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LIFE CYCLE GHG EMISSIONS FROM A WOODEN LOAD-BEARING ALTERNATIVE FOR A ZEB OFFICE CONCEPT

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Abstract

A major contributor to global greenhouse gas emissions is the production of concrete and steel for the construction industry IPCC (2007). To combat global warming, innovative solutions are needed in the construction industry to reduce emissions from both energy and material use in buildings. In a previous study the first phase of a GHG emissions analysis for a Norwegian ZEB office concept was presented. The aim of which was to achieve a zero emission balance where operational and material emissions are accounted for ZEB OM. The results from the first phase showed that the load bearing system accounted for a large share of the embodied emissions. In addition, the ZEB OM ambition level was not met, thus emphasizing the need for further work on alternative solutions and material choices.

This paper presents the results of a comparative study between this original office concept study and a predominantly wooden alternative loadbearing structure consisting of wood trusses, glue laminated beams and columns. The wooden alternative is comparable since it has been dimensioned to fulfil the same technical requirements for bearing capacity, sound and fire resistance. In addition, the system boundary was extended to include three alternative end-of-life scenarios. It was found that the wooden alternative structure almost halved the emissions compared to the original concrete and steel ZEB office concept model. This trend is the same in the cradle to gate and all three end-of life scenario's. The analysis clearly shows that emissions from the production process outweigh any emissions from the material's end-of-life treatment. This means that the material choice plays a major role in embodied emissions, as well as it being crucial to reduce the required construction material quantity.

Keywords:
Embodied emissions; materials; ZEB

1 INTRODUCTION AND BACKGROUND

The results from the office concept study showed that material emissions accounted for a large share of the total emissions. Also, the results showed that the emissions from the load bearing structures were a large contributor. The ambition level ZEB-OM was not met, thus emphasizing the need for alternative options and material choices.

This study looks at material emissions from the original ZEB office concept and compares it with emissions from an alternative wooden load bearing structure. Furthermore, the study includes three end-of-life emission scenarios for the load-bearing alternatives. The first scenario calculates end-of-life emissions based on end-of-life treatment data from Ecoinvent Version 2.2 [1]. The second scenario looks at the effects of incineration of used construction wood in a municipal incineration plant, and the third scenario is based on information from the Norwegian recycling industry. The wooden alternative has been dimensioned by

Hammersland [2]. The full details of this study can be found in Barnes Hofmeister et al. [3].

2 METHOD

The overall method is to document greenhouse gas emissions due to the material use in a wooden load bearing system suitable for an office building. An attributional life cycle carbon dioxide emission analysis is applied. The life cycle assessment methodology is described in Dokka et al. [4].

2.1 Goal and scope

The goal of this analysis is to calculate the embodied GHG emissions for a wooden load bearing alternative for a zero emission office building concept for the production stage (A1-3). Fig. ***1*** shows the life cycle stages considered in the initial concept study (dotted black box) and the expanded boundaries for this study (dotted red box). The service lifetimes are assumed to be 60 years for both the bearing system based on the initial assumption in Dokka et al. [4].

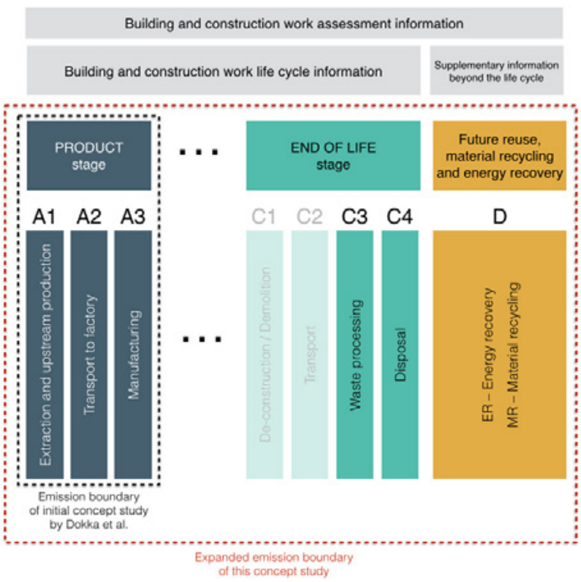

Fig. 1: System boundaries in initial study [4] and the extended boundaries used in this study (illustration based on EN 15978).

2.2 Case building

The building, Fig. 2, is a typical Norwegian four story office building with additional underground parking facilities. The heated floor area is 1980 m^2. The basic design is based on the current Norwegian building codes TEK 10 [5], but the energy concept is based on the Norwegian passive house standard [6] and the building is estimated to have a service life time of 60 years. The model is designed for Oslo climate. Detailed descriptions of the building physics and energy concepts can be studied in Dokka et al. [4].

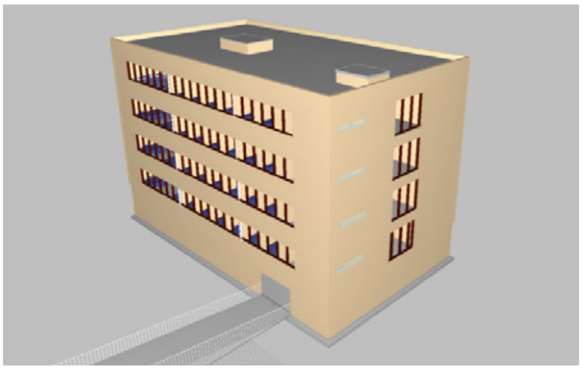

Fig. 2: Revit Model [4].

2.3 Construction alternatives

Hammersland [2] takes the original ZEB Office concept model and dimensions major parts of the loadbearing structure with wood trusses and glue-laminated beams and columns. This work includes details on the load analysis to make a realistic design with the same performance criteria and room program as the base case. The wooden alternative, however, maintains concrete and steel in reduced quantities for the foundation works and technical shafts within the structure. Neither the reference structure nor the wood case has been optimized from a statics perspective.

Base Case: Concrete and steel load bearing structure

The load-bearing structure follows a very traditional approach using concrete slabs supported by steel beams and columns. The building envelope is placed on the outside of this load-bearing skeleton. The basement and foundations are both made of reinforced concrete. The slabs are hollow core elements. The load-bearing element in the original floor is 200 mm reinforced concrete with a 30 mm concrete finish.

Wood Case: Wood load bearing structure

The altered loadbearing structure consists of wood trusses resting on glue-laminated beams and columns. The flooring material itself consists of oriented strand boards (OSB) covering the truss construction, creating a continuous surface (Fig. ***3***). For structural reasons the elevator shaft, the staircase and the ceiling over the meeting room, as well as, the basement (walls, columns, floor and ceiling) are kept as concrete components. However, the foundations are reduced in size since the wooden structure is lighter than the traditional concrete and steel one. In order to take wind loads a steel cross is implemented in the east façade of the building.

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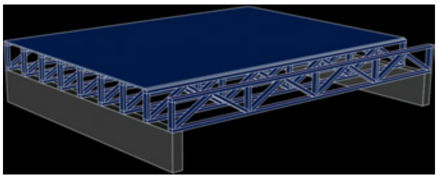

Fig. 3: Revit Model [4].

The wooden alternative is a timber structured floor, where the structural element is a wooden truss. In the ceiling there are two gypsum boards, giving the structure sufficient protection during a fire. Due to the issues of sound spreading through wood sound, impact plates are added underneath and overtop the truss-OSB chip-board ceiling. Sound impact plates are typically made from mixed cell polyurethane foam, while the product *Silencio*, also intended to mitigate sound penetration, is made of wood fibre. The truss will be prefabricated, allowing an efficient building process.

2.4 Inventory

Emission data from Ecoinvent was chosen since it was used in the original ZEB office concept model. Also based on the study by Barnes Hofmeister and Thorkildsen [7] the Ecoinvent proved to be the most comprehensive data source, offering information for all required materials. The load-bearing structure of the original is only composed of four materials whereas the wooden alternative consists of nine different materials. The complete inventories for both alternatives are given in Table 1. The material quantities for the concrete and steel load-bearing structure of the base case are based on Dokka et al. [4]. In the wood case all major components are taken from Hammersland [2]. however, since Hammersland´s work did not go into detail concerning the floor/ceiling build up, material quantities for gypsum plaster boards, sound impact plates and wood fibreboards are derived from information provided by the wood truss producer. Concrete is the major construction material in both cases. This is due to maintaining a concrete basement and foundations also in the wooden construction alternative. Additionally, the wood case uses a larger material variety. All emission factors are converted to $kgCO_2/m^3$ with the respective densities provided by EcoInvent (Table 2).

Material	Base Case [m³]	Wood Case [m³]
Structural timber	0	70
Glulam beams/columns	0	19
Chip boards	0	43
Nail plates	0	0,2
Steel studs	0,3	0
Gypsum plaster boards	32	65
Sound impact plates	0	44
Silencio (wood fibreboard)	0	19
Reinforcing steel	19	5
Concrete foundation	*104*	*33*
Concrete inner load-bearing walls	*134*	*134*
Concrete in columns	*3*	*3*
Concrete in slab structures	*524*	*125*
Concrete in outer walls	*109*	*109*
Concrete total	874	408
TOTAL	**925**	**673**

Table 1: Overview of material quantities for both construction alternatives.

Material	Emissions ($kg\ CO_2/m^3$)	Reference
Structural timber	104	Sawn timber, softwood, planed, kiln dried at plant/ RER U
Glulam beams/columns	205	Glued laminated timber indoor use, at plant / RER U
Chip boards	312	Oriented Strand Board, at plant / RER U
Nail plates / steel studs	27554	Steel, low-alloyed, at plant / RER U + steel product manufactur-ing, average metal working /RER U
Gypsum plaster boards	274	Gypsum plaster board, at plant/ CH U
Sound impact plates	129	Polyurethane, rigid foam, at plant/ RER U
Wood fibre board	56	Fibber board soft, at plant (u=7%)/CH U
Reinforcing steel	11383	Reinforcing steel, at plant/RER U
Concrete	261	Concrete, normal, at plant/ CH U

Table 2: Overview of extracted product stage emission factors.

2.5 Waste Scenario's

In order to gain understanding of the environmental impact of the various end-of-life treatments three scenarios are investigated.

Generic EcoInvent:	This scenario follows the recommended end-of-life treatment for building materials described in table 3.18 in Part V Building Material Disposal of the report collection affiliated with SimaPro [8]. There will be no energy recovery from waste materials treated with the process of municipal incineration.
EcoInvent w/ Energy Recovery:	This scenario is congruent with Generic EcoInvent, but considers energy recovery from municipal incineration.
Norwegian Recycling Contractor:	For a better apprehension of the end-of-life of the building within the Norwegian framework, data has been gathered from a Norwegian recycling contractor regarding typical end-of-life treatments. The provided process descriptions were modelled with SimaPro S 8.0.1 Multiuser Classroom in order to attain emission data. The recovered energy substitutes fossil fuel that leads to factored-in emission savings. For a clear picture of the building material lifetime emissions, product stage emissions were added to the end-of-life emissions.

Table 3: Investigated scenarios.

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3 RESULTS

Fig. *4* below shows the comparison of the three scenarios. It is apparent that the wooden structure (wood case) causes almost 40% less emissions compared to the original ZEB office concept model (base case) in concrete and steel. This trend is the same in all scenarios.

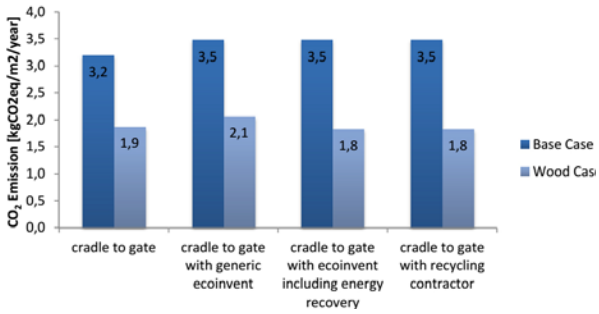

Fig. 4: Three end-of-life scenarios including product stage emissions compared to only cradle-to-gate emissions.

The total emissions (all life cycle stages) for the base case only vary in the third scenario. The reason is that gypsum plasterboards are landfilled instead of recycled, causing a slightly higher impact. For the wood case, however, the emissions fluctuate from scenario to scenario. The scenario based on information from the Norwegian recycling contractor shows the lowest emissions due to larger fossil fuel emissions being substituted with demolition wood (wood replacing fuel oil in private enterprises). The wood products from the scenario *'Ecoinvent with energy recovery'* substitute emissions caused by a mixture of fuel oil and natural gas, which are slightly lower than the ones of pure fuel oil.

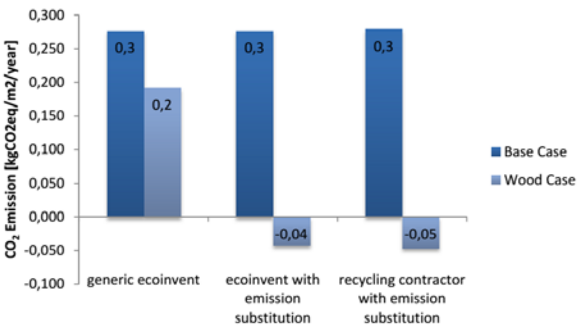

Fig. 5: End-of-life emissions for all three scenarios showing negative emissions in case fossil fuels are substituted with wood.

Fig. 5 shows the overall emissions from all considered life cycle stage. Comparing the data for all three scenarios it becomes obvious that wood as energy carrier substituting fossil fuels leads to negative end-of-life emissions. Despite higher emissions due to landfilling of gypsum plasterboards (four times higher compared to recycling) the Norwegian recycling contractor scenario has the largest emission savings due to demolition wood substituting fuel oil in private enterprises. Considering that a possible future situation in the Norwegian energy sector might be that demolition wood will not substitute fossil fuels, but rather emissions from heat pumps driven by electricity, the benefits of wood as laid out here may decrease.

Since the emission from the end-of-life stages are in the order of one magnitude smaller than the production stage emissions, it becomes clear how crucial it is to be conservative with respect to the material use in buildings, regardless of whether the structure is made of wood or concrete and steel. Especially concrete and steel have a tremendous impact compared to all other materials. In both models concrete is the strongest emission driver. Although the major environmental impact is caused during the product stages (A1-A3), the end-of-life of concrete causes the major fraction of emissions among all end-of-life processes (C3 and C4).

Combustible materials substituting fossil fuels drive negative emissions as shown in *Fig. 5*. This will of course only be feasible as long as the back-up fuels in district heating systems are fossil fuels. Overall, the fossil fuel mixture of 1/3 natural gas and 2/3 fuel oil has 18 times (20 times for pure fuel oil) higher emissions than the end-of-life procedure for wooden building materials including municipal incineration. In the case of wood fibreboards, the emissions are almost comparable (0,8 times the emissions of substituted fossil fuel) due to chemical adhesives used to bind the fibres into solid boards.

The assessment, however, also showed that incineration is not preferable in any case. While wood products are favourable to fossil fuels, the sound impact plates used in the wooden constructions, made of polyurethane foam, cause four times higher emissions than the substituted fossil fuel.

4 DISCUSSION

Since the original ZEB office model concept was modelled after a typical four-story office building including a basement for parking, the same structure has been used in the alternative wooden load-bearing structure. Due to lower weight the reinforced concrete foundations and basement walls are downsized in the wood case. However, the emission picture is still dominated by the emission of the remaining concrete and steel components. In order to really minimize emission in the wooden construction it should be considered to not assume that there is a basement underneath or to use a different technology (e.g. solid wood based basement, e.g. a combination of concrete, steel and wood).

The study shows that it is crucial to keep product life cycle emission in mind while initially conceptually designing a building, since upstream alterations, such as replacing a concrete and steel load-bearing structure with a wooden one, might result in only minor benefits. The study also shows that reducing production stage emissions is highly relevant, since even energy recovery in an end-of-life scenario only will result in about a 20% energy yield.

In order to gain a better understanding of the overall building, in the next steps a thorough ZEB-balance should be established going beyond the changes within the load-bearing structure.

In this preliminary study on how different end-of-life processes impact the building emissions, all numerical data has been extracted from EcoInvent. The scenarios itself are intended to reflect current building practice and are therefore based upon information from the building sector rather than scientific sources. Detailed numerical values for the three investigated scenarios can be found in the appendix of Barnes Hofmeister et al. [3]. Especially in the case of the Norwegian recycling contractor, this data might not be accurate enough, since it was only possible to find information about the specific processes, but with no insights into specific emission values. Given that the electricity mix in Norway has a much lower emission factor compared to other parts of Europe the recycling processes will reflect that. In future analyses it would be recommended to find more precise numerical values either from Norwegian processes or via the means of Norwegian EPDs. To this day Norwegian EPDs, however, were insufficient in their data variety to sufficiently model especially the wooden load-bearing structure.

Consideration of the building's lifetime may impact its environmental load. Quantitatively looking at our current built environment, it seems that masonry buildings can last longer than lighter wooden structures. With more scientific insight, an alteration of assumed lifetimes for lighter and heavier buildings might be necessary to better represent their true environmental impact.

5 CONCLUSION

Our study indicates that the emissions due to the material use in the wooden alternative are around 40% less than the initial concrete and steel bearing system. This also confirms that compared to the production stage emissions, the end-of-life emissions add less than 10 % to the overall balance (8 % base case, 9 % wood case). At the same time, concrete and steel prove to be the responsible for 75 % of the production stage emissions even in the building with the wooden load-bearing structure. Most of the concrete and reinforcing steel is utilized in the basement. We have not considered the impacts of thermal mass on the operational energy use of the buildings.

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