A Comparative Study of the Environmental Impact from Transportation of Prefabricated Building Elements Using Wood or Concrete

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***Abstract*—As many as 240 of Sweden's 290 municipalities estimated that there existed a housing shortage within their region. Therefore, many homes are required to be built in a relatively short period to fulfil the demand. Production is required to take into consideration sustainable building solutions to reduce climate impact. Hence, logistics must become more efficient to contribute to an environmental solution, and the use of transports should be examined reducing the effect of heavy vehicles to meet the climate objectives.**

The focus of this study is to identify differences between the transportation of materials for building projects based on wood or concrete. Different key performance indicators were derived from the collected data and presented in this study, which resulted in two formulas focusing on transport- and environmental impact.

The KPI's indicates that the weight of the load does not have an important impact on the amount of emitted CO_2, but it is the number of transports associated with the projects that are the main problem regarding emissions and environmental impact. Hence, the number of transports and the amount of CO_2 emissions can be calculated by the support of the formulas derived from this study.

***Index Terms*— Multi-family houses, prefabrication, environmental impact, transportation, wood, concrete, transport utilisation.**

I. Introduction

According to Boverket's (National Board of Housing, Building and Planning) building forecast, approximately 710,000 homes need to be built during 2015-2025. It's estimated, by 2020, that 88 000 homes are required per year to meet previous year's production deficit compared to actual market demand [1]. Therefore, a long-term sustainable production solution is a requirement at all level within the building process [2]. Wood has a long tradition in the Swedish construction industry and is used in many suitable areas, such as walls, floors and ceilings [3], [4]. Building houses in renewable materials such as wood is beneficial from an environmental perspective. However, Life Cycle Analysis (LCA) analyses are not normally used in the industry, disregarding the positive effects of wood as a construction material [5]. However, wooden multi-family houses are being built to a greater extent than previously due to the support of new technologies.

According to Miljömål (Environmental Objectives) [6], is the transport sectors responsible for a large proportion of environmentally hazardous emissions in Sweden that needs to be reduced over the coming years to achieve Europe 2020 Strategy [7]. Today, domestic transport accounts for one-third of all CO_2 emissions in Sweden and developing a more efficient energy consumption and replacing fossil fuels with more environmentally friendly alternatives will not be enough to reach the climate targets. [8]. By improving trucks utilisation efficiency, emissions can be reduced, and money saved [9]. In the transport industry, efficiency and resource utilisation are usually measured in idle time, weight, tonnes/km, volume and loading meters [10]. The use of heavy vehicles must be reduced, and logistics must be streamlined and better utilised to reach the climate targets associated with the industry producing wooden multi-family buildings [8].

A. Purpose

The purpose of this study is to identify possible differences between the transportation of prefabricated building elements using wood or concrete. This is conducted to highlight the effect on transports utilisation of different building materials, which in turn have an effect on the environment. Therefore, the study will strive to find a relationship between the environmental impact of transports based on the building material. The transport takes place between manufacturers and construction sites.

II. Review of the Conceptual Framework

Manufacturing of prefabricated building elements is defined as industrial construction, which means that they are manufactured in a factory environment and after that transported to the building site for assembly [11]. Prefabricated building element can consist of walls, ceilings, beams and various fittings [12], [13]. The benefit at the building site is that the prefabricated floor elements easily can be assembled with wall elements, beam, etc. as a fast and cost-efficient building methodology [13], [14]. Wood is one of the most durable construction materials based on its renewability, ability to bind CO_2 and requires a limited amount of energy during processing [5]. Further, wood has a relatively low density in comparison with concrete or steel, which allows for the transport of larger volumes, which is beneficial for industrial construction and the environment due to the reduced transport requirement [15].

There are different types of transport modes used in the construction industry [16]. The advantages of road transportation are the relatively low transhipment costs, easy to transport door-to-door, flexibility and speed, which are important factors when constructing multi-family buildings. The disadvantages that may arise are access limitations, high

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running costs and transport using heavy vehicles are typically done for distances less than 300-400 kilometre [16], [17]. The maximum permissible gross weight of heavy vehicles is determined by the axle, bogie or triple-axle pressure, the distance between the first and the last axle, the maximum allowable weight of the vehicle, but also by the load capacity of the road [18]. Hence, vehicles can be driven on public roads if the weights for the respective classification type are not exceeded [19].

It is common for prefabricated wooden building elements to be loaded standing up to maximize utilisation. Transport of prefabricated building elements in concrete is normally carried out on flatbeds, or on specific A-frames, since there is an access requirement for cranes at the building site [18].

There is currently no clear definition of load capacity, which is problematic since it varies if heavy and dense cargo is transported, or if it is related to cargo with limited weight and large volume. In some cases, this is referred to as loading meters and in other cases as volume utilisation. It is also possible to use a definition related to load capacity based on the total gross weight of the vehicle [20].

According to McKinnon [10], transport utilisation can be defined and calculated in five different ways, where the three first options are the most common in the industry:

- Empty transport: How many kilometres are driven without any load. However, it is important to define an empty truck.
- Weight: Is the relationship between the actual weight of the goods transported and the maximum allowable weight that could be transported.
- Tonne/km: Is the ratio of actual tonne/km transported compared to the maximum tonne/km that possibly could have been transported.
- Volume: Number of cubic meters of cargo in relation to the maximum cubic meters.
- Coverage: Calculates how much of the transports floor area is occupied by cargo.

The disadvantage of measuring transport utilisation in tonne/km is that only the weight combined with the distance is included in the calculations, making it important to define the correct weight, which normally is net weight. In practice, many vehicles are loaded with cargo where the weight is very low in relation to the cargo volume. In these cases, the available cubic meter or floor area is filled without the maximum weight limits of the transport are being met [10]. Studies have shown that transports often are limited by the volume percentage, instead of the weight percentage, where the average utilised cargo area during transport was 80 %, while the height only was utilised by 47 %. Thus, it resulted in transports having an average cubic meter utilisation rate of approximately 28 %. If the volume had been used as a parameter, containers could be adapted to the size of the goods. Thus, an even higher resource utilisation could be achieved [10], [21].

Resource utilisation may vary between zero and 100 %, i.e. 100 % utilisation can only be achieved if the truck is loaded at maximum capacity at the start location and unloads the same amount of cargo at the final location. However, the average measurement is based on all movement and activities of the trucks between different locations, including initial empty transports, full or partial loads and final movement of the day. The advantages of this measurement are the relative ease of understanding it, and the possibility to accumulate the required information for processing and analysis [22].

A. The Environmental Impact of Road Transportation

The traffic of heavy vehicle and passenger cars account for the greater part of greenhouse gas emissions in Sweden. Heavy vehicles account for 86% of all freight traffic in Sweden and heavy freight traffic has increased by 20% without an increase in the total mileage since 1990 [23]. Road transport is an industry that shows no signs of reduced emission rates and the newly introduced regulations have had a limited effect on the emission rates. Therefore, to achieve the climate targets and increase the potential for development of road transports, better fossil-free diesel alternatives would need to be developed, combined with an efficient governmental controlling mechanism [23], [24].

Approximately 97.5% of all heavy trucks in Sweden use diesel since these engines are more energy efficient, releasing less CO_2 than petrol engines. Even if diesel engines release less CO_2 then previously, they still emit other greenhouse gases, which consist of hydrocarbons (HC), particulate matter (PM), nitrogen oxides (NO_x) and carbon monoxide (CO). Emission rates are based on weight per driven kilometre, and emission rates increase proportionately with weight and driving distance. There are currently no rules or standards for how much CO_2 emissions may be released by heavy trucks. The focus has instead been on developing controlling instruments such as taxes based on total weight and exhaust classification of the vehicle [23].

The Handbook Emission Factors for Road Transport (HBEFA) describes a model that identifies emission factors for all categories of vehicles dependent on the way trucks are driven and what kind of roads they drive. This model provides the possibility to calculate emissions based on exhaust gases and fuel consumption for a particular road. The HBEFA model consists of several additional factors such as speed limits, road type and vehicle classification etc. [25].

A formula is developed using the HBEFA model to estimate the fuel consumption of heavy vehicles, which considers the average fuel consumption (g/km), vehicle driving distance (km) and a conversion factor for the selected fuel. The formula is structured into three classes: service weight (vehicle weight), average load and fully loaded [26]. The conversion factor from diesel to CO_2 is 1.00 gram of diesel generates 3.15 grams of CO_2 [26]. Table I, display the average fuel consumption (g/km) for diesel-powered trucks depending on the weight.

TABLE I: AVERAGE FUEL CONSUMPTION FOR DIESEL TRUCKS [26]

Transport	*Load per transport (%)*	*Fuel consumption (g/km)*
Without any load	0%	258
Average load	50%	311
Full load	100%	395

III. RESEARCH PROCESS

This study is based on three specific building projects in Sweden, where two utilise a construction solution out of wood, and one is based on concrete.

A. Research Design

The primary objective was to collect information to create an understanding regarding the impact from transportation of building elements using wood or concrete. After that, quantitative data was collected to be used in the developed formulas and models. This facilitated a comparison between transportation of the different building solutions, creating a possibility to understand the environmental impact derived from the different solutions. The research process is perceived as primarily exploratory with descriptive components [27], [28] and the research design is influenced by the purpose where interviews combined with project data was deemed beneficial for the study [28]. Also, this is an appropriate research approach for complex situations, such as transport strategies [29]. This provides a structured view for a cross-sectional study identifying the most critical factors influencing the transportation associated with building components. Hence, it allowed to capture the full scope within a complex context and to identify transferable understandings contributing to the solution [30].

B. Credibility

The study used a dynamic research process where the contributing companies were an integrated part in the development of the study. This process adds to the credibility and reflects how well the researcher managed to understand and communicate the information in its context [31], [32]. The interviews have been documented to enhance the credibility, after that, summarised for comments within the research group or with key respondents within the industry for additional input and clarification [31]. Additionally, source- and investigator triangulation was applied by having several companies providing data, combined with the research being discussed among the research group and certain respondents for possible adjustments to enhance the result [33]. Validity and reliability were addressed by conducting pre-studies of the field and by having a defined selection process of suitable projects, which also generated sufficient knowledge about the concept. Thereby, have the ability to capture information and data related to the strategies and ideas associated with the transportation of building components. By using systematic analysis and ongoing discussions between the involved researchers and industry stakeholders provided improved validity and reliability [34].

C. Data Collection

The data collection is be based on three projects, and the data was provided by the companies directly, rather than through surveys and direct measurements. External observations and direct interviews were conducted to provide a deeper understanding of the weights and dimensions of the prefabricated building elements included in this study, and how the trucks are loaded at the production site. Document analysis is a major source of data collection for this study as it is a comparative study of the effect of transport optimisation between different building methodologies.

1) Project — Kvillebäcken

It is a combination of four, and five-story houses built using a wood frame, supplied by a Swedish producer. The houses were completed between August 2015 and December 2017.

- Total number of square meters: 1 230 m2
- Square meters per floor: Floor 1-4: approx. 270 m2 and Floor 5: approx. 150 m2
- Number of floors: half of the house have five floors, and the other half have four floors
- Data for three floors are included in this project

The wood building elements are prefabricated in a factory by the manufacturer. Table II display deliveries to the building site and the measurements relevant for this study. The outer walls used at Kvillebäcken is inclusive of; insulation, canvas, frame, plastic foil, fireproofed plaster, windows and doors. The floors include; floorboard, particleboard, Laminated Veneer Lumber (LVL), and insulation. The inner walls include gypsum, fireproof plaster, building frame, insulation, particle board and stud. Additional material such as façade, loose material and cargo to be mounted inside of the walls will also be delivered to the building site using available space on the transport. The prefabricated building elements are transported standing up on steel stands to maximise the capacity. The entire steel frame, including the prefabricated element, is lifted off the truck at the building site and is returned to the manufacturing site at the next return delivery. Floors are transported flat on the truck, enabling several layers of floors to be loaded on top of each other.

2) Project — Pelarsalen

Pelarsalen is five buildings of six-story wooden multi-family houses. The project started in January 2017.

- Total number of square meters: 3 010 m2
- Square meters per floor: 430 m2
- Number of floors: 7 including a penthouse
- Data for five floors are included in this study

The prefabricated elements are manufactured at a factory in Sweden, and the building elements are transported to the construction site for final assembly. Table II presents the measurements relevant to the study. The outside wall is including; insulation, canvas, frame, plastic foil, windows and doors. Floor beams include; floor tiles, particle board, LVL and insulation. The inner walls include; plaster, fireproof plaster, insulation, particle board and stud. Additional material to be delivered to the site is; loose material, façade, internal flooring, white goods and appliances. Distribution is made using wooden one-time holding frames attached to the truck, supporting the prefabricated building elements. The benefit using the disposable handling equipment is that these can be detached from the truck at the building site, which increases the possibility of return loads and higher resource utilisation. The beams and loose material to the building site are transported flat without any specialised handling equipment, which makes it possible to load several layers on top of each other. The deliveries to the building site are coordinated with the assembly schedule, which affects the transport utilisation rate somewhat. In these cases, the volume is considered as a constraint since the maximum weight limits are not exceeded.

3) Project — Vattentornet

Vattentornet is built in Växjö, at the same site as the old water tower. The 19-story high-rise building is built in concrete and was completed in May 2018.

- Total number of square meters: 5 624 m2
- Square meters per floor: 296 m2
- Number of floors: 19 including a penthouse
- Data for 18 floors are included in this study

The prefabricated building elements are made out of concrete and are assembled at the building site. In Table II, the different dimensions are shown in approximate dimensions as they may vary from different walls. The outer wall of Vattentornet is inclusive of; insulation, windows and doors. The floors consist of flat beams that are filled with liquid concrete on site, and the detached inner walls are equally filled with liquid concrete on site. Loose materials, façade and balconies are additionally distributed to the building site. The outer walls and detached walls are transported vertically, directly from the supplier on an A-frame, while the floors are transported flat on during transport. Liquid concrete is transported directly from the concrete supplier to the building site.

TABLE II: DIMENSIONS OF DELIVERED MATERIALS

Building project	*Building part*	*Thickness (m)*	*Height (m)*	*Width (m)*	*m^2 or m^3/part*	*Weight (kg)*
Kvillebäcken						
	Outer wall	0.240	2.975			
	Floors	0.408				
	Detached wall	0.484	2.950			
Pelarsalen						
	Outer wall	0.357	3.000			
	Floors	0.408				
	Detached wall	0.484	2.975			
Vattentornet						
	Outer wall	0.420	2.620	4.634		5948
	Floors	0.310			14,8 m^2	109 kg/m^2
	Liquid concrete				60 m^3	2400 kg/m^3
	Detached wall				112 m^2	232 kg/m^2
	Liquid concrete				15 m^3	2400 kg/m^3

The data in Table III display the actual distribution to the various building sites, including a number of transports for each floor and weight per transport and weight for each floor. Information for the wood building projects is according to the waybill provided by the manufacturer, and the information for the concrete project is based on a combination of waybills and projected distribution plan by the manufacturer.

TABLE III A: SUMMARY OF THE TOTAL WEIGHT (TON) OF CARGO DISTRIBUTED THROUGHOUT THE PROJECTS

Project	*Floor*	*Total weight of the truck*									*Total weight/floor*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9 to 16*	
Kvillebäcken	**1**	9.83	9.54	1.79	0.85						22.00
	2	10.18	10.45	1.64							22.28
	3	10.18	10.37	1.64							22.19
Total weight											66.47

TABLE III B: SUMMARY OF THE TOTAL WEIGHT (TON) OF CARGO DISTRIBUTED THROUGHOUT THE PROJECTS.

Project	*Floor*	*TOTAL WEIGHT OF THE TRUCK*									*Total weight/floor*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9 to 16*	
Pelarsalen	**1**	12.55	4.94	9.47	9.11	1.97	1.71				39.74
	2	12.41	4.52	10.09	8.82	2.09	1.50				39.42
	3	12.41	4.52	10.09	8.82	2.09	1.50				39.42
	4	12.41	4.52	10.09	8.82	2.09	1.50				39.42
	5	12.41	4.52	10.09	8.82	2.09	1.50				39.42
Total weight											197.44

TABLE III C: SUMMARY OF THE TOTAL WEIGHT (TON) OF CARGO DISTRIBUTED THROUGHOUT THE PROJECTS

Project	*Floor*	*Total weight of the truck*							*Total weight/floor*
		1	*2*	*3*	*4 & 5*	*6*	*7 & 8*	*9 to 16*	
Vattentornet	**1**	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	2	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	3	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	4	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	5	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	6	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	7	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	8	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	9	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	10	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	11	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	12	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	13	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	14	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	15	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	16	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	17	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
	18	32.67	34.05	35.62	65.40	26.00	36.00	144.00	373.75
Total weight									6727.43

D. Assumptions

Several assumptions have been required since the prefabricated building elements in wood and concrete cannot directly be compared to each other. Any loose material distributed to the projects based on a wood-building solution has been excluded from the data since the building project in concrete receives similar cargo by a dedicated vehicle at a later stage.

All included outer walls in concrete or wood are assumed to be comparable, sufficiently equipped containing insulation, windows, etc. None of the projects has façade mounted at the factory, which is done at the building site.

The examined inner walls are not entirely comparable. Concrete inner walls are shells that require on-site completion by pouring concrete in the void. These additional transports of liquid concrete have been included in the calculations for the inner walls to be comparable with the wooden solution. Each floor at the different projects has approximately the same number of inner and outer walls compared to the total floor space.

The floors and beams differ between the different building projects. Concrete has to be poured in the empty void of the floor panels to generate the same load-bearing properties as those included in the wood projects. Hence, trucks delivering liquid concrete have been included in the calculations for the concrete project. The floors at Vattentornet has a thickness of 310 mm, which is thicker than usual due to the requirement of a relatively tall building. However, the floors would only have to be 250 mm if should have been comparable to the the six floors of Pelarsalen. Therefore, all calculations for the concrete project will assume it is 250 mm to be comparable.

The various projects have different designs in which surfaces are used for other purposes than accommodation, e.g. gyms, receptions, meeting rooms, shops, etc. These specific areas have been ignored and factored as possible accommodations since space utilisation is up to each building contractor. Furthermore, the engine types used for the different transports was not available for this study. Therefore, an average fuel consumption rate was developed in conjunction with the HBEFA model.

IV. MODEL DEVELOPMENT AND RESULT

The input into the model development is based on the reviewed theoretical platform, as well as the data included in Tables I, II and III above. Hence, three models have been developed to highlight the difference in relation to the number of required transports between multi-family houses using a building solution based on concrete or wood. In Equation (1), weight per m^2 distributed (M_{kg/m^2}) was developed to illustrate weight being a constraint for concrete buildings and volume being a bottleneck for wood buildings.

$$\frac{M_{tot}}{A_{tot}} = M_{kg/m^2} \tag{1}$$

where: M_{tot} is the total weight of the building components included in this study and A_{tot} is the total area of all floors in the building. Equation (2) display the number of transports/m^2 (N_{transp/m^2}) required to build X m^2, which will enable a comparison between the projects irrespectively of their difference size.

$$\frac{N_{transp}}{A_{tot}} = N_{transp/m^2} \tag{2}$$

where: N_{transp} is the total number of transports associated with one building project, and A_{tot} is the total area of all floors in the building. Equation (3) calculates the emissions rate, CO_2, g (E_g), caused by the transportation of building elements in wood or concrete. Therefore, it takes into consideration driving distance and the possible impact of any external return loads. Environmental calculations are based on diesel since this is the most common type of fuel used for heavy vehicles in Sweden. Focused is only on CO_2 emissions due to the direct negative impact on the environment.

$$C_{g/km} \times D_{km} \times F_g = E_g \quad (3)$$

where: $C_{g/km}$ is the fuel consumption in gram per kilometre, and D_{km} is the driving distance in kilometres, and F_g is the conversion factor for diesel to CO_2. Estimations were made in regards to the calculations of emission rates for transports of prefabricated wooden building elements, based on Table I. An average value had to be derived from the vehicle weight and the weight of an average load, considering the normal weight is between 20-30 % of the maximum load weight. Therefore, an average of 25 % on the average load consumption in Table I was used, providing a fuel consumption of 284.5 (g/km).

The fuel consumption for concrete transports will be based on full load, as the utilisation rate of the transporters is between 69-95 % of the maximum weight. However, all but one of the transports have a utilisation rate between 87-95 %. Therefore, an average of 91 % will be used on the full load in Table I, providing a fuel consumption of 382.7 (g/km).

A. Kvillebäcken

The outer- and inner- walls, combined with the floor beams for the first three floors had a total weight of 66.46 tonnes spread over 810 m^2, requiring 8.6 transports to complete. The distance between the manufacturer and Kvillebäcken is approximately 31 km with no optimisations made by a return load. The weight/m^2, transport/m^2 and total emission released by one transport cycle is displayed in Table IV.

B. Pelarsalen

The outer- and inner- walls, including beams, for Pelarsalen had a total weight of 197.45 tonnes, based on 2 580 m^2 over five floors, requiring 26.7 transports to complete. The distance between Pelarsalen and the manufacturer's production site is 255 km. Some of the transports had a return load. The weight/m^2, transport/m^2 and total emission released by one transport cycle is displayed in Table IV.

C. Vattentornet

The total weight of the outer- and inner- walls, floors and required liquid concrete for the 18 floors at Vattentornet was 6 727.42 tonnes based on 5 328 m^2 built-up area, requiring 288.0 transports. The distance between the manufacturing plant and Vattentornet is 31 km, and there were no return loads. The weight/m^2, transport/m^2 and total emission released by one transport cycle is displayed in Table IV.

TABLE IV: CALCULATED KEY FIGURES FOR THE STUDIED BUILDING PROJECT

Project	*Kvillebäcken*	*Pelarsalen*	*Vattentornet*
Weight/m^2	82.1	76.5	1262.7
Number of transports/m^2	0.0107	0.0103	0.0541
Emission/ transport cycle (kg CO_2)	52.7	228.5	62.6

D. Calculated Ratios Between the Studied Projects

The calculations have been delimited based on the different building methods for concrete and wood in these projects, receiving a valid comparison between the projects. The result can be applied in calculating environmental impact but also for factors such as cost and efficiency.

Weight/m^2: The weight differences between wood and concrete are compared to determine how much one m^2 of a prefabricated concrete building weigh in comparison to a building based on wood, Table V.

TABLE V: WEIGHT RATIO BETWEEN WOOD AND CONCRETE

Category		
Weight/m^2 (wood)	79.30	kg/m^2
Weight/m^2 (concrete)	1262.70	kg/m^2
Comparative value between wood and concrete	15.923	kg/m^2

Based on these calculations, a prefabricated concrete building is 15.923 times heavier/m^2 than a comparable building using prefabricated wood elements. This identifies weight as the key constraint for transportation of concrete building prefabricated building elements in comparison to similar space based on a wood solution.

Transports/m^2: The required number of transports of wooden and concrete prefabricated building elements are being compared in Table VI.

TABLE VI: TRANSPORT RATIO BETWEEN WOOD AND CONCRETE

Category		
Transports/m^2 (wood)	0.0105	transports/m^2
Transports/m^2 (concrete)	0.0541	transports/m^2
Comparative value between wood and concrete	5.1524	transports/m^2

It requires 5.15 more transports to distribute one m^2 of a prefabricated multi-family house of concrete than of wood.

Emissions: The environmental impact differs between concrete and wooden elements dependent on driving distance, gross weight of the transport and if there are return loads from the building site, and is displayed in Table 7.

TABLE VII: EMISSION RATIO BETWEEN WOOD AND CONCRETE

Category		
Outbound fuel consumption (wood)	284.5	g/km
Outbound fuel consumption (concrete)	382.7	g/km
Inbound fuel consumption (wood & concrete)	258.0	g/km
Comparative value between wood and concrete (outbound transport)	1.35	CO_2, g
Comparative value between wood and concrete (total transport cycle)	1.18	CO_2, g

Based on this model, approximately 1.35 more CO_2 are released by a truck distributing prefabricated concrete elements in comparison to transports of prefabricated wooden elements. However, return loads are not included in the calculations, and the return transport will be treated as an empty transport from the building site. This provides a comparative value between wood and concrete of 1.18 CO_2.

V. DISCUSSION AND CONCLUSIONS

There is currently a construction boom in Sweden, which has high environmental implications throughout the building process where transportation is one important component responsible for emissions and by understanding the total transport requirement based on material choice and building size provides increased opportunities for optimisation and control. Transportation using heavy vehicle accounts for 86 % of freight traffic in Sweden and show limited signs of reducing emission rates [23]. Currently, there are no standards or rules for how much CO_2 emissions a heavy truck may release based on the usage of diesel. The environmental calculations for this study are based on diesel for all the transports, and the calculations are based on information about fuel consumption (g/km), vehicle driving distance (km) and the conversion factor of the fuel to CO_2 [26].

The purpose of the study was to create an understanding of the different environmental impact between transportation to different types of building projects based on prefabricated building elements out of wood or concrete. The resource utilisation for transportation is a challenge, and volume has proven to be a constraint for prefabricated wood elements, and weight has been the bottleneck for prefabricated concrete elements. Hence, the result showed similar tendencies with high weight utilisation for concrete and, high volume utilisation for the wood building solution, as in the study conducted by the British government that investigated the effect of resource utilisation related to maximum weight or volume constraints [10].

Furthermore, the majority of transports were only utilised one way, due to the required specialised handling equipment limiting the possibility to maximise the utilisation rate by a return load. The overall utilisation will increase for an end-to-end transport if a return load is considered as a possible unexplored recourse [20]. The required number of transports for a multi-family house in wood or concrete can be calculated using the number of transports/m^2, which equates to 0.0105 transports/m^2 for projects based on a wooden building solution or 0.0541 transports/m^2 for concrete buildings. The information generates a possibility to calculate the transport-related CO_2 emissions for a multi-family building project. This is conducted using the transport ration for the appropriate material choice, in Table 6, and multiplying it with the built-up area for the specific building project, after that multiplying it with Equation (3) (including or excluding return loads from building site) inserted with data from Table 7 based on material choice. Thus, building based on prefabricated concrete elements require 5.1524 times more transports than the equivalent solution based on wood and, building solutions based on concrete generate 6.0851 times higher environmental impact than prefabricated wood solutions. Furthermore, concrete solutions have greater difficulties utilising the possibilities for return loads, which minimise the possible utilisation rate and increase the environmental impact beyond the five times mentioned above [22], [20].

The findings in this paper can be used to calculate the required number of transports when constructing a multi-family house in wood or concrete, simply by providing the total number of m^2, which can be beneficial for planning purposes in constricted urban areas. But more importantly the amount of CO_2 emissions released during the transportation of prefabricated building elements in wood or concrete, Equation (4),

$$\left(A_{tot} \times N_{transports/m^2}\right) \times \left(\left(D_{km}^{out} \times C_{g/km}^{out} + D_{km}^{return} \times C_{g/km}^{return}\right) \times F_g\right) = E_g^{tot} \quad (4)$$

Equation (4) can be used by builders, transport companies and government agencies to further optimise their transport activities and to increase the awareness of the environmental impact within specific areas of the construction industry. This can support the development of a comprehensive LCA models providing greater understanding of each stage of the building process. Also, despite wood having an environmental advantage during the transportation phase of the building process, is the driving distance from the production site to the construction site influencing the environmental impact. Hence, the well-established infrastructure of production sites for concrete solutions can provide a better environmental solution than those for production of wood buildings, based on driving distance alone. Further, this comparative study is only based on three building projects, which can be seen as a limitation. Therefore, it is to be seen as indicative how transportation influences the industry, providing room for further studies.

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