Assessment of carbon footprint of laminated veneer lumber elements in a six story housing – comparison to a steel and concrete solution

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ABSTRACT: Many actions have been taken to decrease the operational energy use in buildings. However, with higher energy efficiency standards, the focus is increasingly shifting to energy demand for the production of building materials and the related greenhouse gas emissions. When moving towards zero emission buildings, the developments of more sustainable bearing structure are of interest. A six story housing complex was constructed in Gothenburg, Sweden in 2012 with a structure made of laminated veneer lumber floor elements and glue laminated beams and columns. The use of laminated veneer lumber has the advantage of being a light weight solution.

Building with wood in Norway is generally regarded as a carbon efficient solution, but the impact of additional materials such as glue and insulation can influence the overall results is of interest. Life cycle assessment is used as a tool to calculate the carbon footprint in the production of the main building materials of the structure. The goal of the assessment is to compare the wood structure as built with an equivalent steel and concrete structure and to optimise the use of materials. The scope of the assessment includes the foundation and elevator shaft, structural beams and columns and the floor elements. The results indicate that the steel and concrete alternative have about 35% higher greenhouse gas (GHG) emissions than the as built wood solution, but that almost half of the total emissions are related to the foundation and elevator shaft.

1 INTRODUCTION

The Norwegian research project KlimaTre aims to increase knowledge on the life cycle environmental impacts of different value chains of Norwegian timber. The project is divided into three sub projects focusing on different parts of the value chain, KlimaVerdi, KlimaModell and FramTre. The goal of FramTre is to increase knowledge on the life cycle environmental impacts of timber construction and this study is performed as a part of the activities in FramTre. Moelven Limtre are involved in the research project KlimaTre and have provided the case study of the six story residential building in Gothenburg, Sweden called Trä8. In the Research project MIKADO, Sintef Building and infrastructure prepared environmental declarations (EPDs) for 10 solid wood products, including the glued laminated timber EPD that is used in this assessment (Wærp et al. 2009).

Traditionally energy use in the operating phase has been the largest contributing factor of the entire life cycle energy use, but as shown in Figure 1-1, adapted from the EEBguide (Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative), the importance of the materials is increasing when moving towards more energy efficient buildings. The material impact is especially important in the short time perspective with the climate mitigation goals by 2020 goal, since the material impacts will occur in the nearest future. By looking explicitly at emissions connected to the bearing systems and possible alternatives one gains better knowledge on how these emissions can be reduced. Gustavsson et al., (2006) concluded that the life cycle GHG emissions from a timber framed building are low compared to a concrete framed building. The study concluded that the climate benefits are largest when the biomass residues from the production of the wood building materials where fully used in the energy supply system. Petersen & Solberg (2002) concluded in their most likely scenario that there can be substantial emission reduction from using glue laminated beams instead of steel at Gardermoen airport.

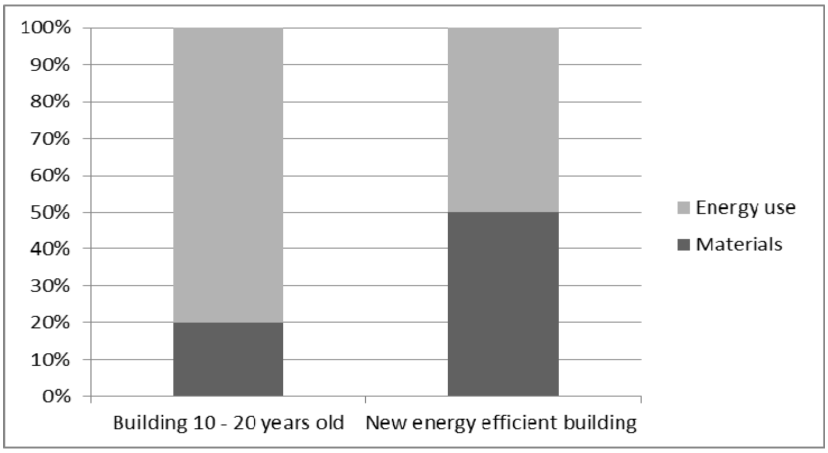

Figure 1-1 The changes of the life cycle material impacts when moving towards more energy efficient buildings. Figure adapted from the EEbguide.eu, 2013

The increased focus of climate change mitigation through low carbon footprint of building materials often leads to methodological questions and disputes. A recent attempt to reduce this dispute is the development of European standards for CEN/TC 350, where EN 15804 and EN15978 are of special interest. This report takes the building Askim Torg hus A (Trä8) as a test case for this standards. This analysis does not analyze the full life cycle emissions, but only the production stage of the different types of building materials.

2 THE BUILDING TRÄ8

The building is located near Gothenburg in Sweden and was built by Moelven Toreboda. General information of the building is given in Table 1. And the building is shown in Figure 2-1.

Figure 2-1 Trä8 in Gothenburg Sweden, (Photo Per Skogstad)

An existing building of two floors was torn down and the new building was built on top of old decking above basement. The wood frame system was chosen because of its low weight. The frame system called Trä8 consists of columns and beams in gluelaminated timber (gluelam) and can have a span up to 8 times 8 meter. The span in this project is up to 7 m. Timber work elements consists of laminated veneer lumber (LVL). These are delivered pre-manufactured. The elevator shaft and the stairway shafts are made in reinforced concrete. In one façade the beam and column system is made of steel and there are diagonal struts of steel in the framework in three corners. The bearing system is shown in Figure 2-2.

Figure 2-2 Gluelam beams and posts in the building (Photo: Per Skogstad)

Table 1. Facts about the building Askims Torg with Trä8

Building owner	Hökerum bygg AB
Area	5000 m^2 BTA, two blocks with common parking and 60 flats
Architecture	Aritekthuset I Jönköping AB
Entrepreneur	Moelven Töreboda
Contract	Property developer, Hökerum bygg AB
Structure	Parking basement in concrete, beams and columns in gluelam, LVL elements for floors. Elevator shaft in concrete with steel for support.

3 METHODOLOGY

3.1 *Goal and scope*

The goal of this assessment is to find the carbon footprint of the bearing system in a six story building built with glue laminated wood frame and to compare it to an equivalent steel and concrete solution. The goal is further to analyze the largest impacts and identify possible means of reduction of green house gas emissions.

The assessment has been conducted on three levels, which are building level, element level and product level. The building level shows the total impact of the equivalent structures and the overall difference of the building alternatives. At the element level, the timber work elements of laminated veneer lumber are compared with pre-casted concrete elements of hollow core slab type where they both have additional materials required for the same functional equivalent. On both the building level and element level, the as built version have been assessed both with generic and specific data, while for the concrete and steel have only generic. At the product level, the different sources of data on laminated veneer lumber (LVL) and gluelam have been assessed for contribution analysis along with the generic data for concrete. SimaPro version 7.3.3 (SimaPro 2012) is used for calculating the emissions and the carbon footprint is calculated with IPCC Global warming potential, measured in kg CO_2-eq. with a 100-year scenario (IPCC 2007).

3.2 *Boundaries*

The analysis is based upon the standards EN15804:2012 and EN 15978:2012 for environmental assessment of buildings. This assessment only includes the products stage, which consists of raw material supply (A1), transport of raw materials to manufacturing (A2) and manufacturing (A3). See Figure 3-1 for the life cycle phases of a building from EN15978. The balconies are not included in the analysis.

A1-3 PRODUCT STAGE			A4-5 CONSTRUCTION		B1-7 USE STAGE					C1-4 END OF LIFE			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4
Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	De -construction demolition	Transport	Waste processing	Disposal

Figure 3-1 This case study includes phases A1-3, the product phase based on the standard EN-ISO-15958.

3.3 *Life cycle inventory*

The material used in the as built construction has been calculated based on detailed construction drawings from the entrepreneur. The parts of the building included in both alternatives foundation are the elevator shaft, structural beams and posts and floors. The inventory, both quantities and environmental data use for the building as built is give in the Tables 2-5 below and the concrete and steel alternative in Tables 6-7.

Table 2. Material use for foundation and elevator shaft

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Concrete	928	m^3	Ecoinvent	-
Reinforcement steel	92 834	kg	Ecoinvent	-

Table 3. Beams and columns inventory for the building as built

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Glue laminated timber	128	m^3	Ecoinvent	Wærp 2009
Supporting steel	10288	kg	Ecoinvent	-
Steel fittings for wood	5055	kg	Ecoinvent	-

Table 4. Flooring elements of laminated veneer lumber type RA100 of 14 m^2.

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Laminated veneer lumber	668	kg	USLCI	Zimmer & Kairi 2001
Glass wool insulation board	75	kg	Ecoinvent	-
Glue	0,919	kg	Ecoinvent	-

Table 5. Additional materials to the looring elements of laminated veneer lumber per m^2.

Input	Use in building		LCI background	
	Amount	Unit	Generic	Specific
Fermacell board	28	kg	Ecoinvent	-
Stone wool insulation board, 25mm	4	kg	Ecoinvent	-
Acoustic profile	1.26	kg	Ecoinvent	-
Gypsum board, standard	9	kg	Ecoinvent	-
Gypsum board, fire	12.7	kg	Ecoinvent	-

An alternative building has been modeled to represent the typical practice for this kind of building. This is a bearing system of steel beams and posts with concrete hollow elements. The concrete hollow elements do not need the additional boards above and under, but have to be 320 mm thick to fulfill the acoustic requirements of Swedish class C. The length of the elements is in this alternative design made with the same as the wood structure. In addition to concrete and steel, 40 mm of screed material and vapor barrier is needed for the concrete floor.

Table 6. Steel beams and columns of building

Input	Use in building		LCI background
	Amount	Unit	Source
Steel	115573	kg	Ecoinvent -

Table 7. Flooring elements of hollow concrete per m^2.

Input	Use in building		LCI background
	Amount	Unit	Source
Vapour barrier, 0.2 mm	0.185	kg	Ecoinvent -
Screed material, 40 mm	72	kg	Ecoinvent -
Concrete hollow element HD320	413	kg	Ecoinvent -

3.3.1 *Use of generic and specific background LCI data*

Specific data on the glue laminated beams is based on an environmental product declaration on glue laminated beams from Moelven Limtre conducted by SINTEF Building and Infrastructure (Wærp 2009). The generic data is all gathered from processes in Ecoinvent version 2.2 (Ecoinvent 2012) except the life cycle inventory of the LVL that was missing in Ecoinvent and therefore taken from the American database USLCI (2012). Specific data is also used for the LVL named Kerto by Finnish manufacturer (Zimmer & Kairi 2002).

4 RESULTS

4.1 *Building level*

The results at building level shown in Figure 4-1 indicate that the carbon footprint of the building as built with generic or specific data have almost the same results. The concrete and steel alternative has an impact that is about 35% higher than the as built wooden building. The building part that has the largest contribution is foundation in all the scenarios and it is also foundation has the same impact on all the scenarios.

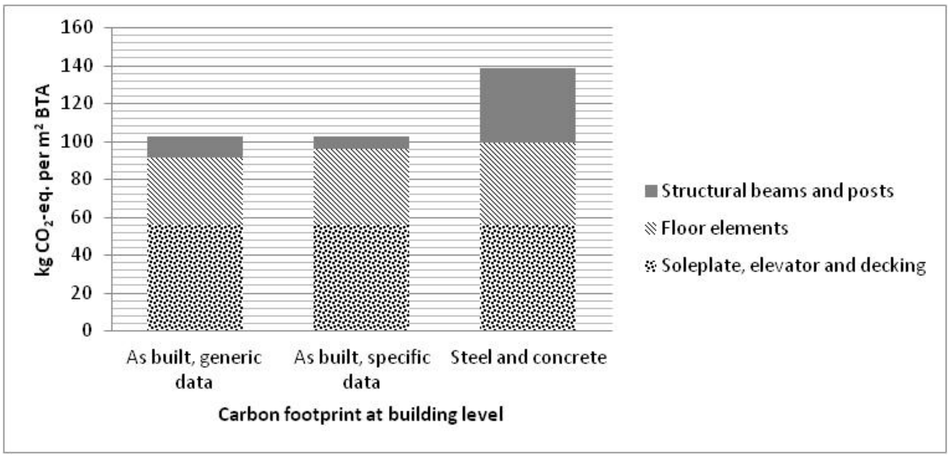

Figure 4-1: Carbon footprint at building level

4.2 *Element level*

Results shown in Figure 4-2 of comparing the flooring elements shows that the as built generic have the lowest impact and the as built with specific data have about 12% higher which is due to higher contribution of the LVL. For the LVL-element, the material needed additional to the element in order to fulfill the functional equivalent to the concrete have about the same contribution as the element itself. The concrete flooring elements have about 25% higher impacts than the generic as built scenario and it is the concrete that contributes most.

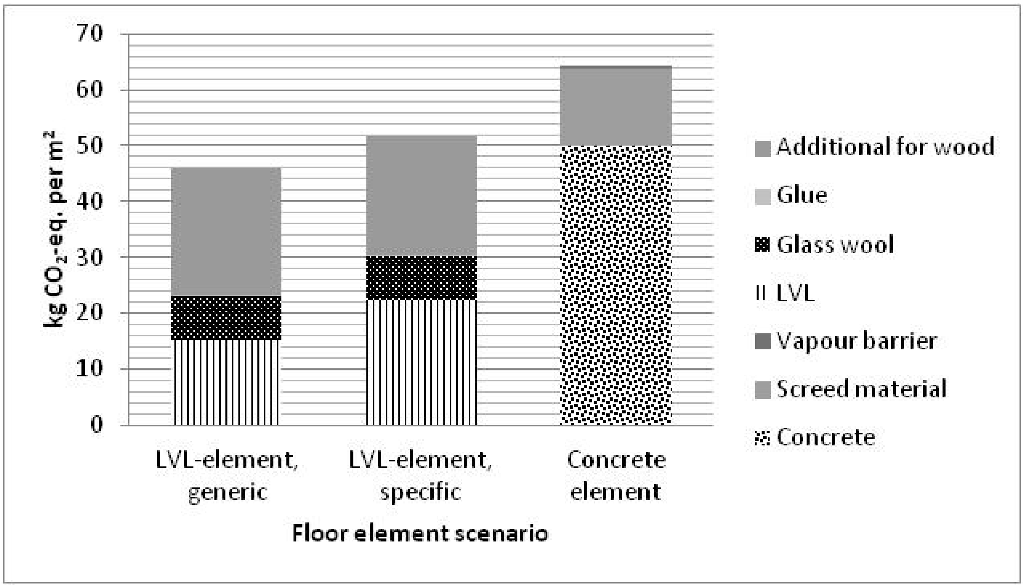

Figure 4-2: Comparing of floor elements at element level

4.3 *Product level - LVL, gluelam and concrete*

The comparing of the LVL material and gluelam for both generic and specific data show large variation in total and in contribution of inputs. Both the generic show large contribution from wood inputs compared to the specific data. The contribution from glue shows large variation between all and especially between generic and specific inventory for LVL.

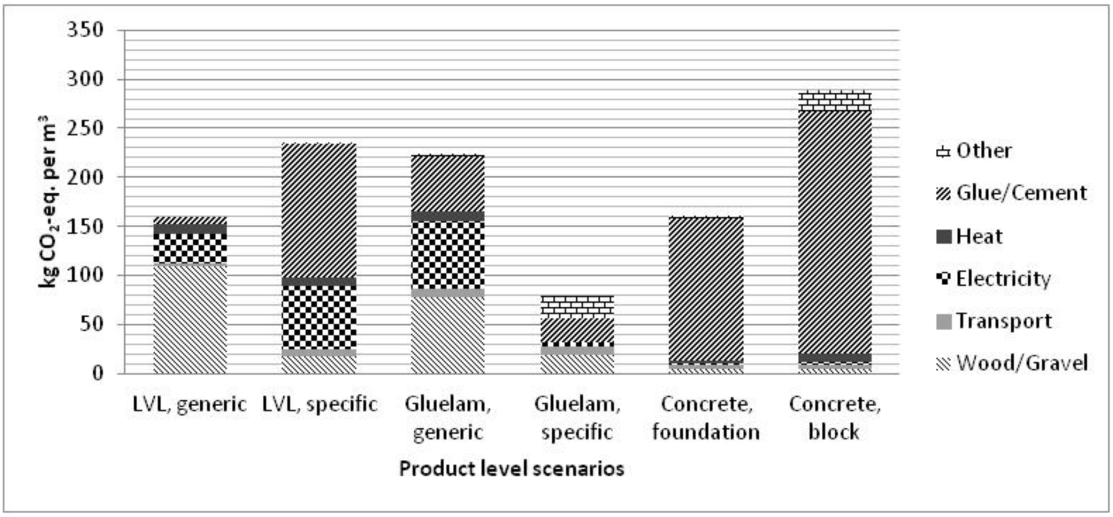

Figure 4-3: Comparing of wood and concrete materials at product level

The Norwegian produced gluelam differs itself from the other wood products by having a much lower total impact and especially the contribution of electricity is low.

The concrete used in foundation is made of cement with blast furnace slag and has only 46% clinker, where the blast furnace slag is considered as a waste input. The cement in concrete on the other hand has 90% clinker at therefore considerable higher impacts (Ecoinvent 2010).

5 DISCUSSION

The carbon footprint of the six-story building as built did not differ substantially between generic and specific data at building level. The difference was, however, quite large when the different materials were compared at product level and it seems that they cancelled out when aggregated to building level. The comparison at element level shows the importance of using functional equivalent where the materials that are needed in addition to wood in the floors are having a considerable impact.

The results showed that the foundation contributed significantly to the emissions of the building. One important reason behind using the Trä8 building system at this place was the low weight making it possible to use an existing foundation from a previous two-story building. Hence, the alternative building of steel and concrete would in reality require more foundation and thus have a higher carbon footprint. Another limitation of the material use in the assumed alternative steel and concrete scenario was that the length of the concrete hollow elements was the same as in the wood scenario. The concrete hollow elements have the strength to cover a length of more than double of this and this could lead to lower steel use.

This study has been limited to the production phase of the materials, but also of importance are the end of life scenarios of the building and especially benefits of recycling and energy recovery beyond the life cycle that are left out. The benefits of wood beyond end-of-life are heat recovery from incineration that is used either for industrial processing or district heating. One other aspect that could have large impacts of the carbon footprint of wood-based materials is the biogenic carbon flows. The wood-based materials are during growth in forest sequestrating carbon dioxide from the air and this is stored in the product until decay or incineration during end of life. As suggested in prEN16485, the biogenic carbon flows will be included in the calculations for GWP for wood products that are sustainably sourced.

6 CONCLUSIONS

The building as built with the Trä8 system shows that the foundation is an important part of the emissions from the structure and an advantage of the light building frame of wood. When assuming the same foundation, the concrete and steel alternative building had 35% higher emissions of greenhouse gasses in production. The comparison at flooring elements between the as built version and a alternative concrete hollow elements, shows the importance of comparing at functional equivalent in terms of requirements to strength, fire and acoustics. At product level the impacts of difference materials varies and especially with generic and specific data, but also the contribution to inputs such as glue.

Further work on the methodology for carbon footprint of wood buildings should be to include end-of-life aspects and the impacts of biogenic carbon flows. At the construction, optimization of materials that are needed in additional to wood in the floor elements and comparing the use of laminated veneer with laminated solid wood in flooring elements.

The practical implication of the results of carbon footprint of the Trä8 system should be to advocate the savings in both carbon emission and potential costs where foundation can be reused because of the lightweight structure. This should be a growing potential with the increasing demand for urban dwellings and the need for higher buildings.

7 ACKNOWLEDGEMENTS

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