A case study to investigate the life cycle carbon emissions and carbon storage capacity of a cross laminated timber, multi-storey residential building.

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ABSTRACT

Forests are a store of carbon and an eco-system that continually removes carbon dioxide from the atmosphere. If they are sustainably managed, the carbon store can be maintained at a constant level, while the trees removed and converted to timber products can form an additional long term carbon store. The total carbon store in the forest and associated 'wood chain' therefore increases over time, given appropriate management. This increasing carbon store can be further enhanced with afforestation. The UK's forest area has increased continually since the early 1900s, although the rate of increase has declined since its peak in the late 1980s, and it is a similar picture in the rest of Europe. The increased sustainable use of timber in construction is a key market incentive for afforestation, which can make a significant contribution to reducing carbon emissions. The case study presented in this paper demonstrates the carbon benefits of a Cross Laminated Timber (CLT) solution for a multi-storey residential building in comparison with a more conventional reinforced concrete solution. The embodied carbon of the building up to completion of the construction is considered, together with the stored carbon during the life of the building and the impact of different end of life scenarios.

Keywords: Building; timber; carbon dioxide emissions; embodied carbon; life cycle.

1. INTRODUCTION

Stabilising the growing concentration of atmospheric carbon dioxide (CO_2) and other greenhouse gases (GHGs), contributing to global climatic change, is a long-term, large-scale challenge, which cannot be addressed by any single solution. Included in the many strategies, is increasing carbon storage. Forests remove CO_2 from the atmosphere through photosynthesis and, globally, could provide abatement equivalent to about 25% of current CO_2 emissions from fossil fuels by 2030, through a combination of reduced deforestation, forest management and afforestation (Read, 2009). Forest sector activities can influence carbon flows directly by storing carbon in forests or forest products and by substituting fossil fuels with bioenergy, or indirectly by using wood products in place of more GHG-intensive materials (Gustavasson, 2006).

If forests are sustainably managed, the carbon store can be maintained at a constant level, whilst the trees removed and converted to timber products can form an additional long term carbon store. Therefore, the total carbon store in the forest and the associated 'wood chain' can be increased over time, given appropriate management.

This increasing carbon store can be further enhanced with afforestation. The UK's forest area has increased continually since the early 1900s, although the rate of increase has declined since its peak in the late 1980s (Moore, 2011), and it is a similar picture in the rest of Europe (PEFC, 2012).

There is potential for increasing the forest area in both the UK and Europe (Read, 2009) and the increased sustainable use of timber in construction is a key market incentive for afforestation.

Responsible procurement of wood products is a major issue in this strategy, and there are several forest and chain-of-custody certification schemes which offer assurances that all the wood or wood-based inputs in a product or product range originated from sustainable sources, the two main schemes being those of the Forest Stewardship Council (FSC), and the Programme for the Endorsement of Forest Certification (PEFC), founded in 1994 and 1999. Currently about 9% of the world's forests and 51% of Europe's forests are certified but these proportions are rising rapidly (PEFC, 2012).

There is increasing awareness amongst construction professionals for the need to specify certified timber, backed up by the UK Government's Timber Procurement Policy and by the recent UK Contractors Group (UKCG) statement that all timber products purchased for either temporary or permanent use on UKCG member sites are to be certified as sustainably sourced. Certified responsible sourcing of timber is now a mandatory requirement of the Breeam schemes.

The case study presented in this paper investigates the carbon benefits of a cross laminated timber (CLT) solution for a multi-storey residential building in comparison with a more traditional reinforced concrete solution. The embodied carbon (E_c) of the building up to completion of the construction is considered, together with the stored carbon during the life of the building and the impact of different end of life scenarios.

2. CROSS LAMINATED TIMBER

Cross laminated timber is a form of large timber board, built up of layers of planks, or lamellas, bonded together, with adjacent layers at right angles to each other. It is similar to large scale plywood, usually with 3, 5, 7 or 9 layers, each between 20 to 50mm thick. Board sizes of up to 20m long by 4.8m wide are available in thicknesses from 60 to 500mm. Panel sizes in the UK are normally limited to 13.5m long by 3m wide because of transport.

The wood lamellas are usually fast growing spruce softwood from conifer trees bonded together with polyurethane adhesive. Each lamella is a relatively small section and often off-cuts can be utilised in low stress areas of the boards, which together help to maximise wood utilisation.

CLT boards can be used as structural wall, floor and roof panels in both low rise and multi storey buildings, and this system is capable of increasing the maximum height achievable for more traditional timber frame construction from 7 up to 12 storeys.

It is a prefabricated system with factory formed cut-outs for doors and windows resulting in reduced erection times on site.

Other advantages, including: low weight; dimensional stability; good fire resistance due to charring rate in large mass sections; airtight construction is relatively easy to achieve; good thermal and acoustic insulation properties; potential to store large amounts of carbon in the building structure.

It is generally intended for dry conditions only and not for external or below ground applications, and external walls normally need to have an additional weathering cladding system.

There are currently six manufacturers of CLT, located in Austria, Germany and Switzerland

3. THE CASE STUDY BUILDING – BRIDPORT HOUSE

The case study building is an 8 and 5 storey residential building in Hackney, London containing forty one affordable homes. It replaced a previous 1960s 5 storey masonry block on a narrow site with a large 3m diameter sewer running diagonally across it.

Building plan dimensions are approximately 58m long by 14m wide giving a gross internal floor area of 4,154m^2. The building was completed in autumn 2011 to Code for Sustainable Homes Level 4 standard at a project cost of £6 million.

Details of the building construction are:

Foundations: cfa concrete piles, concrete pile caps and ground beams, with a deep beam concrete transfer structure over the sewer.

Ground slab: In-situ concrete ground slab supported on ground beams.

Superstructure: CLT external and internal walls, floors and roof panels, varying in thickness between 97mm and 223mm. Figure 1 shows a model of the CLT frame, which was manufactured by Stora Enso in Austria, using PEFC certified spruce timber. External balconies are steel construction.

Figure 1: Bridport House CLT structural frame (http://www.ttjonline.com)

External walls: CLT, insulation and brick cladding with internal plasterboard lining.

Internal walls: Main walls between housing units consist of CLT with insulation and plasterboard lining on both sides. Other internal walls within units are light gauge steel stud and plasterboard.

Floors are finished with cement fibre board and sound insulation over the CLT floor panels, and ceilings are lined with insulation and plasterboard. The concrete ground floor has an additional levelling screed and thermal insulation. The roof areas are finished with a sedum roof system and insulation over the CLT roof panels.

4. THE CASE STUDY

An embodied carbon study, using whole life cycle assessment (LCA), has been carried out on the constructed building and also on a more conventional reinforced concrete (RC) frame option for comparison.

4.1 The Concrete Frame Option

The RC frame considered consists of 275mm thick flat slab floors with screed, and 600x250mm RC columns on a 5.63m x 6.5m/5.7m asymmetric grid to suit the internal wall layout. The flat slab at roof level is reduced to 200mm thick. Lateral stability is provided by 200mm thick RC lift shaft walls. Lightweight steel stud and plasterboard is used for all internal walls and the inner leaf of external walls. The external steel balconies are retained.

Overall this results in a heavier superstructure, requiring longer piles and a larger transfer structure over the sewer. The layout of piles and pile caps is modified to support the higher concentrated loads at column positions.

The CLT frame was erected in 10 weeks, but this is assumed to be increased to 14 weeks for the RC frame.

4.2 Methodology and Key Assumptions

Embodied carbon (E_c) here is considered to be the ‘cradle to grave’ CO_2e emissions (all GHGs converted to a CO_2 equivalent) occurring over the whole life cycle of the building, excluding the operational carbon during the building use

The full basket of GHGs is included in emissions data for some of the materials and processes involved but for others only CO_2 emissions data were available. Hammond and Jones (2011) estimate that, for most building materials, CO_2 represents around 94% of the emissions, based on energy use.

The building elements considered in the assessment are the structure and those non-structural items affected by the two different structural solutions. For example, the CLT structure provides the internal leaf of the external walls and the internal dividing walls but the RC structure does not. Therefore, the lightweight steel stud and plasterboard walls in the RC solution have to be included, allowing the difference between the two solutions to be assessed. However, it does not give a complete picture of the total E_c of the building as M&E services, intermediate refits and other architectural finishes are not included.

Emissions data have been taken from a variety of sources, for the closest equivalent product or process, in an attempt to provide the most complete and accurate assessment.

Environmental Product Declarations (EPDs) with third party verification have been used where available. These include CLT (IBU, 2012), mortar and screeds (IBU, 2010a), insulation (IBU, 2008), (IBU, 2010b), (IBU, 2011) and cement fibre board (IBU, 2009).

Industry data for steel (Target Zero, 2012) and concrete (Concrete Centre, 2012) have been adopted. Concrete mixes are assumed to use 30% fly ash or ground granulated blastfurnace slag cement replacement for Portland Cement, which reduces emissions. This is considered to be an industry representative level of replacement without having significant adverse impact on construction programmes.

Life Cycle Inventory (LCI) core data sets from the European Reference Life Cycle Database have been used to determine emissions factors for other materials and for end of life scenarios (ELCD, 2012).

Transport emissions are based on Defra/DECC's guidelines (Defra/DECC, 2011), Department for Transport statistics (Department of Transport, 2011) and on Concrete Centre data (Concrete Centre, 2010).

Emissions from construction and demolition works on site have been estimated using Environment Agency data, the programmed construction periods and an estimate of the period required for demolition (Environment Agency, 2010).

End of life options have generally been selected in line with the construction industry' waste hierarchy obligation of prevention, re-use, recycle, other recovery and disposal. Concrete, excluding non-recoverable foundations, is down-cycled (recovered) to provide granular fill material, metals are recycled, bricks are 50% re-used and 50% down-cycled for fill material, timber and foam insulations incinerated with energy recovery, and plasterboard, plaster and other insulation going to landfill.

5. RESULTS AND DISCUSSION

The results of the study are shown in Figure 2.

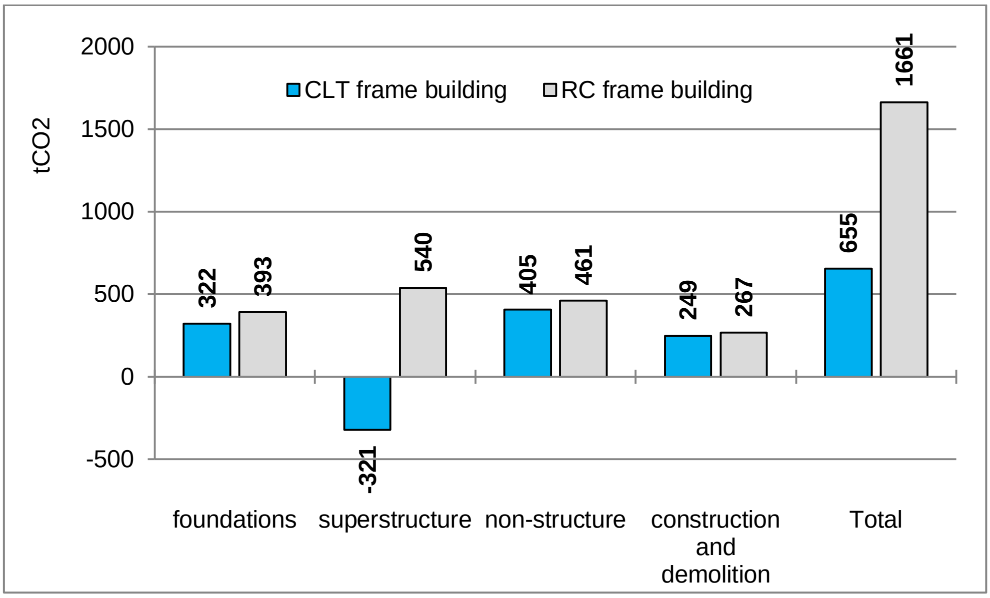

Figure 2: Cradle to grave CO_2e assessment – 100% sequestration and incineration with energy recovery at end of life assumed for CLT

This shows that the E_c of the CLT frame building is 1006 tCO_2e lower than the RC frame equivalent, approximately equal to the carbon footprint of all the building occupants for one year. The total weight of the CLT frame is 721t, which equates to 325t of stored carbon or

1192t of CO_2.

The effect of different life cycle assumptions for timber on these figures is examined below.

5.1 Sequestered CO_2

There is some debate about whether sequestered carbon should be credited to timber in a lifecycle assessment. Figure 2 takes into account 100% of the CO_2 sequestered during the growth of the trees which provided the timber for the CLT frame, and also includes the emissions from the timber at end of life. Table 1 shows the E_c for the CLT frame only, with different levels of sequestration up to the end of construction. At 50% the difference between the total building E_c is reduced to 410 tCO_2e and at 0% the CLT frame building E_c is greater by 186tCO_2e

Table 1: Ec for the CLT frame at end of construction with different levels of sequestration

	tCO$_2$e		
	100% sequestration	50% sequestration	0% sequestration
Growth	-1192	-596	0
Production and transport	47	47	47
Construction	45	45	45
Total	-1100	-504	92

The debate is largely about timescales and whether the timber resource is replaced. There is little disagreement about a material such as straw being ‘carbon neutral’ because it can be produced sustainably on an annual rotation. At the opposite end of the spectrum is coal, which when burnt releases CO_2, sequestered around 300 million years ago. This is clearly not ‘carbon neutral’ in terms of human timescales and because the resource is not being replaced. Softwood spruce timber used in the CLT is typically produced on a 40 to 60 year rotation (Moore, 2011), and is sourced from sustainably managed forests. Although currently the global forest area is decreasing, largely due to loss of tropical forests as a result of agricultural practices, the area of forest in Europe is increasing. Tropical hardwoods and European softwoods are essentially different commodities with different end uses and, therefore, restricting the use of softwoods will not halt the loss of tropical forests.

On this basis, it seems reasonable to consider 100% of the sequestered CO_2, particularly when taken on a life cycle basis where the emissions at end of life are accounted for.

5.2 End of Life Scenarios for Timber

The effect of six different end of life scenarios for the CLT frame has been considered: re-use in its existing form; re-engineer the panels into smaller sections and re-use; incineration without energy recovery; incineration with energy recovery; landfill, assuming 20% of the timber decays (Weight, 2011) and no energy recovery from landfill gas. The results are shown in Table 2.

They indicate that re-use of the CLT panels is the best option and could potentially reduce the total building E_c to 136tCO_2e and increase the differential to 1525 tCO_2e. The worst option in terms of emissions is incinerated without energy recovery, increasing the total building E_c to 1283tCO_2e with the differential reduced to 378tCO_2e.

Table 2: Ec for the CLT frame with different end of life scenarios

	tCO₂e				
	re-use	re-engineer	incinerate	incinerate with energy recovery	landfill
to end of construction	-1100	-1100	-1100	-1100	-1100
Demolition	22	22	22	22	22
Transport	12	12	12	12	12
Manufacture		10			
Transport		12			
Construction	45	45			
Combustion			1192	1192	
Energy from combustion				-628	
Emissions from landfill					1013
Total	-1021	-999	126	-502	-53

6. CONCLUSIONS

The results of the study show that the total weight of the CLT frame is 721t, which equates to 325t of stored carbon or 1192t of CO_2.

It is concluded that it is appropriate to consider 100% sequestration of CO_2 during timber growth in the LCA process for timber sourced from sustainably managed forests.

The E_c of the CLT frame building is 655tCO_2e, 1006tCO_2e lower than the RC frame equivalent. This is on the basis of 100% CO_2 sequestration and incineration with energy recovery at end of life for the CLT frame.

The choice of treatment at end of life has a significant effect on the E_c of the CLT frame. The E_c for the different treatments considered ranged from -1021tCO_2e for re-use to +126tCO2e for incinerate without energy recovery, resulting in a differential with the RC frame building of between 1525tCO_2e and 378tCO_2e. All treatments resulted in lower total emissions for the CLT frame building.

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