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Case study

Increasing the sustainability potential of a reinforced concrete building through design strategies: Case study

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ABSTRACT

This paper aims to investigate the influence of design strategies on the economic and environmental performance of 30-storey residential reinforced concrete (RC) building located in the Southern Brazil, through a case study. Four design options are simulated for the same building, including structural design as rigid frame system or hinged frame system with second order/P delta effects. In both cases buildings were designed with concrete strength class 25 MPa (C25) applied in all the structural elements or a concrete strength class range of 50 MPa to 25 MPa (C25–C50) applied in columns, varying along the building height. Environmental impacts were quantified through Life Cycle Assessment (LCA) based on measurements of environmental loads of processes and products, from cradle to grave. Results show reduction of environmental impacts, embodied energy and construction costs when a decrease in the amount of steel is combined with the increase in the concrete compressive strength of columns, which is more representative for the building designed as hinged frame system. The production of materials phase showed to be the major contributor to environmental impacts with steel and concrete being the most relevant impact producers. Concrete represents important impacts for stratospheric ozone depletion and climate change while steel dominates the ecotoxicity-related indicators. Results highlight the importance of design strategies to increase the sustainability potential of a RC structure and contribute to consolidate contemporary approaches that suggest the need to incorporate the degree of environmental impacts in design methods.

1. Research significance

Building and construction sector is a major contributor for CO_2 emissions, accounting for about 30% of all energy-related greenhouse gas (GHG) emissions [1–4]. Apart from that, it is responsible for about 40% of global resource use, including 12% of all fresh-water [5]. Nevertheless, there is a great potential of CO_2 emission reduction in the building and construction sector, especially in developed and developing countries [5,6].

Concrete is one of the most important building material in the world and is the second most commonly used product in the planet, after water [7,8]. Thus, considering the volume of concrete produced and the environmental impacts associated, the design of optimized reinforced concrete (RC) structures is a goal to the sustainable development. Global CO_2 emissions

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from fossil fuel combustion, cement production and other industrial processes account for about 70% of total global greenhouse gas emissions, and were estimated at a total of 35.8 $GtCO_2$ for 2016 [6]. In Brazil, production of cement is responsible for 8.5% of the CO_2 emissions due to calcination of raw materials and burning fuels, against 28.9% of steel, considering industrial process and energy sectors [9]. Such emissions can be reduced significantly through a more efficient use of both concrete and steel, which can be achieved by optimization, or even by reflecting emissions of each structural material in the design stage [10–13]. In fact, reducing material requirements is only one of a wide range of measures that can effectively reduce environmental impacts of the construction industry [14]. According to Vítek [15], application of advanced materials, efficient structural systems, and appropriate construction technology are examples of strategies to build RC structures that satisfy sustainable design criteria.

Typically, RC structures are designed to satisfy a wide range of criteria such as safety, serviceability, and durability [15], while measures to reduce energy consumption are rarely incorporated [14]. There are few studies, for instance, reporting environmental impact assessment or embodied energy of different design alternatives for the same building, even though it is well stablished that at the design phase, environmental impact reductions are, according to [16], cost-savings.

The quantification of environmental impacts for any particular building is an inexact science and requires an evaluation considering the entire life cycle of the building, which can be achieved through Life Cycle Assessment - LCA [7,13,17–21], specified in ISO Standards. However, performing an LCA is a complex and time-consuming task and experts are constantly improving the methodology in order to solve issues related to inconsistency, transparency, comparability and data quality and availability [22]. LCA has been widely used in the construction sector [3,7,17–20,23–25]. LCA can be applied to buildings on different levels, including building materials and products, building parts and elements, whole buildings and even entire neighbourhoods [22]. Furthermore, the environmental evaluation of a RC structure requires the environmental impact assessment during production of materials, construction, maintenance, use/operation, and end of life. Given the millions of tonnes of materials used in construction projects all over the world, the emissions associated with materials are always likely to be significant to the emissions during the whole building lifetime [3]. The operation phase, on the other hand, is considered the main responsible for the largest portion of the total emissions of a RC building [3,12,26]. However, the use phase represents only one chapter in the life cycle story of a building [11]. Studies have reported that when the energy matrix includes a strong presence of renewable sources, the structural system becomes one of the main contributors to environmental loads of a RC building. [27–31]. Thus, the importance of energy consumption and CO_2 emissions due to stages other than the use of a building has been increasing in the recent years and the accuracy of prediction methodologies has been improved, resulting in more energy efficient building designs [32]. Contemporary approaches regarding sustainability of RC buildings consider that the degree of environmental impacts should be incorporated in design methods as environmental performance additionally to well established serviceability, safety and durability performances [16].

Thus, this paper aims to investigate the influence of structural design and concrete compressive strength on the economic and environmental performance of a RC building, through a case study of a 30-storey residential building.

2. Presentation of the case study

Four design options are simulated, including rigid frame system (BI) and hinged frame system with second order/P delta effects (BII), both with C25 (concrete strength class 25 MPa) applied in all structural elements (MI) or a C50-C25 (concrete strength class 50 MPa to 25 MPa) range applied in columns varying along the building height (MII). Complementary data about RC buildings and structural design procedures are provided in the supplementary material.

2.1. Life cycle assessment

Life Cycle Assessment (LCA), based on international standards series ISO 14040 and ISO 14044 [53,54], has been used to assess the environmental impact generated by the different structural systems. Analysis has been performed with Open LCA, free LCA software with open source code [33]. The LCA methodology used to perform the environmental impact analysis involves four iterative phases (definition of the goal and scope, inventory analysis, impact assessment, and results interpretation). Environmental loads of processes and products are considered during the entire life cycle of the building, from cradle to grave.

2.1.1. Goal and scope

The goal of the study is to assess and compare environmental impacts of four different structural design solutions for a 30-storey residential building, located in the Southern Brazil. Thus, the functional unit is the structural system of a 30-storey residential building over its service life. The functional unit presents equivalent load-bearing capacity in all assesses scenarios. Fig. 1 shows boundaries of the studied system.

Production of Materials, which corresponds to Product stage of BS 15978 [52], includes raw material supply (A1), transport (A2), and manufacturing (A3) of concrete, steel, and wood formwork. Construction of the RC Structure corresponds to Construction Process stage of BS 15978 [52] and includes transport (A4) and construction/installation process (A5). End of Life includes demolition (C1), transport (C2), waste processing (C3), and disposal (C4), in accordance with End of Life stage of BS 15978 [52]. Use stage defined in BS 15978 [52] is not in the scope of this paper. Use (B1), maintenance (B2), repair (B3),