CO_2 emissions from Super-light Structures

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Summary

CO_2 emission from the construction of buildings is seldom taken into account because focus is primarily on building operation. New technologies have therefore mainly been developed to reduce the energy consumption connected to operation. Super-light technology is a new structural principle giving rise to a substantial reduction of the CO_2 emission in the construction phase. The present paper describes how the CO_2 emission is reduced when using Super-light technology instead of traditional structural components. Estimations of the CO_2 emissions from a number of projects using various construction methods suggest that building with Super-light structures may cut the CO_2 emission in half, compared to traditional concrete structures, and reduce it to 25% compared to traditional steel structures.

Keywords: *Super-light, concrete structure, clean technology, CO_2 emission.*

1. Introduction

The building sector has significant potential to become more sustainable, both in terms of its use of natural resources, energy consumption connected to construction and operation, use of environmentally damaging materials, generation of waste, and reuse of materials and building parts.

1.1 Energy consumption in the building sector

When considering man's total use of energy 30-40% is used in the building sector for operational activities during the buildings' lifetime, such as heating, cooling, lighting, appliances etc., 10% is used to produce building materials and components, transport and construction of the buildings, and only a small percentage is used in demolition and recycling of building parts.

Since operating accounts for the largest energy consumption, energy savings in this area is most often in focus when new solutions and products are developed for the building industry. Technology is continuously developed by means of which energy consumption for operation is reduced dramatically, even to nil or to negative values in passive- or plus-energy houses. These technological efforts should always be evaluated together with emissions from the construction, since bad choice of materials and structures can result in unnecessary emissions during construction, which may never be gained by the savings obtained in the operation.

When emissions from operation are reduced dramatically, it becomes increasingly important to consider the contribution from construction.

1.2 Terms used

The term *carbon footprint* refers to the amount of greenhouse gas emissions caused by a product, across the product's entire life cycle. The determination of such a value involves an assessment of the emissions associated with attaining the raw material, the fabrication of the product, distribution, consumer use and disposal/reuse. Methods of determining the carbon footprint of a product can be found in e.g. [1].

The term *embodied energy* in connection with buildings refers to the energy consumed by the production of the building materials and components.

When assessing the carbon footprint of a building, the building's lifetime can be divided into five phases [2]. The first phase involves the manufacturing of materials and components, which corresponds to the embodied energy of the building. The second phase is the transport of materials and components to the building site, and the third phase is the construction process. The fourth phase is the service life of the building – the energy consumption during this phase is connected to operation and renovation. The fifth phase is the demolition process, and possible recycling of materials or building parts.

1.3 Scope of this paper

This paper focuses on the embodied energy in components of a new structural concept called Super-light structures [3]-[7]. Values for the embodied energy in Super-light structural elements are in the following assessed and compared to corresponding values for traditional structural solutions. The comparison shows that significant savings in the emission of CO_2 can be attained when using Super-light technology instead of traditional solutions.

Data for CO_2 emissions for different activities and products seem to vary considerably in different sources of information, because local conditions and production methods have a large influence on the results. In addition, the data varies considerably with the age of the source, as production methods have improved greatly over the years. The data used in the present analysis is therefore assessed as the best estimates from a number of sources.

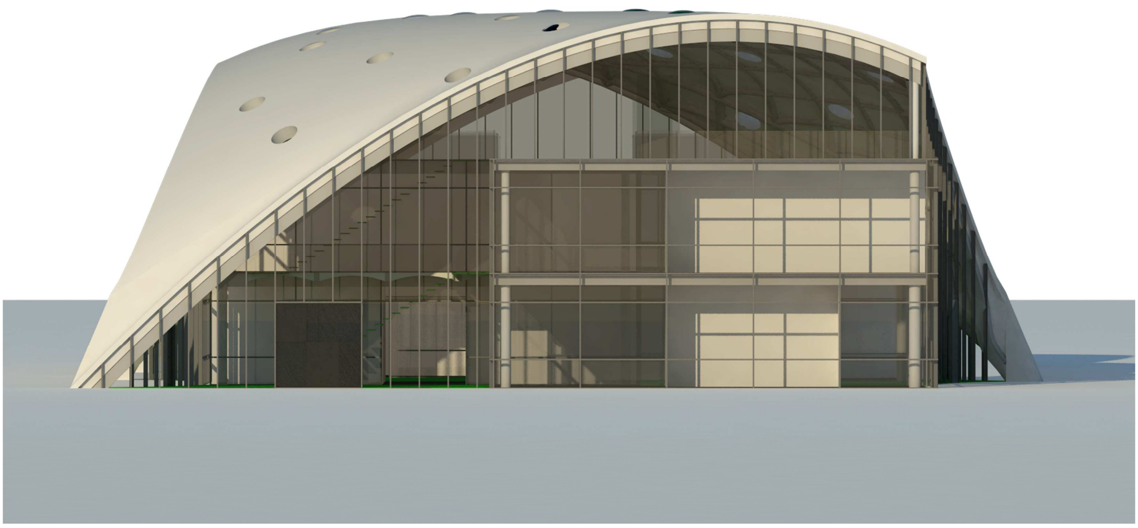

Fig. 1: Super-light student project with ribbed shell and Pi-Omega system. By Andreas Castberg.

2. Embodied energy in concrete structures

Production of cement is estimated to contribute to 5% of the total CO_2 emissions caused by man [2]. In the production of concrete, cement is by far the largest contributor to the embodied energy. Methods to bring down this contribution could therefore have a significant effect on the total amount of CO_2 emissions.

Cement is produced by heating carbonates and other minerals to 1400 degrees, and thereafter pulverizing the material. On average, 50% of the CO_2 emissions from this process stem from the chemical changes of the raw materials, 40% from fuel combustion and 5% from electric power and transport [2]. Due to the carbonation process in the cement, a part of the CO_2 is bound back into the concrete over time [8]. This effect is not reflected in values for embodied energy, as these refer only to the production process.

A part of the cement in concrete is replaced with other hydraulic binders, including ground blast-furnace and fly ash, which are waste products from other industries.

A possible way to bring down CO_2 emissions from cement production is to optimize the heating process, so that less heat is lost.

Another way is to simply use less cement in concrete structures. This can be achieved by using more than one type of concrete in a given structural element: in areas with smaller stresses, a lighter concrete with lower cement content can be used.

Super-light structures are invented at Technical University of Denmark, and the concept won the Danish championship for Clean Technology in November 2010 as well as the World championship (Clean Tech Open Global Ideas) in San Francisco the same year. This technology uses the idea to use more than one type of concrete in a structural element, thereby minimizing the weight of the element as well as the amount of cement. This results in a considerably lower amount of embodied energy in Super-light structures compared to normal concrete structures, as shown by the following calculations.

2.1 Embodied energy in Super-light structures

Super-light structures consist of normal concrete (or high strength concrete), light concrete and as little steel as possible [3]-[7]. Some examples are shown in Figures 1, 2 and 3.

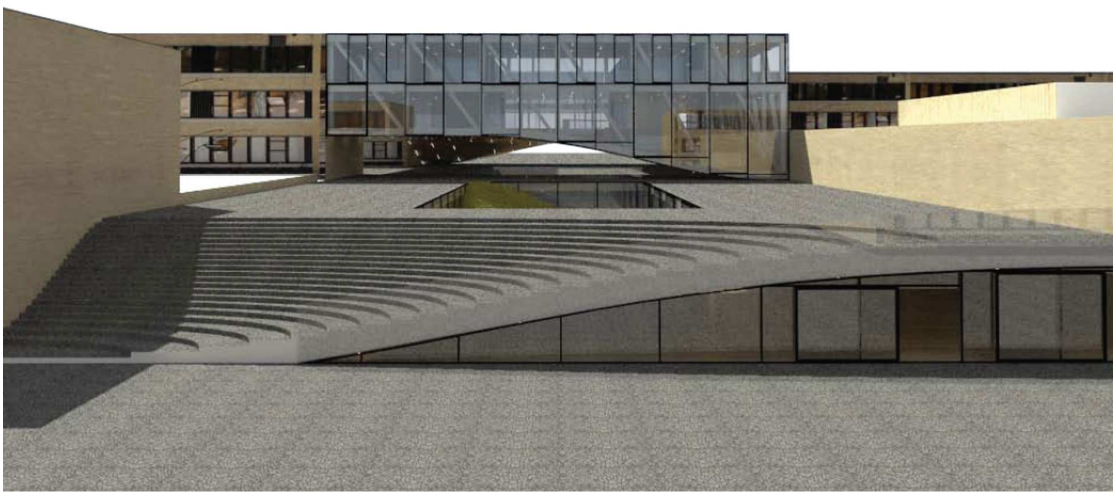

Fig. 2: Super-light proposal for DTU Building 324. Architect BIG, Engineer Werner Sobek.

The light concrete can be made from a variety of materials. Their CO_2 emissions differ from place to place because of differences in natural resources and the transport distances to them.

In Table 1, values for the embodied energy for the different materials used in traditional and Super-light structures are listed. The values are found by using information from [1], [8], [9], [10], and [11]. The values for the light concrete do not include emissions stemming from attaining the sand, as this contribution to the embodied energy is assumed negligible compared to the other processes. The light concrete with expanded clay assumes a heating of clay to 1200 degrees, with a heat loss of 50% from the oven, and a heat capacity of the clay of 1 kJ/kg/C. The light concrete which uses pumice is assumed produced in an area where pumice is readily available, except from “Light concrete, pumice in DK” which is assumed produced in Denmark, using pumice from Iceland which is then transported to Denmark by ship.

Tables 2 and 3 refer some values used to find the values in Table 1.

Table 1: Embodied energy in building materials

Material	kg CO_2 / kg	kg CO_2 / m^3
Steel	3,00	23600
Concrete, 40MPa, 2300 kg/m^3	0,160	367
Light concrete, expanded clay, 900 kg/m^3	0,220	198
Light concrete, expanded clay, 600 kg/m^3	0,306	183
Light concrete, pumice, 900 kg/m^3	0,166	149
Light concrete, pumice, 600 kg/m^3	0,225	135
Light concrete, pumice in DK, 900 kg/m^3	0,174	156
Light concrete, pumice in DK, 600 kg/m^3	0,232	139
Foam concrete, 900 kg/m^3	0,322	290
Foam concrete, 600 kg/m^3	0,467	280

Table 2: CO_2 emission from energy production [10]

Fuel	kg CO_2 / kWh	kg CO_2 / MJ
Diesel oil or gas	0,24	0,067
Coal or wood	0,37	0,103
Estimated weighted average	0,3	0,09

Table 3: CO_2 emission from transport [12]

Transport method	
Ship	13 g CO_2 / km / ton
Railway	23 g CO_2 / km / ton
Truck	120 g CO_2 / km / ton
Car	1 kg CO_2 / 8km

A typical example can be a shopping centre with 15 m column distance. Such a structure has been designed using traditional Danish prestressed TT concrete beam elements, which traditionally is among the most economic structures for the purpose.

Below, it is compared to a new prefabricated Super-light structural system called “Pi-Omega”, which uses a light concrete with expanded clay aggregates.

The traditional concrete structure uses 682 kg concrete and 7,6 kg steel pr. m^2 which yields an embodied energy of **132 kg CO_2/m^2**.

If the deck structure is done as a steel structure, where 100 kg steel pr. m^2 is assumed, the embodied energy of the structure is **300 kg CO_2/m^2**. This does not include embodied energy in the fire protection of the steel.

The Super-light structure uses 241 kg concrete, 120 kg light concrete and 3,7 kg steel pr. m^2, and this yields an embodied energy of **77 kg CO_2/m^2**.

For a 90.000 m^2 shopping centre, when comparing Super-light technology to traditional concrete structure, the total saving is roughly 5000 ton CO_2. This is comparable to the emission from a car driving a distance equal to 1000 times around the world.

In addition to these savings from the production of the materials, Super-light structures results in energy savings from the production of lighter moulds, saving of scaffoldings, lighter transport and lighter erection, and in the operation phase also from better insulation of the building. These values are not reflected in the embodied energy, as this value only refers to the production of the structural elements.

Other examples like this indicate that Super-light structures can often halve the CO_2 emission from construction of a raw concrete building and reduce it to 25% of that of a similar steel building.

Fig. 3: Opus Shopping Centre. Architects Årstiderne.

3. Conclusion

Comparison of the embodied energy of a typical industrial building, when considering Super-light structures and a traditional concrete structure respectively, show that CO_2 emissions from a raw building may be reduced by as much as 50% when using Super-light instead of concrete structures and even 75% if steel is the alternative. In Super-light structures the internal distribution of load carrying material in the structural elements is optimized, so that material is concentrated where the loads are greatest, and minimized in areas with less load. This reduces the need for cement and steel, which again has a significant effect on the embodied energy.

In the present study, a typical structural system of slabs has been considered, in order to make as direct a comparison to traditional load carrying elements as possible. However, when designing a building with Super-light structures, other load carrying systems can be applied, which utilize the advantages of this structural principle even better.

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