

Cross-laminated timber construction - an introduction

Introduction

In Timber Engineering Bulletin No. 2, the engineered wood product known as cross-laminated timber (CLT) is introduced. This article provides a more detailed introduction to the applications and use of CLT as a structural timber product.

Subsequent bulletins (Nos. 12 and 13) will provide information on the manufacture, detailing and erection of CLT and detailed advice on the structural design of CLT based on the latest knowledge and experience.

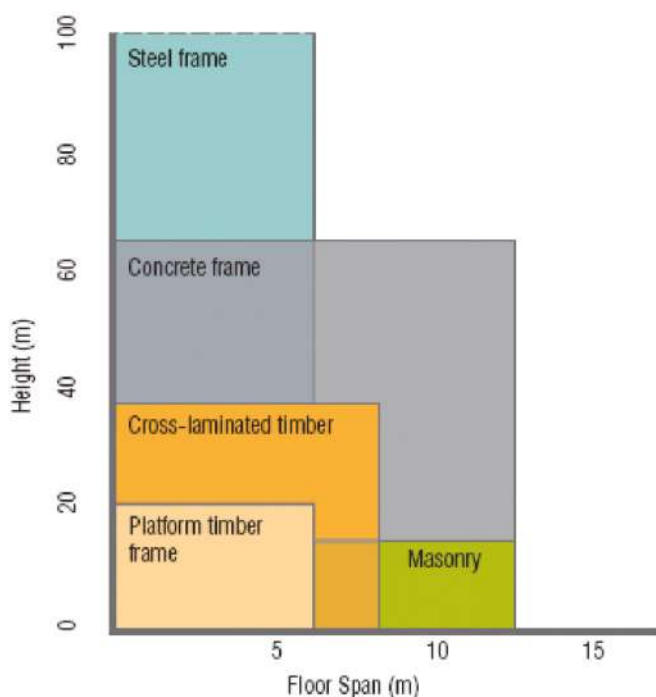


Figure 1

Span and height capabilities of mainstream structural materials in standard design.

History of CLT use

CLT is an engineered wood panel product that was developed in Europe in the 1970s and has been in continuous development ever since, particularly in Austria and Germany. CLT is a form of large volume wood panel construction. Table 1 indicates some typical characteristics of different forms of large-volume engineered wood panel products.

Large-volume timber structures, such as CLT, are a natural choice of construction where low-embodied-carbon materials are required for where the aesthetic requirements for a dimensionally stable exposed timber finish are required. CLT construction has also been used to extend the feasible height range for timber-framed building structures (Table 2 and Figure 1) and to provide shear walls in open plan timber frame structures.

CLT is currently imported into the UK from mainland Europe but, as the UK market develops, a UK plant producing CLT from local timbers may become commercially viable. Some feasibility and research work has already been undertaken on CLT manufactured in the UK from Scottish-grown Sitka spruce.

The use of CLT for structural applications in North America is also rapidly expanding with the publication of a number of harmonised standards and design guides. There is currently no equivalent design guide in the UK, but TRADA is in the process of developing design and specification guidance to support the UK design industry.

Overview of CLT

CLT panels consist of not less than three cross-bonded layers of timber typically ranging in thickness between 20mm and 45mm. The timber is strength graded to BS EN 14081-1:2005 and glued together in a press, which applies pressure over the entire surface area of the panel.

CLT panels have an odd number of layers (3, 5, 7, 9) which may be of differing thicknesses; layers are arranged symmetrically around the middle layer with adjacent layers having their grain direction at right angles to one another (Figures 2 and 3).

The overall thickness, as well as the loadbearing performance of the composite panel, is determined by the build-up of the individual laminates. Commonly used CLT panel thicknesses are in the range of 80–200mm.



Figure 2
CLT panel configuration



Applications of CLT

CLT is manufactured into solid wood panels which are used as walls, roofs, floors and even stairs. The building envelope can be insulated and clad with other materials such as timber, brick, render or composite panels.

CLT timber structures of eight storeys have already been constructed in the UK. Current knowledge supports up to 12-storey designs, but the feasibility of building a timber structure up to 30 storeys tall using CLT has been investigated and a number of engineers around the world are currently investigating the use of CLT for taller structures. Table 2 shows approximate span and height capabilities of the mainstream structural materials. Figure 1 shows how CLT extends the potential for timber in structures previously only possible using other materials.

Structural configurations

CLT panels can be used for a number of different applications (Table 3). It may also be possible to use CLT panels as pre-insulated wall and roof cassettes, but care would be needed to avoid damaging the insulation in transit.

Room-in-the-roof construction highlights the opportunity for prefabrication. Where a roof is required to have a simple arrangement of continuous ridges and gable ends, a room in the roof can be formed using CLT panels. A breathable roof underlay and rigid insulation will normally be located above the CLT panels to give a 'warm roof' construction which can be prefabricated as an insulated cassette.

CLT sloping roof panels are typically supported by external walls or eaves, purlins and ridge beams. However, where resistance to horizontal forces can be provided at the eaves, a 'coupled' roof is also possible to form clean

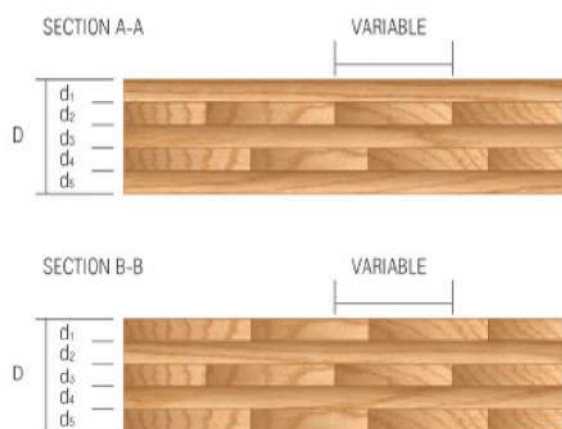
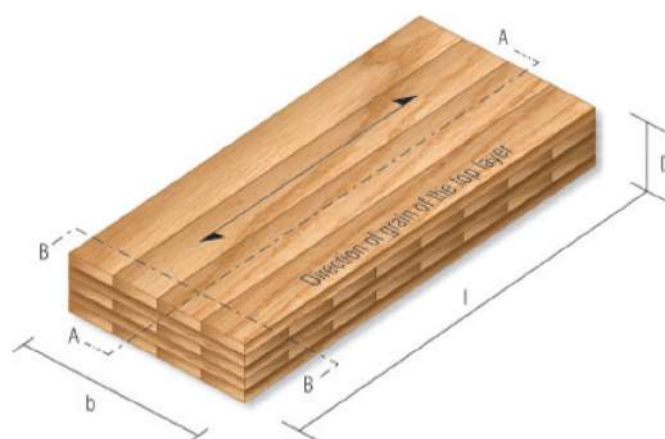


Figure 3
Examples of CLT panel cross-sections and direction of grain of top layers



Figure 4
CLT roof panels formed as 'coupled' roof

Figure 5
Multistorey platform-frame
construction using CLT

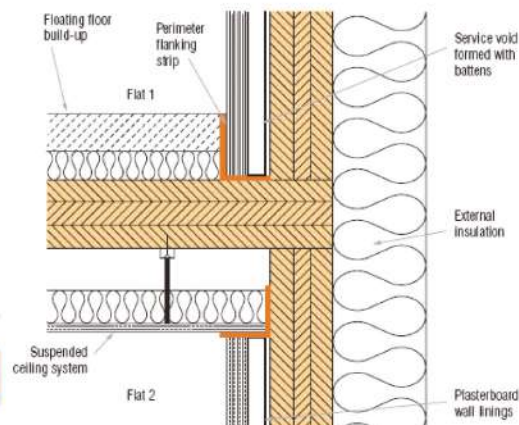
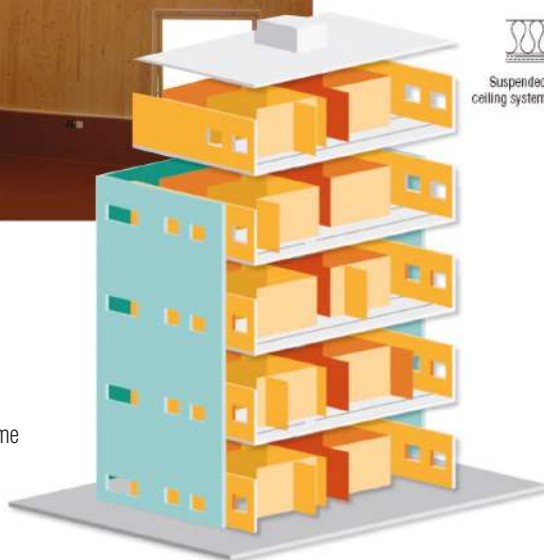


Figure 6
Typical CLT platform-frame external
wall-floor junction

structural ceiling lines (Figure 4). The CLT panels must transfer vertical and horizontal load to the walls, purlins and ridge beams using suitably engineered mechanical fixings.

Platform-frame construction

CLT structures are typically built using a 'platform frame' approach, meaning that walls are temporarily braced with raking props (if possible, erection commences from a corner or braced location) before floor panels are lowered onto them and fixed. The completed floor structure provides the 'platform' for the erection of the wall panels to the following storey. Figure 5 shows a typical multistorey construction using CLT and Figure 6 shows a typical CLT platform-frame external wall-floor junction.

Floor structures are typically arranged as one way spanning slabs, although with computer-aided analysis techniques, the two-way spanning capabilities of large slabs can be utilised. Figure 7 shows a typical floor 'slab' arrangement using CLT.

Hybrid forms of CLT construction

CLT and platform-frame timber frames can be combined in a number of different ways to produce a more efficient structural form.

Using external non-loadbearing walls comprising highly insulated panels

CLT floor slabs can be arranged to span parallel to external walls so that external walls can be highly insulated non-loadbearing 'infill panels' (Figure 8). This method is suitable where a regular arrangement of cross-walls can be used to provide the loadbearing structure and a high degree of thermal performance from the external walls is required. It may be necessary to consider the torsional stiffness of the frame if shear walls are arranged asymmetrically throughout the building, but CLT floor slabs can act as efficient horizontal diaphragms provided the connections between adjacent slabs are designed accordingly.

CLT floor and wall components combined with other forms of construction

Timber-frame walls or concrete or masonry basements may be used to support CLT floor slabs where a thin (or exposed soffit) floor section is needed. Similarly, where there is an aesthetic requirement for exposed timber walls, CLT wall panels may be combined with either joisted or concrete floor structures. However, for low-rise construction, the increased loadbearing capacity of CLT wall panels may not add any benefit over conventional stud-framed walls.

CLT used with other types of engineered timber floor structures

Other types of engineered floor joists may be combined with CLT wall panels where a lightweight floor/roof structure is more appropriate or where an exposed CLT wall panel is an aesthetic requirement.

Engineered timber floor structures can be supported on top of (platform-frame approach) or inside of (balloon-frame approach) the CLT wall panels. Figure 9 shows an engineered I-joist floor structure supported in a balloon-frame configuration.

Where CLT wall panels are combined with engineered timber joists built into the wall panels (in a platform-frame approach), vertical load can be transferred through the floor zone using timber ring beams and solid timber blocking between the joists (Figure 10). In this detail the solid blocks and ring beam should be an engineered timber product such as laminated veneer lumber (LVL) or laminated strand lumber (LSL) in order to minimise shrinkage across the floor zones.

As an alternative to using engineered timber within the platform frame floor zones, top-chord supported open web joists can be used to avoid the requirements for solid blocking beneath walls (Figure 11).

Reference should be made to TRADA Guidance Document 10 (GD10)5 for a comparison of the relative stiffness and self-weights of various engineered timber floor structures.

Composite timber/concrete floors

CLT floor slabs can also be used to form wood/concrete composite floors, where the CLT slab is used as a permanent formwork with horizontal shear transfer between materials being provided by shear plates and screws.

CLT walls have also been used to support precast concrete floors where it is considered that the increased thermal mass of a concrete floor would be beneficial.

CLT supported by glulam/steel frames

As an alternative to forms of construction using loadbearing walls, CLT floor slabs can also be supported on a frame of glulam or steel downstand beams and columns in order to create large open-plan areas. This method can also be used where loadbearing CLT walls are not possible or would add unnecessary weight (Figures 12 and 13).

Table 1: Characteristics of large-volume engineered wood panel products

Solid wood construction or 'massive timber'	CLT
Large sections of strength-graded timber either adhesively or mechanically bonded together	Relatively small lengths of strength-graded timber 'planks' (usually 25–40mm thick kiln-dried spruce) adhesively bonded together under pressure to form a large board product
Individual sections usually orientated in the same direction to form a structurally monolithic form	Individual layers orientated perpendicular to the previous layer into multilayer panels
Examples: • <i>Brettstapel</i> , which is fabricated from softwood timber posts connected together with dowels or fasteners ¹ • Glulam slabs made from strength-graded horizontally laminated glued-laminated timber elements with tongued and grooved edges to enable adjacent elements to be mechanically connected together to form slabs and wall elements • Laminated veneer lumber (LVL) or orientated strand board (OSB) panels ¹	Some manufacturers also edge-glue planks in individual layers or provide LVL layers to improve airtightness performance

Table 2: Approximate span and height capabilities of mainstream structural materials

Material	Floor span capability	Height capability
Steel frame	6–7m for composite steel/concrete floors	>100 storeys
Concrete frame	8–12m for solid, prestressed, troughed and ribbed slabs	>20 storeys
Platform timber frame	5–6m for engineered timber joists	7 storeys or 20m
CLT construction	6–8m	12 storeys or more possible*

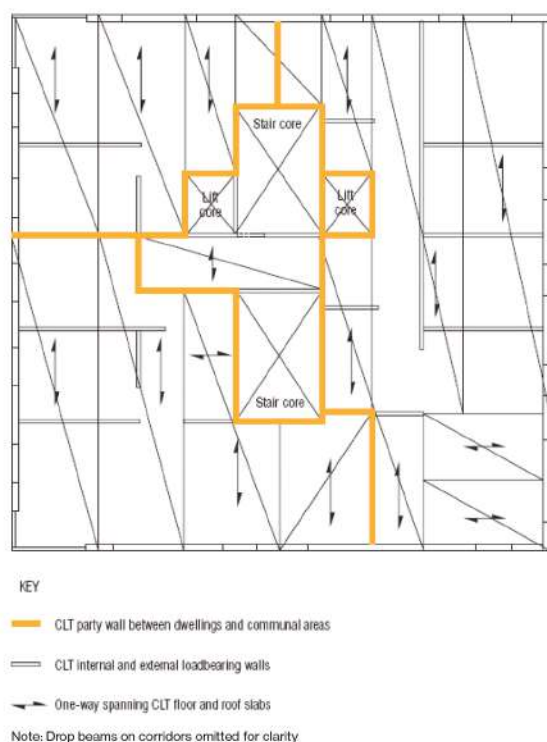
* Design height limits above 12 storeys are subject to the engineering of the floors-to-walls interface design specific to the project.

Table 3: Applications of CLT

Type of element	Applications of CLT
Wall elements	• Loadbearing single and compartment wall leafs • External walls – either loadbearing or infill panels • 'Balloon-framed' walls with joisted floors • Non-structural partitions with and without linings • Parapet walls formed from balloon-framed wall panel elements • Curved loadbearing wall structure • Shafts and towers • Shear walls
Floor (ceiling) elements	• Floor slabs – either one-way or two-way spanning • Cantilevered floors, e.g. balconies
Roof elements	• Room-in-the-roof sloping panels – either as couple roof or supported by purlins • Flat roof slabs
Other elements	• Stair flights • Furniture

Figure 7

Typical floor slab arrangement using CLT showing continuity over internal loadbearing walls but discontinuity over separating walls.



Hybrid CLT products

Some hybrid CLT products are also available, including Leno® Plus (MERK), which is a cross-laminated panel product containing a central layer of 32mm LVL. Due to the layer of LVL, there are no joints in the panel.

Benefits to construction process of using CLT

Using CLT for prefabricated wall and floor panels offers many advantages:

- the cross-laminating process provides improved dimensional stability compared to sawn timber, which allows for prefabrication of long, wide floor slabs, long single-storey walls and tall wall panels

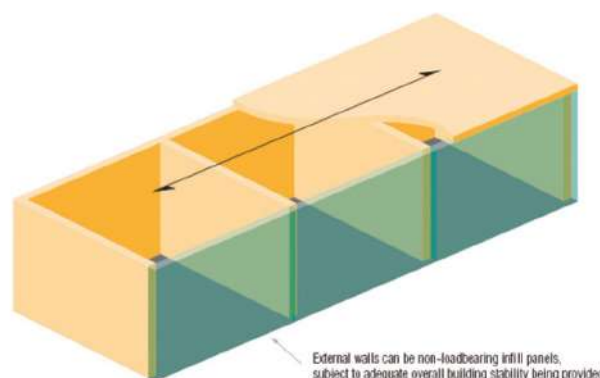


Figure 8

Hybrid options for combining highly insulated external walls with CLT loadbearing cross-walls

- CLT, like other structural wood-based products, lends itself well to prefabrication, resulting in very rapid construction, reliable on-site programming and ease of dismantling at the end of its service life
- CLT panels are inherently robust during transport and construction, resulting in fewer defects
- CLT structures require fewer onsite mechanical fixings where large prefabricated panel elements are adopted
- CLT structures require no wet trades and are assembled with lightweight power tools, although cranes are needed to lift the panels into place
- fixing cladding materials, services and fittings to CLT walls is easier to achieve with woodscrews than with, for example, concrete and masonry walls. Items can be fixed directly to the CLT panels
- the relatively low level of noise and disruption on a CLT site may offer advantages on infill sites where the impact on neighbours is an important consideration
- the added benefit of being made from a renewable resource makes all wood-based systems desirable from a sustainability point of view. CLT buildings have a very low carbon footprint because the wood material locks away the carbon absorbed during growth. This can result in carbon-negative construction.

Structural benefits of CLT

The structural benefits of CLT over conventional softwood wall framing and joisted floor constructions include its large axial and flexural loadbearing capacity when used as a wall or slab, its high inplane shear strength when used as a shear wall, its fire resistance characteristics for exposed applications and its superior acoustic properties.

Due to its arrangement as a solid wall panel, rather than a framed construction comprising discrete loadbearing post elements, CLT also distributes concentrated loads as line loads at foundation level, which will reduce the requirement for localised pad foundations.

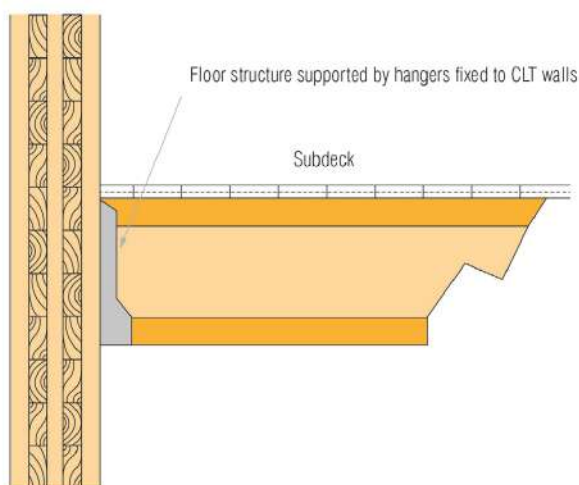


Figure 9
Wall-joint detail – balloon-frame method

The reinforcement effect provided by the cross-laminations in CLT also considerably increases the splitting resistance of CLT for certain types of dowel-type fasteners. Problematic end-grain connections are also avoided since there is always a layer of cross-grain to fix into.

Designers will generally find that working stresses are low due to the large cross-sections. The structural benefits of CLT construction when compared to traditional platform timberframe construction are that:

- CLT walls have high axial load capacity due to the bearing area of loadbearing elements
- CLT walls have high in-plane shear strength walls to resist horizontal loads
- CLT structures can have significant deadweight to resist overturning forces, resulting in less need for mechanical holding-down resistance to be provided
- CLT wall panels have inherent fire resistance due to their large section size compared to timber-frame walls comprising discrete studs. During a fire, a charred layer forms on the surface of the CLT, which insulates the remaining CLT section, thus reducing the entry of oxygen and heat from outside to enable the section to retain its loadbearing capacity, and significantly delays the further surface spread of flame. The fire resistance of CLT can be utilised for both the in-service and construction stage fire resistance requirements of the structure (the STA Design Guide to separating distances during construction provide more information on fire resistance of timber)
- CLT slabs require slimmer floors than joisted timber floor solutions because edge distances are less likely to be an issue, structural fixings are easier to provide and more likely to achieve their design capacity.

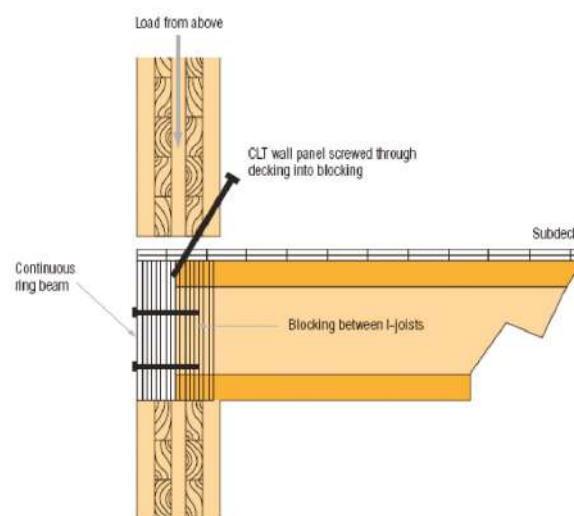


Figure 10
Wall-joint detail – platform-frame method

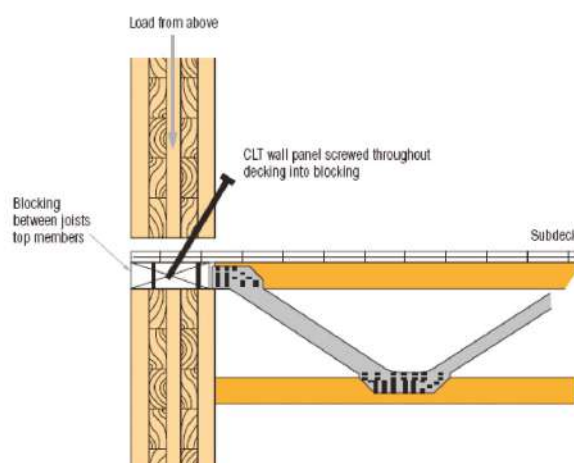


Figure 11
Wall-joint detail – platform-frame method using top-chord supported joists

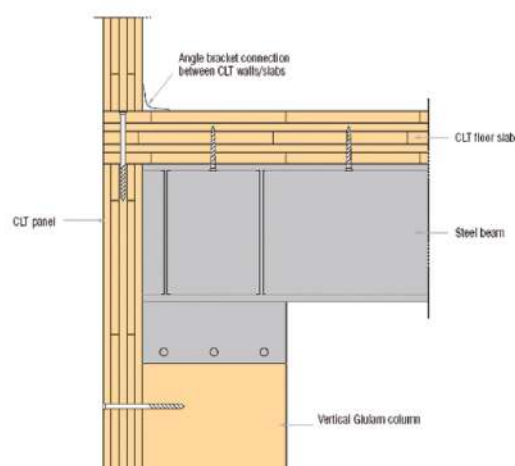


Figure 12
Detail of steel/glulam frame used to support CLT floor



Figure 13
Steel/glulam frame used to support CLT floor

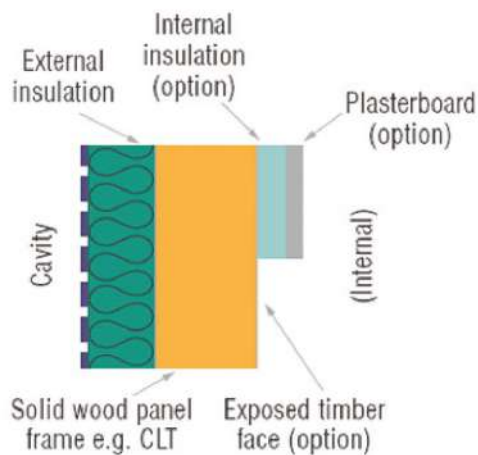


Figure 14
Typical build-up of CLT external wall construction

Thermal and acoustic performance

Good thermal insulation performance and good sound insulation properties are additional benefits of CLT. CLT can be used to contribute towards the overall 'U' value of the building envelope (Figure 14) and typically has a thermal conductivity of 0.13W/mk. Due to this relatively low thermal conductivity, CLT therefore performs well in cantilevered slab situations or other partially exposed situations where thermal bridging will occur.

For wall panels of at least 85mm thickness, airtightness can be achieved without additional sealing strips by gluing joints and reveals between CLT wall panels during erection.

RELEVANT CODES OF PRACTICE

BS EN 338:2009 Structural timber. Strength classes

pr EN 16351:2013 Timber structures. Cross laminated timber. Requirements

BS EN 1990:2002 Eurocode 0: Basis of structural design

NA to BS EN 1990:2002 UK National Annex to Eurocode 0: Basis of structural design

BS EN 1995-1-1:2004 Eurocode 5: Design of Timber Structures. General. Common rules and rules for buildings

BS EN 1995-1-1:2004 Eurocode 5: Design of Timber Structures. General. Common rules and rules for buildings

PD6693-1:2012 Recommendations for the design of timber structures to Eurocode 5: Design of timber structures. General. Common rules and rules for buildings (UK Non-Contradictory Complementary Information (NCCI) to Eurocode 5)

DEFINITIONS

CLT – cross-laminated timber (CLT) is an engineered wood product made up of at least three cross-bonded layers of timber

Platform-frame construction – a method of construction where the floor structure is supported on loadbearing walls and acts as a ‘platform’ for the next level of construction

Balloon-frame construction – an alternative method to platform frame construction where the floors are supported off the inside face of walls which are continuous for one or more storey heights

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