many architects regard it as a desirable replacement for concrete or masonry.

This system is available now using homegrown softwoods as a bespoke, niche product made by one Welsh manufacturer. Nevertheless its simplicity and 'scale-ability' make this technique an attractive construction option for Welsh SMEs.

Several demonstration buildings using Ty Unnos box beams have already been completed in Wales using homegrown timber. Although a niche system at present, it is relatively straightforward and components can be machined using a conventional planer-moulder. Although not a mainstream product, **Ty Unnos is currently produced by one Welsh manufacturer.**

Post and beam construction has undergone a significant revival in Wales; SMEs produce bespoke post and beam frames for aspirational or 'life-style' customers who regard this building technique as embodying both traditional and ecological values. Although mostly using imported green oak, some SMEs are offering homegrown Douglas fir or larch as locally sourced alternatives.

Although not enjoying the cost efficiencies offered by a mass production method such as open panel, the use of local timber in post and beam buildings constructed using local craftsmen will continue to appeal to some clients. **This technique can immediately deliver attractive buildings using homegrown timbers to a niche market. With the development of glulam using Welsh softwoods, there is potential to construct repeatable sophisticated glulam post and beam structures capable of incorporating floor or wall panels manufactured using techniques such as Brettstapel/Dowellam or closed panels.**

System	Costs provided by:	Typical cost of system £/m²
Durisol recycled wood blocks	Durisol	£95/m²
Modcell closed panel straw bale	Modcell	£195/m²
Open panel/Post and beam	Ecoframes	£195/m²
Twin-wall timber frame	Fforest Timber Engineering	£225/m²
Closed panel timber frame	EcoFrames	£225/m²
Ty Unnos timber frame	WSA, Cardiff University	£270/m²
Dowellam timber frame	Williams Homes	£500/m²

Table 12: Indicative costs per m² of identified wall systems

7. Engineered beams, joists and rafters

In addition to the timber construction methods discussed above, there is potential to utilise Welsh-grown timber sources in value added engineered beams and joists.

7.1 Glulam

Glulam beams are made by a relatively simple process of glueing smaller pieces of timber together to create larger stable elements, normally using spruce or pine softwoods. The impacts of potential individual defects within individual lamellae are effectively eliminated by the random, stochastic nature of the layering and bonding process. Glulam beams can be manufactured to dimensions far greater than is possible with sawn solid timber elements; generally only limited by logistical considerations. Because the timber used in glulam is kiln dried, there is also little risk of dimensional change or distortion when in service. Glulam can utilise softwoods of different strength grades, optimising their location by placing stronger lamellae on the outer layers of beams. There may be potential to utilise the MTG hand grading tool to grade batches of high stiffness species such as larch or Douglas fir in order to select high strength grade lamellae when new grading settings become available.

To date, glulam has only been produced in Wales in small quantities for one-off projects; the negative perception of the 'quality' of Welsh softwood has limited its development. However, the recent research findings from studies of Welsh grown softwoods have changed this situation; Welsh softwood processors Clifford Jones Timber (CJT) of Ruthin have invested over £1 million in state of the art kilning facilities and a volume production line capable of producing glulam elements up to seven metres long and at least two bespoke sawmills in Mid Wales can already supply lamellae cut to this length. CJT have so far produced glulam from Welsh-grown timber for simple outside applications such as signage.

They intend to start producing structural larch glulam as soon as new grader settings data is available. Selected Welsh-grown Japanese larch and Douglas fir are ideal for glulam production in Wales and providing that CJT can fulfil certification requirements associated with this process, structural glulam using homegrown softwoods should be available in Wales during 2014.

Specialist glulam production has great potential in Wales because of the availability of various softwoods with particular desirable characteristics, for instance larch and Douglas fir for high stiffness and western red cedar (WRC) for durability and flexibility. Spruce and western hemlock are both suitable for 'run of the mill' glulam but economic viability would be dependent on the strength of the pound and the price of imported commodity glulam. English housing developers ZEDfactory have expressed interest in Welsh larch glulam for use in the floors of their 'Zero Bills' houses and White Design are interested in using Welsh glulam in their Modcell cassettes.

Figure 34: The new radio frequency high volume glulam press at Clifford Jones Timber, Ruthin

7.2 Engineered joists and rafters

Engineered joist and trussed rafter systems provide lightweight, high stiffness, high stability solutions for spanning floors and roofs. Many may also be used as vertical load carrying elements in open or closed panel systems, as mentioned previously. They use longitudinal top and bottom high stiffness timber chords or flanges joined and braced with composite timber panels (I joists and beams), galvanised diagonal braces or solid timber diagonal braces, all of which are called the web. Services can be installed through the web while the chords allow for attachment of further elements. Examples:

1. I joists or beams are manufactured using finger-jointed knot-free high stiffness softwood or laminated veneer lumber (LVL) flanges with OSB or particleboard webs. LVL is not currently produced in the UK, although no technical barriers exist. These beams are often marketed as 'silent floor' systems under trade names such as 'Trus-joist'. James Jones make 'JJI'- branded I joists in Scotland. Because OSB (for webs) is not produced in Wales, production of I joists is probably not economically justifiable here.

2. Galvanised metal open web joists are made using high stiffness timber chords with pressed metal diagonal webs, trade names include 'Posi-joist', 'Easi-joist' and 'Space-joist'. These trussed joists allow services to be routed through the openings between metal webs. Several Welsh firms, e.g. Fforest Timber Engineering in Swansea and Williams Homes in Bala make these trusses. This type of joist is used vertically as the load bearing element in the 'New Welsh House' design. There are no technical barriers to the use of homegrown timber in this type of joist; Fforest Timber Engineering have produced open web beams using homegrown C16 spruce up to 7 metres long (Aldridge, 2013). The Wolf Easi-Joist technical guide allows spans of up to 8 metres long using imported TR26 softwood and it may be possible that larger section homegrown softwood could be substituted to achieve the same span.

3. Timber open web joists with galvanised punched steel plate or nail-plate fasteners use both timber chords and solid timber diagonals to form the web. The nail-plate fasteners are stamped to create integral perpendicular nails and may be used for trusses up to 30 metres long. There are no technical barriers to the use of homegrown timber in this type of joist.

4. Glued timber open web joists use solid timber diagonal braces finger-jointed and glued into the high stiffness chords. They may have short OSB webs at their ends for final trimming and are marketed as 'all timber' solutions under trade names such as 'Open Joist'. There are no technical barriers to the use of homegrown timber in this type of joist.

5. Ladder beams, as used for non-load bearing intermediate beams in the Ty Unnos system can utilise Welsh grown softwood chords and orthogonal cross-ties to create joists. Strictly speaking, they should not be called trusses because they do not use diagonal or triangulated ties or struts. These simple engineered joists have been used as rafters, purlins and the vertical elements in the Ty Unnos wall cassettes. This ladder system is a light and stable alternative to solid timber joists. However as this engineered joist is not manufactured in volume, there are doubts about its economic viability in competition with existing high volume trussed or solid panel web solutions.

Welsh larch or Douglas fir could be an ideal material for use in options 2, 3, 4 and 5 above and Welsh Sitka spruce could also be an option especially when C24 material comes on stream here in Wales. As the machine grader settings for these species become available, engineered beams, joists and rafters in homegrown softwoods may be more attractive for Welsh manufacturers seeking roof and floor design options. Other reasonably simple engineered truss or beam designs show considerable potential for development in Wales and some options are under discussion by Napier University and Woodknowledge Wales.

Figure 35: Posi-joists at Fforest Timber Engineering - these could utilise Welsh softwoods now

8. Engineered roof systems

8.1 Lamella structures

Catenary arch and barrel roof lamella structures were originally designed by Friedrich Zollinger around 1921. They need no special processing lines or heavy investment and may be built using sawn, strength graded joists and simple bolted connections. Short, portable and identical larch glulam elements could be manufactured in volume now at Clifford Jones Timber in Ruthin and utilised to construct large span lamella structures. This technique has potential for increased uptake; modern 3D CAD and finite element analysis software can speed up the design stage considerably and could make this technology accessible to mass markets.

It may be possible to construct contemporary housing, commercial and public buildings using standardised glulam components produced in several already existing small workshops rather than within a large expensive purpose-made facility, providing that production quality can be assured. Research might be focused on innovative end connection systems in order to speed up assembly and erection processes although some proprietary solutions are already available “off the shelf”.

Lamella timber structures were built during challenging times. They were a creative response to constructional needs using standardised components in order to build large structures efficiently. There are few constraints on applications and lamella roofs and structures offer imaginative solutions to the problem of constructing wide spans using short timber components. The diamond shaped interstices offer opportunities to include insulating and/or stiffening materials. The lamella roof demonstrates the value-adding potential of innovation but without the drawbacks of risk from heavy investment (Dauksta, 2011).

9. Conclusion

There are now few technical barriers to wholesale adoption of timber construction systems in Wales using homegrown softwoods. It is possible to build structures in strength graded homegrown softwood certainly to six and probably to eight storeys right now (Lewis, 2005). One mainstream open panel timber engineering firm in Wales is using homegrown spruce; at least one more is committed to do so in the very near future and another has requested a meeting with Woodknowledge Wales to discuss the proposition.

We are only just beginning to properly understand the potential for conifer plantations to deliver an effective supply chain of renewable construction materials to the building industry in Wales. Ironically, Wales was one of the world’s first industrial societies, still has one of the lowest proportions of forest cover in Europe and yet is carrying out more innovative work in the field of timber construction than Canada with all of its forest resources.

It is wood science that will enable us to meet the challenges that Welsh Government and the construction industry pose; to deliver sustainable and affordable construction solutions to Wales. Bangor University, Britain’s first institution to offer forestry degrees, has played no small part in pioneering the research which underpins the progress we are making in Wales. Woodknowledge Wales are now formalising their partnership with Edinburgh Napier University, Britain’s leading timber engineering institution, and are working within other academic and commercial partnerships to ensure the continuation of this progress.

The potential that can be derived from timber engineering and innovation is clear and the growing number of exemplar projects around the country confirms the increasing interest and mounting enthusiasm to fully explore the possibilities and capabilities of homegrown softwoods in construction.

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