A COMPARATIVE LIFE CYCLE ASSESSMENT APPROACH OF TWO INNOVATIVE LONG SPAN TIMBER FLOORS WITH ITS REINFORCED CONCRETE EQUIVALENT IN AN AUSTRALIAN CONTEXT

Bella Basaglia 1,*, Kirsten Lewis 1, Rijun Shrestha1, Keith Crews1
1 University of Technology Sydney (UTS), Faculty of Engineering and Information Technology (FEIT)
Building 11, 81 Broadway, Ultimo, NSW, Australia.*Email:bella.m.basaglia@student.uts.edu.au

ABSTRACT
The building sector contributes 24% of the total greenhouse gas emissions in Australia. This is expected to rise by 110% by 2050. Consequently, there has been an increased demand for more sustainable building materials which can play a significant role in reducing carbon emissions. Engineered timber wall and floor panels are being seen as a viable alternative for multi-storey buildings for both strength and environmental purposes and are gaining popularity in Europe, North America and New Zealand. A number of previous Life Cycle Assessments (LCA) comparing timber and concrete mid-rise buildings have highlighted the environmental benefits of using timber, particularly during material production and on-site construction stages. Furthermore, the choice of end-of-life scenario had a significant effect on the LCA outcome. The objective of this paper is to compare the environmental impacts associated with alternative designs for a long span floor in a multi-storey building in Australia. The comparison, using an LCA approach, is based on a recently built long span Timber Concrete Composite (TCC) floor in a University building in Sydney. Three design options are considered: the original design of TCC, a Cross Laminated Timber (CLT) panel, and a traditional in-situ reinforced concrete (RC) slab. The CLT and RC designs were conceived with reference to the floor plans and structural loads obtained from issued-for-construction drawings. With this evaluation, recommendations for increasing the competitiveness of CLT and TCC within the Australian market are made.

KEYWORDS
Sustainable materials, Cross laminated timber, Timber concrete composite, Life-cycle assessment.

INTRODUCTION
The Australian population is expected to jump by 60% from 23.3 million to 37.6 million by 2050 (Joye 2013). Increased foreign investment and historically low interest rates will push residential construction spending by 20% to just under $90 billion by 2017-18 (ACIF 2014). Particularly for multi-level apartment developments, 14.5% growth is expected in 2015 followed by a 4.1% increase for 2016. Commercial construction is also growing by 1.3% in 2015 and 1.5% in 2016 (Willox & Le Compte 2015). All these figures indicate that construction of new infrastructure and buildings is on the rise, and so will our greenhouse gas emissions.

The building sector contributes nearly a quarter of the nation’s greenhouse gas emissions. This means that engineers, architects, and developers have the opportunity to decrease this figure by designing and constructing more sustainable buildings. Past construction has heavily involved concrete and steel, both of which are highly energy intensive when combining the materials production, transport and construction stages. However, timber has the potential to avoid majority of fossil fuel consumption and CO₂ release related to these conventional materials. Naturally through the photosynthesis process, trees produce oxygen by absorbing carbon dioxide which is then stored inside the wood. It is only when the wood decomposes in a landfill or during burning that the carbon is released back into the atmosphere. Hence, if wood products are used in construction, the carbon stored can be taken out of the carbon cycle for at least the duration of the life of the structure.

In this context, there has been a number of life cycle analysis (LCA) case studies undertaken comparing the embodied energy and embodied carbon of engineered wood products to concrete and/or steel construction (Buchanan & Honey 1994; Dolan & Harte 2014; John et al. 2011; Nassen et al. 2012; Page 2006). A particular study was undertaken by Oliver et al. (2012) comparing wood and a substitute product (steel or concrete) wall.
and floor assemblies. The common theme throughout these studies is that the timber alternative has less environmental impacts than their concrete and steel counterparts and a greater use of wood in construction would lead to decreased CO$_2$ emissions. Furthermore, several case studies showed that due to the volume, floors have the highest or second highest potential for savings in embodied energy and carbon (Aye et al. 2012; Buchanan & Honey 1994; Dolan & Harte 2014). However, it is important to note that many of these aforementioned case studies did not consider the use of laminated timber (glulam and cross laminated timber).

This paper will compare the environmental impacts associated with three designs for a long span floor within a mid-rise building. The research will be based on a case study timber concrete composite (TCC) floor constructed in 2014 within the Oval Room of the Dr Chau Chak Wing Building of the University of Technology, Sydney (UTS). Alternative designs will include an innovative cross laminated timber (CLT) option and a more conventional reinforced concrete (RC) option. An LCA approach will be undertaken where various stages from cradle-to-grave will be discussed and compared. This will then be used to determine whether the inclusion of wood products within floor design provides improved environmental performance over conventional construction methods within Australia.

**BACKGROUND**

**Engineered Wood Products**

Structural timber comes in a number of different forms depending on the use, durability and strength required. Structurally graded sawn timber is the most commonly used material for domestic construction and is manufactured from both softwood and hardwood species. Hardwoods being denser than softwoods are therefore usually stronger and used for more high strength applications such as bearers and joists. Softwoods are used in general framing including studs, rafters and noggins. Sawn timber is cut from logs in standard industry sizes and is seasoned through a kiln drying process which ensures minimal dimensional changes. The timber is then visually or machine graded to determine the strength class.

Timber density can be increased even further through the manufacturing of engineered wood products (EWPs). EWPs are manufactures from thin veneers or small timber pieces which are then bonded together using a structural adhesive. This process allows EWPs to have more consistent structural properties. Two common EWPs used for structural applications include glulam and CLT.

**Glulam**

Glued-laminated timber is an engineered wood product produced by bonding a number of graded, seasoned, mostly finger-jointed sawn timber laminated with a structural adhesive (Figure 1(a)). The laminates are bonded with the grains running parallel and are therefore used for one-way spanning products such as beams. As the product is made up of a number of laminates, any strength reducing characteristics such as knots are removed. This results in a product which has a higher strength grade than the individual laminate pieces. Glulam is manufactured in Australia and has its own grade called GL in AS 1720.1 (2010).

**Cross laminated timber**

Cross laminated timber (CLT) is a prefabricated EWP generally manufactured from seasoned softwood. It is a panel element that is made up of usually three or five layers of orthogonally stacked timber boards which are bonded together with structural adhesives, as shown in Figure 1(b). The process of cross-lamination allows for improved dimensional stability and prefabrication of large floor and wall slabs. Due to the orthogonal nature, CLT has relatively high strength and stiffness characteristics in both directions, allowing it to act in two-ways similar to a reinforced concrete slab.

CLT was first developed in Austria and Germany in the 1990’s and has been gaining increasing popularity throughout Europe and North America. There are several established manufactures of CLT in Europe, a few in North America and one in New Zealand. This means that if CLT is designed for an Australian structure, the panels will have to be imported from an overseas supplier. Despite this, at the time of writing, Australia is home to the tallest CLT building in the world with Forté in Melbourne.

There is currently no Australian standard which covers CLT. For CLT design in Europe, the ‘gamma method’ as outlined in Annex B Eurocode 5 Part 1 is used. This method accounts for the semi rigid link between layers by introducing a stiffness reduction factor. In Canada, the CLT Handbook (FPInnovations 2010) has been produced which provides comprehensive details of manufacturing, design and serviceability.
Timber Innovations: Timber Concrete Composite Floor Systems

A timber concrete composite (TCC) floor system consists of a timber beam, typically manufactured from glulam or laminated veneer lumber (LVL), connected to a reinforced concrete layer via a number of shear connectors, as shown in Figure 1(c). This means that there is only a small amount of slip at the interface as opposed to no slip if it were to act in a full composite manner. The strength of both materials is effectively utilized with the timber joist acting in tension and the concrete resisting the compressive stresses.

Availability of Wood Versus Consumption: Is It Sustainable?

Globally, the demand for wood has doubled in the last 40 years and is currently 3.4 billion m³/year (UN-FAO 2012). This is expected to increase by just over 50% to 5.2 billion m³/year by 2050 (Lam 2001). The concern has been raised as to whether forest harvesting is, in fact, sustainable. In particular, with laminated timber products such as LVL, glulam and CLT, larger volumes of timber will need to be processed. Do we have enough wood available to meet the potential global consumption? Can we manage harvesting sustainably? Oliver et al. (2014) collated a number of sources to obtain the average forest growth across all ecoregions and estimated that the potential global growth of wood is 17 billion m³/year. This indicates that the world is harvesting approximately 20% of the potential growth if managed with moderate intensity (Oliver et al. 2014). Furthermore, it was found that by substituting wooden I-beams and plywood for a steel beam and concrete slab floor structure, an additional 27% of wood would need to be harvested. This means that forests and harvest rates are sustainable for efficient wood products.

On a more national level, in 2012-13, Australia harvested 22.8 million m³ of wood from the 123 million hectares of native forests (FIAC 2015). However, although this seems sustainable, it has been projected that over the next forty years, softwood availability will increase only marginally at a rate of 0.5% per year (Ferguson et al. 2002). This is in contrast to a consistent growth rate of approximately 5% per year from 1959 to 2003 (Davidson & Hanna 2004). Softwood is the major source of production of EWPs within Australia and therefore could potentially highlight an area of concern for the EWP industry. This could result in higher consumption of imported softwood products to meet increased demand.

Life Cycle Assessment Approach

An LCA is an assessment tool that is used to outline the environmental impacts over a product’s life cycle. There are five main stages that are evaluated while undertaking an LCA on a building or a part of a building: (1) raw material acquisition, (2) material production, (3) construction phase, (4) operation and maintenance and (5) demolition/end of life disposal. In a number of case studies comparing the LCA of a timber framed building to an alternative concrete or steel building, the operation and maintenance phase was found to be very similar for all construction materials (Aye et al. 2012; Guggemos & Horvath 2005; John et al. 2011). These sources, combined with the fact that only the floor structure will be assessed, heating and cooling requirements and maintenance has been assumed to be constant for all floor design options in this paper.

To conduct a complete LCA, an inventory of relevant inputs and outputs of a system needs to be compiled. This information is usually obtained from databases which store inventories of the environmental burdens related to the manufacturing of a product. However, to date, there have only been a few LCAs conducted on engineered
wood products throughout the world. In the United States, the Consortium for Research on Renewable Industrial Materials (CORRIM) was the first to produce a database for forest and wood products. In a bid to address this gap in Australia, Forest and Wood Products Australia (FWPA) has collaborated with CORRIM to produce a Life Cycle Inventory of Australian forest and wood products (Tucker et al. 2009). An LCA of the floor system is not within the scope of this paper, however, the environmental impacts will be quantified based on two common measures: embodied energy (EE) and global warming potential (GWP).

EE is defined as the cumulative amount of primary energy consumed and stored throughout the raw materials acquisition, transport to factory and material production stages. Essentially, this is a cradle-to-gate measurement. This is usually measured in megajoules/kilogram (MJ/kg). GWP is the embodied carbon measured in kgCO₂/kg of material and is a measure of the contribution of a product to potential warming of the atmosphere. It is important to note that energy consumption figures alone do not necessarily provide a good indication of the environmental effects associated with this consumption. However, the calculation is important in highlighting areas where significant reductions in consumption can be achieved (Aye et al. 2012).

**METHODOLOGY AND KEY ASSUMPTIONS**

This paper evaluates and compares the embodied energy and embodied carbon using an LCA approach of a long span TCC floor used in a multi-storey environment with different material alternatives. A case study floor is identified with structural drawings and loading plans used to design an approximate equivalent floor that could potentially be used in the place of the original design. Non-structural items such as services and ceiling boards that were installed post construction were not considered in this analysis. The surrounding framing system and the main concrete building that the Oval Room sits within was also not considered. The assessment was based purely on the floor system.

After the alternative floors were designed, a bill of materials was calculated for all three options. This includes the mass of timber, concrete and reinforcement required for each option. These values have then been used to evaluate the environmental impact in terms of EE and GWP of each design scenario.

**Floor Design Assumptions**

To allow a simple assessment, the floor envelope consists of a rectangular portion of the original Oval Room floor outline, as shown in the highlighted area in Figure 2. The envelope has a total floor area of approx. 45m² with dimensions of approx. 10m long by 4.5m wide. This section of the floor has been selected as it includes the longest spanning area of the floor.

![Figure 2 Plan of floor area to be assessed in this study (ARUP 2014)](image)

The design of the alternative floors is based on the following general assumptions:

- simply supported floor system
- strength and serviceability limit states have been considered
- superimposed dead load of 1.5kPa and live load of 3kPa as per original design of the case study floor
- dynamics, acoustics and fire design have not been considered

Specific assumptions have also been made for each material used for the alternative options. The concrete will be of 40MPa strength grade with a 20 - 30% fly ash cement replacement mix. This is considered as a typical concrete mix for multi-storey buildings within Australia (Cement Australia 2015). The fly ash mix can be left
variable as it has been found that a simple change by adding 5% more fly ash has minimal effect on embodied energy of the concrete (Robertson, Lam & Cole 2012). The CLT panels are assumed to be supplied from KLH in Austria. KLH is the leading CLT manufacturer for the UK market (KLH UK 2015). KLH panels were also used for the Forté building in Melbourne. The ‘gamma method’ outlined in Eurocode 5 has been used.

System Boundaries

As mentioned earlier, conducting a whole LCA using Life Cycle Inventory data was not included in the scope of this assessment. EE and GWP rates have been researched from a variety of sources and the values from the most comparable reference have been used as a quantitative assessment of the floor structure from cradle-to-gate. Transport to the construction site is included in the construction stage. The operation and maintenance stage of the LCA has not been considered as it is assumed the energy required when the floor is in use will be similar for all materials. A qualitative investigation and review was then undertaken on the environmental implications of the on-site construction stage, transportation during construction and end-of-life choices.

THE CASE STUDY

Case Study Floor: Dr Chau Chak Wing Oval Room

The case study floor is located within the Oval Room of the Dr Chau Chak Wing Building completed in 2014. The building is part of the UTS and is located in Haymarket within Sydney’s CBD. The Oval Room structure, engineered by ARUP, is 10.4 m high and consists of two ‘log cabin’ style classroom levels which are intricately framed by 142 glulam blocks stacked on top of each other.

The case study is based on the TCC floor on the first level of the Oval Room structure. The design consists of 450mm wide by 580mm deep glulam beams spaced at 1500mm connected to a 120mm reinforced concrete topping via notched birds-mouth shear connections. The floor has a clear span of 10 metres. The glulam was manufactured and imported from New Zealand. A plan and cross section of the floor is shown in Figure 2 and Figure 3, respectively. Reinforcement in the concrete was purely for shrinkage and crack control and consisted of N10 bars at 300mm spacing on the bottom running both ways and a SL102 mesh on top.

The CLT Panel Option

A 320mm thick CLT panel would be required for a 10m span which was governed by deflection. The panel would consist of five layers with 80mm lamella thickness for the top, middle and bottom layers and 40mm thickness for the second and fourth layers. As the panel would be spanning in one direction, the direction of the fibre of the odd numbered layers would be running parallel to the span.

The floor would be separated into three panels with equal dimensions of 1.5m wide x 10m long. When sizing CLT panels, both the supplier’s standard dimensions as well as the shipping container dimensions need to be considered. KLH produces panels with a maximum length of 16.5m, maximum width of 2.95m and thickness of 0.5m. In regards to shipping, a High Cube standard container has internal dimensions of 12m in length, 2.65m in height and 2.33m in width. Therefore, the nominated panels would fit within one container when stacked.

The Reinforced Concrete Floor Option

The reinforced concrete (RC) floor alternative was originally designed to be a 440mm thick one-way spanning slab. Due to the 10 metre span, the design was governed by deflection limits and a large amount of reinforcement had to be used. This ensured the reinforcement to concrete ratio contributed enough to the effective second moment of area calculation in order to reduce deflections. This thickness would not be economical in practice.
Typically, for spans over 7m, prestressed concrete would be used as the net savings in material cost can range between 10 – 20% when compared to a reinforced concrete alternative (Roy 2008).

It is crucial that this study remains unbiased towards any particular material and represents design practice as best as possible while staying within the scope of the paper. Therefore, several alternative measures have been undertaken which increased reinforcement ratio in order to reduce the concrete depth. This has resulted in a 335mm thick slab with N32 bars at 100mm spacing for use in this study. This design satisfies AS 3600-2009.

RESULTS AND DISCUSSION

Material Quantities

A quantities take-off for the materials contained in the TCC, CLT and RC floor designs have been calculated in order to undertake a comparison of the EE and GWP. Approximate material quantities can be seen in Table 1. As the shear connections in the TCC design only contribute to less than 1% of the total material quantities, they have been considered negligible for the purposes of this study.

<table>
<thead>
<tr>
<th>Material group</th>
<th>Unit of measurement</th>
<th>TCC design</th>
<th>RC design</th>
<th>CLT design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>kg</td>
<td>13762</td>
<td>38417</td>
<td>-</td>
</tr>
<tr>
<td>(Reinforcement)</td>
<td>kg</td>
<td>190</td>
<td>2912</td>
<td>-</td>
</tr>
<tr>
<td>Timber (CLT)</td>
<td>kg</td>
<td>-</td>
<td>-</td>
<td>7339</td>
</tr>
<tr>
<td>Timber (Glulam)</td>
<td>kg</td>
<td>3759</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Embodied Energy and Global Warming Potential

In order to quantify the EE and GWP of each floor structure, a number of references were sourced that had already conducted an LCA on different construction materials. For the purposes of this study, values from Alcorn (2003) have been selected to be used for multiplication with bill of quantities data. These values have been presented in Table 2. Although these values are for New Zealand building materials, the properties of the material most closely relate to the materials used within this case study. There are also a number of other studies that provide embodied energy and carbon data relevant to Australian context (Buchanan & Honey 1994; Fernandez Perez 2008; John et al. 2009; Treloar & Crawford 2010).

<table>
<thead>
<tr>
<th>Embodied energy (MJ/kg)</th>
<th>GWP (kgCO₂/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glulam</td>
<td>Concrete</td>
</tr>
<tr>
<td>13.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>

There have been very few LCA’s conducted on CLT building case studies, particularly due to the fact that it is a recent EWP. However with the recent completion of the Forté building in Melbourne, FWPA have published a LCA comparing the Forté building to a reinforced concrete equivalent (Durlinger, Crossin & Wong 2013). It concluded that the GWP of the building materials for the Forté building were 30% lower than the reference building, however, this did not include transportation to the building site. KLH have produced an environmental product declaration in accordance with ISO 14025:2006 (ISO 2006). Since embodied energy accounts for a cradle-to-gate system boundary, these figures will be used for evaluating the embodied energy of the CLT floor design option. The values have been presented in Table 3.

<table>
<thead>
<tr>
<th>GWP (kgCO₂/kg)</th>
<th>Non-renewable primary energy (MJ/kg)</th>
<th>Renewable primary energy (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLT – 320mm thick panel</td>
<td>-1.75</td>
<td>3.11</td>
</tr>
</tbody>
</table>

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Figure 4(a) indicates that the concrete floor option is comparable to the TCC option in terms of embodied energy with only a 10% difference. The inclusion of concrete in the TCC floor system contributes approximately 20% of the total embodied energy. The CLT option is nearly 2.5 times more energy intensive than both the concrete and timber options. However, it is important to remember that 88% of this energy is derived from renewable sources. As expected, Figure 4(b) reveals that the concrete option has the largest GWP. The carbon stored in the glulam from the TCC option outweighs the carbon emitted from the concrete portion of the system and therefore there is still 1.6 tonnes of carbon that can be credited. The CLT option has the least amount of GWP with the floor system reclaiming nearly 8 times the carbon contained within the TCC system. This accounts to over 12 tonnes of recovered carbon.

**On-site Construction and Transport**

The construction stage of an LCA consists of the actual construction and erection of the building or structural system being investigated. Cole (1999) categorised the construction stage into five main areas: (1) transportation of crew to site, (2) transportation of materials to site, (3) transportation of plant and equipment to site, (4) use of on-site equipment and (5) any supporting processes such as formwork. Generally, it has been found that the transportation of workers to and from site is the largest contributor to construction energy and greenhouse gas emissions (Cole 1999).

Construction methods for the three different scenarios would be as follows:

- **Wet concrete:** typically delivered to the building site from a central batching plant using a diesel powered mixer truck in order to keep the concrete fluid during transport. The transport distance is governed by the setting time of the mixed concrete.
- **Glulam:** flat deck trucks would generally be used to transport the glulam from the supplier to site. In the case that the glulam is imported (this case study), the elements would be shipped from the supplier.
- **CLT:** panels would be imported from Europe and involves shipping as well as trucking from port to site.

A study undertaken by Cole (1999) concluded that cast-in-place concrete assemblies have the highest construction energy and greenhouse gas emissions per square metre ranging from 90 – 120 MJ/m² and 13 – 20kg/m², respectively. Transportation of workers was the largest contributor at approximately 40 – 50% of the total. This is most likely due to the additional trades introduced with wet concrete including formwork and propping. In fact, Guggemos (2005) noted that minimising the amount of temporary materials used, including reusing temporary materials where possible, is one of the main areas that could assist in reducing impacts. Cole (1999) also obtained results for the construction of glulam frames (for spans of 6.1 – 9.2m) and found that energy use and carbon emissions were 17 – 20MJ/m² and 2.3 – 2.5 kg CO₂ eq./m², respectively. These values reveal that concrete construction is significantly more energy intensive than timber.

Junnila (2006) undertook an LCA case study on a mid-rise commercial building in Europe and the US, both having RC slabs. In contrast to Cole (1999), it was found that equipment use accounts for the majority of energy use and emissions during the construction stage. Findings from Guggemos and Horvath (2006) also show that emissions during the construction phase were mainly as a result of the frequent use of heavy diesel equipment.
It is also important to note that construction times associated with timber buildings, in particular using CLT panels or prefabricated sections, are significantly less when compared to in-situ concrete. For example, a study undertaken on the Stadthaus, a 9 storey apartment building in London with 8 storeys of CLT floors, had found that there was a 22 week saving in program time by choosing CLT over concrete (Toosi 2011).

Despite these results, it has been concluded from a number of researchers that the construction phase has relatively small impacts to the overall life cycle. Gong et al (2012) case study on multi-storey residential buildings in Beijing revealed that contribution from construction is less than 2% of the total life cycle. Furthermore, Guggemos and Horvath’s (2005) two case studies on commercial buildings in the US have found that contribution from construction is 0.4 – 11%.

Based on the above literature review, it can be estimated that the RC floor option would be the most energy intensive due to the equipment use. However, the CLT floor option may be comparable or potentially more energy intensive when considering the shipping of the panels from Austria where an LCA undertaken on the Forté building estimated that GWP for transport of CLT was 8.2 times that of a concrete option (Durlinger, Crossin & Wong 2013). The energy consumption and GWP of the TCC floor is estimated to be between the concrete and CLT options due to the combination of both wet trades and timber.

**Demolition and End of Life Scenarios**

There are two definitions of the end of life phase of an LCA. One definition involves all activities related to the demolition of the building, waste of materials, transport of materials off-site and the consequent recycle, reuse or landfilling of materials. Another definition supported by Guggemos and Horvath (2005) and Aye et al. (2012) argues that the potential future use or disuse of demolished materials is uncertain and cannot be guaranteed when the process occurs in over 50 years’ time. However, their argument states that if the materials are recycled, this should be credited for within the materials production stage of the LCA of the new building in which these materials are used.

There has been unanimity among researchers that the demolition portion of the end of life phase is insignificant in relation to the overall life cycle energy use and carbon emission of a building (Crowther 1999; Gustavsson, Joelsson & Sathre 2010). Many studies (Aye et al. 2012; Cole & Kernan 1996; Junnila, Horvath & Guggemos 2006) have even disregarded this section altogether within their LCA.

Currently in New South Wales, approximately 95% of concrete is recycled (Hyder Consulting 2011). This rate is similar in other capital cities. Timber, however, has a limited reuse capacity and is mostly taken to landfill. When timber decomposes, carbon is released; although, the rate of decomposition is slow. Research by Ximenes et al. (2006) have revealed that more than 95% of the carbon in wood remains stored even after 30 years in landfill. Regardless of this, eventually the stored carbon and methane which has 25 times more warming potential of CO₂ will be emitted and has the potential to contribute up to 85 per cent of Australia’s carbon budget in 2050, depending on the reduction target (Angel & Castle 2007).

This highlights the potential and benefit of incinerating timber waste with energy recovery. A study undertaken by Robertson et al. (2012) has revealed that timber design has over five times more feedstock energy than a concrete design scenario. Feedstock energy is the easily accessible potential energy contained in renewable fuel sources that can be used to form another fuel or energy product. The high amount of feedstock energy in both glulam and CLT indicates that the materials can be readily combusted and utilised as energy sources after their useful life (Robertson, Lam & Cole 2012). The use of this recovered bio-energy instead of fossil fuels has the potential to significantly reduce the net emission of CO₂ (Gustavsson, Joelsson & Sathre 2010). If the end result of the material in the end of life phase is included, the recovered energy can be subtracted from the total energy use of the building.

In a study undertaken by John et al. (2009) both landfill and reutilisation scenarios were investigated for four different building frames. The landfill scenario assumed all building materials would be sent to landfill while in the reutilisation scenario wood waste was used for energy and all concrete and steel was recycled. It was found that in the reutilisation option, total primary energy use was lower than in the landfilling scenario for all four buildings. When comparing the total GWP of the concrete and timber buildings in the reutilisation phase, the concrete building had 13% greater GWP. This is due to the fact that over 25 times more CO₂ was retained from the reutilisation of wood waste from the timber building than the concrete building which was credited into the total GWP.
Considering the above references, the demolition stage of the floor system in this study, regardless of material, can be assumed to be minimal when looking at cradle-to-grave energy consumption and carbon emissions. It is difficult to speculate future use and end of life scenarios in 50 years’ time. However, it can be estimated that if wood waste from the TCC and CLT floor options was burned and feedstock energy was recovered, the total GWP involved in the whole life of the floor system would be less than the concrete option.

CONCLUSIONS

This paper has evaluated and compared the environmental impacts through an LCA approach of three different design options for long span floors, namely RC, TCC and CLT. In terms of embodied energy, results indicate that a TCC floor system is comparable to an RC floor system. The CLT floor option contained the most embodied energy but the least amount of GWP where nearly 12 tonnes of carbon could be recovered from a potential LCA. The RC floor option contained the largest amount of GWP which can be accountable to its energy intensive production process.

A qualitative assessment was undertaken on both the construction and end of life phases of the three floor design options. From review of various references, it was concluded that on-site construction does not significantly contribute to the total primary energy and GWP of a floor system. Due to the wet trade and supporting processes involved, the RC floor option would potentially have the highest primary energy and GWP out of all floor scenarios. During the end of life phase, a large opportunity in reducing total energy consumption and GWP becomes apparent if feedstock energy contained within timber products can be accessed. If this scenario were to be explored for the CLT and TCC floor options, energy and carbon could be recovered from a cradle-to-grave assessment.

Many comparative LCA case studies have not included the use of EWP such as glulam and CLT. This paper has illustrated the environmental benefit of using timber products within a long span floor structure when compared to a typical RC construction process.

REFERENCES


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