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High-Rise Timber Buildings as a Climate Change Mitigation Measure - A Comparative LCA of Structural System Alternatives

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Abstract

This paper reports on a study examining the potential of reducing greenhouse gas (GHG) emissions from the building sector by substituting multi-storey steel and concrete building structures with timber structures. Life cycle assessment (LCA) is applied to compare the climate change impact (CC) of a reinforced concrete (RC) benchmark structure to the CC of an alternative timber structure for four buildings ranging from 3 to 21 storeys. The timber structures are dimensioned to meet the same load criteria as the benchmark structures. The LCA comprises three calculation approaches differing in analysis perspective, allocation methods, and modelling of biogenic CO_2 and carbonation of concrete. Irrespective of the assumptions made, the timber structures cause lower CC than the RC structures. By applying attributional LCA, the timber structures are found to cause a CC that is 34-84 % lower than the RC structures. The large span is due to different building heights and methodological assumptions. The CC saving per m^2 floor area obtained by substituting a RC structure with a timber structure decrease slightly with building height up to 12 storeys, but increase from 12 to 21 storeys. From a consequential LCA perspective, constructing timber structures can result in avoided GHG emissions, indicated by a negative CC. Compared to the RC structures, this equal savings greater than 100 %.

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Keywords: High-rise buildings, timber buildings, LCA, climate change mitigation, CLT

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1. Introduction

In their fifth assessment report [1], the Intergovernmental Panel on Climate Change (IPCC) confirms that there is a 95% probability that human influence is the dominant cause of climate change. The temperature increase needs to be stabilised below 2°C relative to pre-industrial levels in order to prevent severe and irreversible impacts on the climate system. Reaching this target requires an urgent and fundamental departure from business as usual. Alongside reducing anthropogenic greenhouse gas (GHG) emissions to maintain global warming below 2°C, several counteracting trends need to be handled: Rapid population growth, extensive migration to cities and increased levels of wealth for billions of people in developing countries. UN Habitat estimates that 3 billion people will need a new home in the next 20 years [2]. In 2010 buildings accounted for 35% of total global energy use, and 19% of energy-related GHG emissions [3]. This energy use and related emissions may double or potentially triple by 2050 if business as usual is practiced to meet our demands. Consequently, reducing the energy use and climate change impacts of buildings is seen as a critical climate change mitigation measure by the IPCC.

The last decades have seen extensive efforts to increase the efficiency of building operations, to reduce the related energy use and GHG emissions. With reduced energy consumption and GHG emissions in the use phase, the relative contribution from building materials increase. In new energy-efficient buildings, the embodied energy use related to construction, transport and production of building materials and demolition can constitute 40-50 % of the total life cycle energy consumption [4, 5]. The embodied GHG emissions can be even more significant than the embodied energy use [6], due to the hitherto stricter regulations governing renewable energy use in building operation, than in building materials production. Embodied GHG emissions can constitute more than 50-60 % of the total life cycle GHG emissions for modern buildings. EU's revised Directive on Energy Performance of Buildings (EPBD2) states that all buildings shall be built as "nearly zero energy buildings" by 2020. In buildings where the operational energy use is to a large extent balanced by renewable energy production on the building site, embodied energy will account for up to 100 % of net energy consumption. The next step in reducing building sector GHG emissions is thus to minimise energy use related to production and transport of building materials.

The combination of population growth and GHG emission reduction targets stimulates construction of more densely concentrated urban areas with high-rise buildings. Dense cities allow for increased public transportation and less car travel. In addition, denser cities with multi-unit apartment buildings have a reduced energy need for residential heating due to a lower building surface to volume ratio and more shared walls [7, 8]. However, constructing taller comes with a "structural premium": taller buildings require stronger structures, and have greater use of materials per floor area [9]. As an effect, high-rise buildings have higher embodied energy use and GHG emissions per m^2 floor area compared to low-rise buildings. This have been described in the literature as the "energy premium" and the "CO_2 premium" for building height [10-14]. Thus, choosing environmental friendly construction materials is especially important for taller buildings.

Structural systems for high-rise buildings have traditionally consisted of steel and concrete. Production of these materials is energy and emission intensive, and accounts for a great portion of total GHG emissions from materials production in the building sector. Timber building materials prove to cause considerably lower climate change impact (CC) than materials of steel and concrete [15-20]. The interest in multi-storey and high-rise timber buildings has consequently grown around the world, and several structural systems for high-rise timber buildings have been proposed [21-23].

The purpose of this study is to assess the potential of reducing GHG emissions from the structural systems of multi-storey buildings by substituting structures of reinforced concrete (RC) with timber structures. Life cycle assessment (LCA) is applied to compare the CC of a RC structure with a corresponding timber structure, for building heights of 3, 7, 12 and 21 storeys. The CC per m^2 gross floor area (GFA) is plotted as a function of building height for both structural alternatives, to investigate the relation between building height and GHG saving potential. Different methodological approaches are applied in order to get a holistic picture of the CC of the different structural alternatives.