Viability of cross-laminated timber from UK resources

Cross-laminated timber is an innovative engineered timber product that can be used for almost all superstructure elements. It is typically produced from kiln-dried, fast-growing softwood timber. Currently there is no commercial production in the UK and hence the majority of cross-laminated timber used within the UK construction industry is manufactured in central mainland Europe and imported. This paper presents the key factors required for implementing a cross-laminated timber production and construction capability using available UK timber resource, thus offering a sustainable alternative to multi-storey steel and concrete construction. Further to this the structural performance of a cross-laminated timber product manufactured using a home-grown resource is compared with the current product imported from Europe. A series of standard design scenarios for multi-storey residential and education buildings in the UK have been considered and the structural design criteria reviewed for both products.

1. Introduction
Cross-laminated timber (CLT), first conceived in Western Europe during the late 1980s, is an innovative (plate-like) engineered timber product, optimised for carrying loads in and out of plane. CLT typically comprises kiln-dried, quick-growing softwood boards (lamellas), finger-jointed to length, stacked at right angles to one another and bonded by structural adhesive in either three, five or seven layers (an example of a five-layer CLT product is shown in Figure 1). Panel dimensions have not yet been standardised and vary depending upon the supplier; the overall panel thickness is governed by the lay-up of the lamellas (and the corresponding thickness of the laminations in each layer) and commonly ranges from 60 to 400 mm. The width and length are often limited by the processing equipment or by the transportation requirements. Panel sizes range from 1.25 to 3.5 m wide and 6.0 m to 20.0 m long; however, the production dimensions are usually governed by transportation restrictions (i.e. 2.95 m wide and 13.5 m long). The load-bearing behaviour of CLT elements is directly influenced by the mechanical properties of the lamellas and the orientation of the individual layers (Mestek et al., 2008).

CLT is regarded as a lightweight construction method (in comparison with steel and concrete) and given its inherent properties can be specified for application as wall, floor and roof elements, as well as for other load-bearing structural components. Added to this is the flexibility to create (window and door) openings within the panel without causing significant detriment to the overall performance. The low mass, improved stiffness (due to the redistribution effect of lamination) and the bearing capacity in plane and out of plane make CLT ideally suited for multi-storey residential and office buildings, healthcare facilities, schools, commercial and industrial units as well as single family dwellings (Brandner, 2014).

2. UK market
There are in excess of 30 CLT production sites worldwide, over 85% of which are located in Europe. In terms of volume, in 2012 total production (worldwide) was in the region of 432,000 m³, Austrian and German production is estimated at 307,000 m³ and 86,500 m³, respectively (Plackner, 2013). Other countries currently producing CLT include: Czech Republic, Canada, Finland, Italy, New Zealand, Norway, Spain, Sweden and...
Switzerland. Currently, there is no commercial CLT production within the UK and, as a result, it is imported directly from Europe or Scandinavia.

It should be noted that a number of the key CLT producers within the Austrian and German market (i.e. Binderholz GmbH, KLH Massivholz GmbH, Mayr-Melnhof Kaufmann, Metsa Wood and Stora Enso) also work, own or have alliances with formatting operations in the UK, which act as a direct route to market. Formatting companies, which offer various services such as consultation, design, supply and erection, are the main driver behind the UK CLT market. At present there are three main formatting companies in the UK. These are:

- Eurban (2003): purchasing CLT product from a wide range of suppliers
- KLH UK (2005): subsidiary of KLH Massivholz GmbH
- B&K Structures (2011): joint venture partnership formed in 2011 with Binderholz GmbH called the ‘XLAM Alliance’.

### 2.1 Current and forecast demand

One of the first mainstream CLT projects in the UK was the Caldicot school in south-east England, which was completed in early 2003. Since then the growth of CLT within the UK has shown significant increase on a year to year basis. Information provided by KLH UK showed that they alone imported 15 293 m³ of CLT in 2011, a 42-3% increase on their 2010 figures (TimberFirst, 2012). It is estimated that ~27 000 m³ of CLT was used in UK construction in 2011 and in excess of 32 000 m³ was used during 2012. Forecast data (as shown in Figure 2) would suggest that by 2016 the total consumption of CLT within the UK construction industry will be between 39 000 m³ and 78 000 m³.

CLT by its nature is a versatile product which is suitable for various applications, but is more suited to medium- to high-rise or large open-plan designs. The main competitors for CLT in the UK are concrete and steel and hence the target market should reflect this. Low-rise housing (four storeys or less) in the UK is consumed by timber frame and/or brick and block and it is yet to be confirmed whether CLT can compete in this sector. An overview of CLT project data from 2003 to 2011 can be used to produce a breakdown of the UK CLT market by sector, as shown in Figure 3.

During 2003 to 2011, education accounted for over 40% of the total market share. This is most likely attributed to the introduction of the government investment schemes such as ‘Building schools for the future’ and the ‘Priority school building programme’. The housing sector provides the second largest market share and accounts for 20%. As the product is becoming more established in the UK, existing sectors are continuing to grow and develop, and new sectors are beginning to emerge. Given that CLT is still relatively new to the UK construction industry, its growth and recognition will only help to promote the use and specification of CLT in current and developing sectors.
3. Potential of a UK CLT product: drivers and barriers

The commercial construction industry perceives CLT to be a more expensive product in comparison with traditional steel and concrete construction methods in the UK. However, when considering the various benefits of CLT, including reduced foundation costs, reduced construction time, safer construction environment as well as the overall life-cycle analysis (LCA) of a typical building, CLT has the ability to be a cost competitive low-carbon-dioxide alternative to traditional building materials. However, for CLT to be truly sustainable, environmentally, socially and economically, it should utilise local timber resource and serve the market in order to reduce transportation requirements, create security of supply and provide employment.

Currently CLT production facilities supplying the UK market are required to travel in excess of 700 miles (supplier and destination dependent). Various locations in Scotland could be considered for CLT production and the distance to London (= 400 miles from the central belt Scotland), the nexus of building in the UK, is significantly less than that from Europe. In addition, transportation costs from central Europe and Scandinavia are variable depending upon the supplier and the final destination; they are between 30% and 50% greater than would be expected from within the UK. Another driver for CLT production in the UK is unpredictability in the fluctuating exchange rate that accompanies imported products. This can result in large variations in total project cost that would be eliminated if UK manufacture was established.

The challenge, therefore, is to build upon the apparent economic and environmental credentials of CLT by further developing the market for it in the UK and to establish the technical feasibility and commercial viability of manufacture in this country from home-grown resource.

4. UK resource

In order to determine the technical capability of utilising UK timber resource for CLT manufacture the suitability of resource needs to be assessed. Sitka spruce (Picea sitchensis) accounts for approximately 50% of the UK softwood resource and over 60% within Scotland (FCS, 2011). As a consequence this species makes up the majority share of all structurally graded softwood timber within the UK sawmill industry. It is therefore anticipated that Sitka spruce would be the primary species considered for CLT production in the UK.

4.1 Resource compatibility

One of the key issues regarding the utilisation of home-grown timber resource within CLT production is the security of supply of material which is kiln dried to 12 ± 3% moisture content (MC) and structurally graded in accordance with EN 14081-1 (BSI, 2006b) and the anticipated draft CLT standard EN 16351 (BSI, 2011). Currently it is not common practice for UK sawmills to kiln dry constructional timber below 18–20% MC, hence UK timber requires further kiln drying before it can be utilised within CLT production. This further drying process presents a dimensional tolerance challenge: given that the dimensions of a piece of timber across the grain alter by 0-25% for every 1% MC lower than 20% (BSI, 2013), thus changing the dimensions of the piece of sawn timber and potentially increasing material rejection rates.

It is well known that, as timber dries, differential shrinkage occurs (tangential and radial) and as a consequence distortion takes place. The main aspects of timber distortion are twist, bow and spring – each of which can cause issues during CLT fabrication, construction and serviceability. Presented in Table 1 are the specific maximum distortion levels as referenced in EN 14081-1 (BSI, 2006b), which graders have to meet as part of the manual override when strength grading.

4.2 Experimental kiln-drying cycle

Implementation on a commercial scale requires kiln-drying schedules that ensure the resource is supplied at the correct MC and dimensional tolerance without incurring a rate of rejection that is not economically viable. There are concerns surrounding the dimensional stability of UK Sitka spruce when drying beyond 18% MC. Therefore, in order to assess the impact on grading rejects due to distortion when drying to the requirements for CLT production (i.e. 12 ± 3% MC) a research study, the European regional development funded (ERDF) wood product innovation gateway project (Crawford, 2013), was undertaken.

Preliminary analysis has been undertaken into the distortion of timber sizes (22 × 100 mm, 22 × 150 mm, 32 × 100 mm, 38 × 100 mm and 38 × 150 mm) that are expected to be used within CLT production. The distortion study was conducted through the first half of 2013 at the Forestry Commission’s northern research station (NRS). In total, 60 samples were tested, each supplied from the north of Scotland, and upon arrival the MC was above the fibre saturation point (i.e. green). At this stage the distortion in cross-section was measured using the laser timber distortion scanner device designed by Freiburg university (Freiburg’s improved timber scanner or FRITS frame). Data from the FRITS frame were recorded and compared with requirements given in BS EN 1310 (BSI, 1997). The material was then subjected to an 18-stage kiln-drying cycle in order to achieve a target MC of 12%. Upon completion of the kiln drying it was noted that the average MC was approximately 10% following this the material was then re-measured using the FRITS frame and the results were compared. The rationale was to record the dimensional stability of the material upon kiln drying to the required 12 ± 3% MC.
The first stage of the distortion analysis ascertained the dimensional reduction of the timber relative to reducing also the MC to the level required for CLT production. When considering the width after kiln drying an overall average shrinkage value of 9.93% was noted; the maximum results within each of the sample sets were relatively consistent (ranging from 4.53% for the 38 × 150 mm to 5.47% for the 22 × 100 mm). For the thickness, an overall average shrinkage value of 4.65% was noted. However, the maximum shrinkage values for thickness were found to vary depending on the sample set and ranged from 6.51% for the 38 × 100 mm to 17.23% for the 22 × 150 mm.

In order to be deemed suitable for CLT production, each lamella must meet the criteria given for twist, bow and spring. Therefore, in order to give a full representation of UK Sitka spruce when drying for CLT production each piece of timber must be considered individually. Figure 4 shows the visual override percentage classification (as per EN 14081-1 (BSI, 2006b)) before and after kiln drying for sideboard material (also known as saw-falling boards, which are cut from the outer core of the log), centrecut material (cut from the core of a log) and the overall population.

The samples were assessed against the visual override criteria given in Table 1 to determine an approximation of the percentage of rejection if the material is kiln dried ready for use in a commercial CLT application. The outcomes of this distortion study suggest that kiln drying UK Sitka spruce to the requirements for CLT production, namely 12 ± 3% target MC (an average value of 9.7% was achieved for this study) result in approximately 85% of the material being suitable for use. It is understood that the current reject rate at UK sawmills when drying to ≈ 20% MC is approximately 6%. Therefore if the rejection rate found from this study (15%) is considered, then the additional rejection rate to dry UK Sitka spruce to ≈ 12% MC is in the region of 9%. Although this material does not meet the requirements for CLT production, it still holds values for the sawmill and is likely to be re-processed and sold as a by-product.

It should be noted that, although as much effort as possible was taken in order to replicate the drying practices undertaken on a commercial basis, it was not feasible to apply a large degree of restraint or top loading to the stack of timber. It is anticipated that the inclusion of top loading or restraint would in turn lead to a decrease in the level of distortion. Further to this, the kiln-drying process was undertaken on samples with varying cross-sectional dimensions. This is not best practice and is generally avoided on a commercial scale. As a result, the samples with smaller cross-sectional dimensions dried more quickly and to a lower MC than the larger pieces and in turn this led to an increase in distortion. This study therefore gives some indication as to the expected results; however, further trials are required in order to accurately determine the large-scale commercial impacts. It is worthwhile noting that given the limitations of this study an improvement on the results achieved is highly possible.

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![Figure 4. EN 14081-1 (BSI, 2006b) percentage classification when considering twist, bow and spring: (a) green MC, (b) kiln-dried MC](image-url)
5. Structural viability of a UK-produced product

5.1 Certification and standardisation
Currently the mechanical properties of CLT products are certified in line with the common understanding assessment procedure (CUAP) by way of various European technical approvals (ETAs), which are specific to each manufacturer. However, a draft CLT standard (EN 16351: ‘Timber structures – Cross laminated – Requirements’ (BSI, 2011)) has been under development since 2011 and it is anticipated that this will help to regulate and standardise the product. Further to this, EN 16351 (BSI, 2011) stipulates criteria for the analytical calculation and performance testing of key mechanical and physical properties. Hence there are two methods which can be utilised in order to determine the properties of CLT (Unterwieser and Schickhofer, 2013)

- on the basis of mechanical properties of the single layers (lamellas) in combination with bearing models
- on the basis on performance testing of the CLT elements.

It should be noted that a date for implementation of this standard is not yet known; it is also believed that there is some dispute from certain CLT manufacturers regarding the exact details of standardisation.

A study by Bogensperger et al. (2012) presents an overview of the various methods which can be utilised in order to verify key mechanical properties of CLT product, and further to this their suitability when considering bending stresses is discussed. In accordance with EN 1995-1-1 (BSI, 2006a), the design of flexibly connected bending members (CLT) is based upon the ‘gamma method’ (Blaß and Görlache, 2003). However, there is a series of other methods which can be adopted for the analysis/calculation of CLT elements, namely the ‘shear analogy method’ (Kreuzinger, 2001; Mestek et al., 2008) and the ‘Timoshenko method’. It should be noted that the findings within this study are based on calculations that are in line with the ‘shear analogy method’.

5.2 Indicative structural testing
In 2012 the ERDF wood products innovation gateway project assessed the technical feasibility of producing CLT from the UK timber resource (Crawford, 2012; Crawford et al., 2013). One of the key objectives of this study was to determine the relative mechanical properties and performance of CLT products using home-grown timber species. A range of different permutations was considered, with three final panel types selected for structural testing (details of these panel dimensions are shown in Table 2).

The raw material for this project was sourced from the north of Scotland, the 40 × 95 mm and 40 × 140 mm material was of typical C16 structural grade sawn from the central core of the log. The 20 × 95 mm sideboard material was not structurally graded. However, previous studies (Brandner, 2014; Moore, 2011) have demonstrated that this saw-falling material typically yields greater modulus of elasticity (bending stiffness) characteristics in comparison with centrecut material. Further to this it should be noted that UK Sitka spruce is grade limited by its bending stiffness as opposed to its bending strength; this is contrary to the majority of softwood species grown in Scandinavia and central Europe, which are typically grade limited by strength characteristics.

The test results from the aforementioned CLT study (Crawford, 2012, Crawford et al., 2013) have been summarised and are presented in Table 3; it should be noted that where key mechanical properties were not determined by structural testing they have been derived from relationships presented in BS EN 338 (BSI, 2009, 2013) or guidance within technical literature (Unterwieser and Schickhofer, 2013).

It should also be noted that this pilot test programme was undertaken as a benchmark study and hence these results should be used for indicative purposes only. In order to validate fully the mechanical properties of a CLT product utilising UK timber resource, a rigorous body of work would need to be completed using product which is manufactured in controlled conditions and tested to strict European standards.

<table>
<thead>
<tr>
<th>Sample reference</th>
<th>Lamella dimensions: mm</th>
<th>Layer no.</th>
<th>Panel dimensions: mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth</td>
<td>Width</td>
<td>Edgewise</td>
</tr>
<tr>
<td>HG-SS1</td>
<td>40</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td>HG-SS2</td>
<td>20</td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>HG-SS3</td>
<td>40</td>
<td>140</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2. Panel type, test permutations
Properties for mechanical actions perpendicular to CLT slab

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic bending strength</td>
<td>$f_{m,k}$</td>
<td>16.14</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Characteristic shear strength</td>
<td>$f_{s,k}$</td>
<td>3.00</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Characteristic rolling shear strength</td>
<td>$f_{R,v,k}$</td>
<td>0.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Characteristic compression strength</td>
<td>$f_c$</td>
<td>2.85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Mean modulus of elasticity parallel to grain</td>
<td>$E_{0,\text{mean}}$</td>
<td>9477.10</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Mean modulus of elasticity perpendicular to grain</td>
<td>$E_{90,\text{mean}}$</td>
<td>315.90&lt;sup&gt;b&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Fifth percentile modulus of elasticity</td>
<td>$E_{0.05}$</td>
<td>6349.66&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Mean shear modulus</td>
<td>$G_{\text{mean}}$</td>
<td>592.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Rolling shear modulus</td>
<td>$G_{R,\text{mean}}$</td>
<td>59.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
</tbody>
</table>

Properties for mechanical actions in plane of CLT slab

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic bending strength</td>
<td>$f_{m,k}$</td>
<td>23.95</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Characteristic shear strength</td>
<td>$f_{s,k}$</td>
<td>5.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Characteristic compressive strength</td>
<td>$f_c$</td>
<td>23.95&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Mean shear modulus</td>
<td>$G_{\text{mean}}$</td>
<td>250.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>N/mm²</td>
</tr>
</tbody>
</table>

Other

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>$\rho_{\text{mean}}$</td>
<td>431.18</td>
<td>kg/m³</td>
</tr>
</tbody>
</table>

<sup>a</sup>In accordance with findings of Unterwieser and Schickhofer (2013).

<sup>b</sup>In accordance with BS EN 338 (BSI, 2009).

Table 3. Indicative UK CLT material properties

5.3 CLT effective bending stiffness
In the case of CLT the bending stiffness is based upon an effective cross section, which considers the mechanical properties and orientation of the lamellas within each layer, their distance from the neutral axis and the direction of the applied load.

As discussed previously a series of UK CLT samples were tested in order to determine key material properties. The CLT samples subject to testing were fabricated using a combination of machine-graded C16 and saw-falling (sideboard) material. Owing to the inclusion of higher stiffness sideboard material the performance (specifically the mean modulus of elasticity parallel to the grain) of these panels is greater than if only C16 machine-graded material was used. Currently sideboard material is used to produce fencing products and for pallets and packaging. Hence the optimisation of UK CLT by way of the specification of sideboard material not only leads to an increase in product performance but also adds value in the process.

It is specified within various European CLT manufacturers’ ETAs (DIBt, 2006, 2010, 2011a, 2011b; StoraEnso, 2013) that production may utilise a combination of both C24 and C16 grade material; however, it is noted that the total volume of C16 within each panel cannot exceed 10%. In practice this is not the case and generally 100% of European production is undertaken using C24 grade material as a consequence of available volume. In the UK, the vast majority of structural timber is centrecut material machine graded to C16 in order to optimise UK CLT by way of the specification of sideboard material not only leads to an increase in product performance but also adds value in the process.

Figure 5. CLT effective bending stiffness ($E_{\text{effective}}$) comparison (note: CLT effective bending stiffness is based on the material properties and product configurations of European CLT (DIBt, 2011b; StoraEnso, 2013))
enhance yield volume (reduce the percentage of rejection due to distortion upon drying and low stiffness), as a consequence sideboard material, because of increased levels of stiffness, was highlighted as a potential solution.

Figure 5 shows an overview of the effective bending stiffness performance for a typical European CLT product and a UK CLT product (based on test results). The analysis of the data shown in Figure 5 is based on the ‘shear analogy method’ and considers a range of standard panel configurations/lay-ups from a 60 mm three-layer system (60 L3s) to a 260 mm seven-layer (260 mm L7s-2) with double outer laminations running in the same direction and therefore both contributing fully to bending stiffness.

It is evident from the results shown in Figure 5 that, in terms of effective bending stiffness, a typical European CLT product offers an increase in performance over a UK CLT product. On average it was noted that a UK CLT product returns an effective bending stiffness which is 13-85% less than its European equivalent. This is not unexpected given the different grade of timber (lamellas) used within each of the two products.

5.4 UK structural design examples: home-grown as opposed to European CLT

Section 4.3 highlights that the material properties of a UK CLT product offer reduced performance compared with European CLT. However, it is worth considering that for the majority of design application this may not restrict its utilisation. In order to demonstrate the structural compatibility of UK CLT it is therefore compared directly with European CLT considering a range of standard design cases. The large majority of CLT used in the UK construction industry is used for multi-story residential or education sectors and hence the design scenarios chosen reflect this. Key design criteria including strength, shear, deflection, vibration and buckling are presented within each example in accordance with EN 1995-1-1 (BSI, 2006a).

The indicative properties highlighted in Table 3 have been used for the UK CLT product and the material properties as defined in the technical literature have been used for the European CLT product (DIBt, 2011b; StoraEnso, 2013). Three different scenarios have been considered for both floor and wall elements and the results are presented accordingly.

5.4.1 Floor design

In order to demonstrate the difference in terms of performance between UK CLT and European product the design has been optimised based on the panel configuration. To this extent the panel thickness and lay-up have been fixed (in each example); as a consequence the results demonstrate the maximum allowable span of a European as opposed to a UK CLT product.

The examples shown (simple span with pinned supports) consider the design of a floor element for two residential buildings and one educational building; the loadings of each of the examples are shown in Tables 4–6 and the design utilisation is shown in Figures 6–8. Relevant design factors for each of the examples are taken in accordance with EN 1995-1-1 (BSI, 2006a). It was found that the limiting criterion in each of the example floor designs is vibration (currently this check is based on the requirements given for residential property) and as a result the span has been altered in order to ensure a minimum value of 8 Hz has been achieved. By doing this, the two products are compared directly in terms of their limiting load span conditions. It should be noted that each design calculation is based on a 1 m wide strip of CLT.

Floor design example 1

... considers a 120 mm, three-layer (120 L3s) panel specification in a residential application with an applied dead load of 2-1 kN/m² and a live load of 1-5 kN/m²

Table 4. Floor example 1: load conditions

<table>
<thead>
<tr>
<th>Panel specification</th>
<th>120 L3s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load</td>
<td>2-1 kN/m²</td>
</tr>
<tr>
<td>Live load</td>
<td>1-5 kN/m²</td>
</tr>
<tr>
<td>Service class</td>
<td>1</td>
</tr>
<tr>
<td>Shortest term action duration</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 5. Floor example 2: load conditions

<table>
<thead>
<tr>
<th>Panel specification</th>
<th>160 L5s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load</td>
<td>1-0 kN/m²</td>
</tr>
<tr>
<td>Live load</td>
<td>1-5 kN/m²</td>
</tr>
<tr>
<td>Service class</td>
<td>1</td>
</tr>
<tr>
<td>Shortest term action duration</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 6. Floor example 3: load conditions

<table>
<thead>
<tr>
<th>Panel specification</th>
<th>260 L7s – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load</td>
<td>1-0 kN/m²</td>
</tr>
<tr>
<td>Live load</td>
<td>3-0 kN/m²</td>
</tr>
<tr>
<td>Service class</td>
<td>1</td>
</tr>
<tr>
<td>Shortest term action duration</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Educational building: Category C – Congregation areas

Construction Materials Viability of cross-laminated timber from UK resources Crawford, Hairstans, Smith and Papastavrou

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a maximum span (based on vibration being the limiting design criteria) for the UK CLT product is 3.59 m; however, the European CLT can achieve a maximum span of 3.67 m.

Floor design example 2

- considers a 160 mm five-layer (160 L5s) panel specification utilised within a residential building with an applied dead load of 1.0 kN/m² and a live load of 1.5 kN/m²
- vibration was again found to be the limiting design criterion; in this case the maximum span for the UK CLT product is 4.95 m and 5.03 m for the UK CLT and European CLT, respectively.

Floor design example 3

- a 260 mm seven-layer panel with double outer laminations (270 L7s-2) is specified; this scenario considers a CLT

Although UK CLT does not yield the same mechanical properties as a European product, the examples shown above demonstrate that UK CLT ‘maximum span’ is on average 73.34 mm less than European CLT. This is a relatively small reduction in span utilisation and the design impacts are likely to be negligible. Further to this it should be noted that when designing CLT structures the spans are often pre-determined and hence the panel specification is selected relative to the design criteria. In the case of the examples (based upon typical design scenarios for multi-storey residential and educational buildings) presented above the CLT panel thickness would be the same regardless of whether European CLT or UK CLT were used.

5.4.2 Wall design

Three wall designs are considered below: one residential project and two educational buildings. The specific load conditions for each example are shown in Tables 7–9 and the
design utilisation is shown in Figures 9–11. Relevant design factors for each of the examples are taken in accordance with EN 1995-1-1 (BSI, 2006a). It should be noted that a notional eccentricity was applied to the axial load and a notional lateral load was applied to the design. Buckling was found to be the limiting design criteria within each of the wall design examples; therefore in order to compare the performance of a UK relative to European CLT the buckling lengths (wall heights) were altered to ensure that the buckling criteria were satisfied.

Wall design example 1

- utilises a 60 mm three-layer (60 L3s) panel specification in a residential project; this scenario considers an applied dead load of 25 kN/m and a live load of 15 kN/m
- in order to satisfy the design criteria for buckling the UK CLT wall height was set at 2.88 m; however, it was possible to increase the wall height of the European CLT to 3.30 m.

Wall design example 2

- considers an 80 mm three-layer (80 L3s) CLT wall element within an educational building with an applied dead load of 1.0 kN/m and a live load of 3.0 kN/m
- the maximum wall height was 2.67 m and 3.13 m for the UK CLT and the European CLT, respectively; in each case the design was governed by the buckling criteria.

Wall design example 3

- considers a 140 mm five-layer (140 L5s) panel for application within an educational project; the loading conditions include an applied dead load of 140 kN/m and a live load of 170 kN/m
- the maximum wall height (based on buckling being the limiting design criterion) for the UK CLT product is 3.28 m; however, the European CLT can achieve a maximum height of 3.89 m.

It was found that in each case the UK CLT product would have to be increased by at least one panel size in order to satisfy the design requirements. For example, using the loading conditions for wall design example 2 but specifying a fixed span of 3.0 m can be satisfied by specifying an 80 mm three-layer (80 L3s) panel. However, for the UK CLT product to be utilised in this scenario the panel configuration would need to be changed to 90 mm, three-layer (90 L3s). A similar impact was noted for all of the example wall calculations whereby the overall cross-sectional dimensions of the UK CLT product needed to be increased by at least one product size.

5.5 Design impact

As highlighted in Section 5.4.1 a UK CLT could be specified in each of the floor design examples as a direct replacement for European CLT. However, it is noted within Section 5.4.2 that when considering the various wall design examples a UK CLT product cannot be specified as a direct replacement for CLT design criteria: 60 L3s

![Figure 9. Wall example 1: design utilisation](image)

Educational building: Category C – Congregation areas

<table>
<thead>
<tr>
<th>Panel specification</th>
<th>80 L3s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load</td>
<td>1 kN/m</td>
</tr>
<tr>
<td>Live load</td>
<td>3 kN/m</td>
</tr>
<tr>
<td>Service class</td>
<td>1</td>
</tr>
<tr>
<td>Shortest term action duration</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 8. Wall example 2: load conditions

![Figure 10. Wall example 2: design utilisation](image)

Educational building: Category C – Congregation areas

<table>
<thead>
<tr>
<th>Panel specification</th>
<th>140 L5s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load</td>
<td>140 kN/m</td>
</tr>
<tr>
<td>Live load</td>
<td>170 kN/m</td>
</tr>
<tr>
<td>Service class</td>
<td>1</td>
</tr>
<tr>
<td>Shortest term action duration</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Table 9. Wall example 3: load conditions
European CLT. In order for the design requirements to be satisfied the panel thickness needed to be increased by at least 10 mm. However, this does not have a significant impact on the building footprint and can be put into perspective when considering a standard school classroom at 7.5 m × 7.5 m, when a 10 mm increase in wall thickness would result in a 0.27% reduction in floor area. Of more importance would be the increased timber volume required during the production and specification of UK CLT wall panels and the associated cost implications.

6. Conclusion

It is evident that there is a well-defined market for CLT in the UK and forecast data suggest that there is great potential for future growth. Estimated figures (as highlighted in Section 2.1) show that the UK CLT consumption is likely to increase from its current annual figure of ≈ 32 000 m³ to between 39 000 m³ and 78 000 m³ by 2016. Given that 100% of the CLT product used within the market is imported, this would therefore suggest that there is an opportunity for UK CLT production to be sustained. Initial research has proven the feasibility of utilising home-grown Sitka spruce for CLT production; however, the commercial viability is yet to be confirmed.

Currently the UK sawmill industry does not kiln dry material beyond 18% MC; this is notably greater than the 12 ± 3% specification given for CLT production. Therefore, in order for raw material to be made suitable for CLT production there is additional kiln drying required. As a result of the additional drying, it is likely that the volume of reject material within the structural grading process will increase. Dimensional stability is therefore a key factor that will impact upon the commercial viability of CLT production in the UK. Indicative small-scale research undertaken in collaboration with Forestry Commission Scotland (FCS) has shown that it is possible to kiln dry Sitka spruce to the levels required for CLT production without significantly increasing the percentage of reject material. However, there are a number of factors that need to be further assessed in order to accurately determine the commercial implications when kiln drying Sitka spruce to this level of MC.

Indicative UK CLT material properties have been utilised within a number of design examples for residential and educational projects in the UK. Calculations were carried out using design software developed by Smith and Wallwork Engineers, the results of which are presented based upon key design criteria such as strength, shear, deflection, vibration and buckling. Where floor elements are concerned, the limiting design criterion is often vibration or deflection in serviceability. Buckling out of plane was found to be the primary factor when considering the design of CLT wall elements.

In each example the design was optimised for a typical European CLT product and the design utilisation was compared directly with a UK CLT product of similar dimensions. Interestingly, it was noted that for floor design the UK CLT product was capable of spanning a distance (in the worst-case scenario) that is only 80 mm less than the European CLT product when subject to the same load conditions. On average the UK CLT product could span approximately 98% of the equivalent European product. However, when considering the wall design examples it was noted that a UK CLT product was only capable of satisfying the design criteria for buckling when at approximately 85-6% of the capacity of its European counterpart. In some instances this would lead to an increase in wall thickness as the real-life design examples in this paper have shown.

REFERENCES


DIBt (2011a) European Technical Approval ETA-06/0138. KLH-Massivholzplatten. DIBt, Berlin, Germany.

DIBt (2011b) European Technical Approval ETA-08/0271. CLT – cross laminated timber. Stora Enso Wood Products Oy Ltd. DIBt, Berlin, Germany.


Unterwieser H and Schickhofer G (2013) Characteristic values and test configurations of CLT with focus on selected properties. In Focus Solid Timber Solutions – Proceedings of European Conference on Cross-Laminated Timber (CLT), Graz, Austria (Harris R, Ringhofer A and Schickhofer G (eds)). University of Bath, Bath, UK, COST action FP 1004, pp 53–73.

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