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Environmental impact as a parameter in concrete structure parametric associative models

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HIGHLIGHTS

- A practical engineering tool is being developed for structural engineers.
- The tool should create awareness about the environmental impact of design choices.
- A case study using a simple concrete beam has demonstrated the method.
- Using parametric modelling gives more insight in complex interrelations.

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ABSTRACT

A practical engineering tool is being developed for structural engineers. The tool allows for an engineer to quickly evaluate structural element design variations for structural performance, while adding information on environmental performance. This paper explains the structure of the tool and uses the design of a concrete beam element as a case to demonstrate its functioning. The tool is to be expanded to include more materials, building costs and complete building structures in its intended environment.

1. Introduction

The construction, use and demolition of buildings are sources of a significant part of human-induced environmental burden [1]. Currently, energy consumption in the total building stock is responsible for most of the environmental burden. However, as new buildings are increasingly energy efficient, the environmental burden related to the use of construction material resources in those buildings is becoming more important.

European and national policies contain regulations on building materials. The use of certain materials such as asbestos is prohibited for health and safety reasons. Furthermore, the European Union (EU) has developed an Integrated Product Policy (IPP) approach which seeks to improve the environmental performance in each phase of the life cycle of products [2]. One of the tools is the Environmental Product Declaration (EPD). An EPD contains environmental information about a product, according to the guidelines in the international ISO 14025 standard [3], which allows manufacturers to provide aggregated environmental information without releasing any confidential data. An additional international standard, ISO 21930 [4], is being developed for building products. The current standard is to be revised in the review stage.

In the design practice of new non-residential buildings, concrete structures are mostly not made of standard size building products, but rather they consist of unique compositions specific to the building. A concrete structure is designed based on strength and stiffness of the structure. The type of concrete and the position and amount of rebar reinforcements are decided upon for technical reasons. Environmental considerations are rarely taken into account, mainly because there is no suitable instrument available.

The IPP concludes that life cycle assessment (LCA) is the best available instrument for assessing the environmental impacts of products [5]. LCA has also been adopted in the ISO 14025/ISO 21930 international standards. However, in the early design phases LCA is a highly impractical instrument, because it needs too many detailed data and the calculations take too long to quickly assess alternatives. Therefore, a design tool has been developed which aids in finding different compositions of concrete structural elements that are strong and stiff enough, while providing information on the environmental impact of the elements. Subsequently, the tool provides insight into how to improve the environmental performance of the elements. In the current version, the tool is suitable for the design of single structural elements, namely floor

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beams, in normal indoor conditions for utility or residential buildings. The intention is to expand the tool to include other structural elements in relation to each other, including different material options.

The objective of this paper is to introduce this new practical tool and show its possibilities. It explains the parameters and interrelations in the tool. The structural calculation model is based on simplified Eurocode guidelines, while the environmental impact of materials is calculated by using life cycle assessment (LCA) and the ReCiPe method. The use of the modeling tool is shown by outlining the engineering process of a concrete floor building component, including the preconditions and the optimization process within the design boundaries set by the preconditions. For the purposes of this paper, no academic literature has been consulted on design tools. To the knowledge of the authors, no practical tools exist which specifically assist in making quick design decisions during work in daily practice and which complies with the lower level of detail available in early design stages.

The parametric associative model can eventually be used to automatically optimize complete structural building designs, but that is not its intended use in our daily practice. The model shows structural engineers the consequences of design choices with regards to sustainability, challenging them to come up with innovative and more sustainable solutions for concrete structures.

2. Design calculation model

The design model is meant to be used in the early design phase of a new building. Its main purpose is to allow for easy evaluation of structural variations and create awareness of the environmental impact of concrete structural elements. The model has been based on Eurocode structural guidelines and environmental impact data calculated by the ReCiPe LCA method.

2.1. Calculation model structure

The calculation model is built up as shown in Fig. 1. The input parameters are (a) the dimensions of the concrete structure, (b) the amount of steel rebar reinforcement, (c) the material properties and (d) loads. The design process contains two loops. In the first loop, the structural performance is determined by comparing bending moments, axial forces and shear to the capacity of the structure. The capacity is determined using simplified Eurocode 2 guidelines for concrete [6]. If the structural requirements are not met the designer receives visual feedback and should change input parameters. In the second loop the environmental impact is calculated based on the type and mass of the material resources. It shows which material has the highest environmental burden, so the designer knows which parameters to change in order to optimize the structure.

2.2. Eurocode guidelines

A realistic structure should be the input for the optimization with regard to sustainability. Parametric associative modeling gives plenty of possibilities to model a structure, where one can go as much in detail as one likes. However for insight in certain design choices it is not necessary to get very detailed information and a simplification of both the mechanics and the material properties is justified. In a lot of situations it is even better, because the number of parameters is limited to only the relevant parameters, it reduces calculation time and gives a better insight in the process. However it asks also some structural knowledge of the user, because he or she is responsible for the right input.

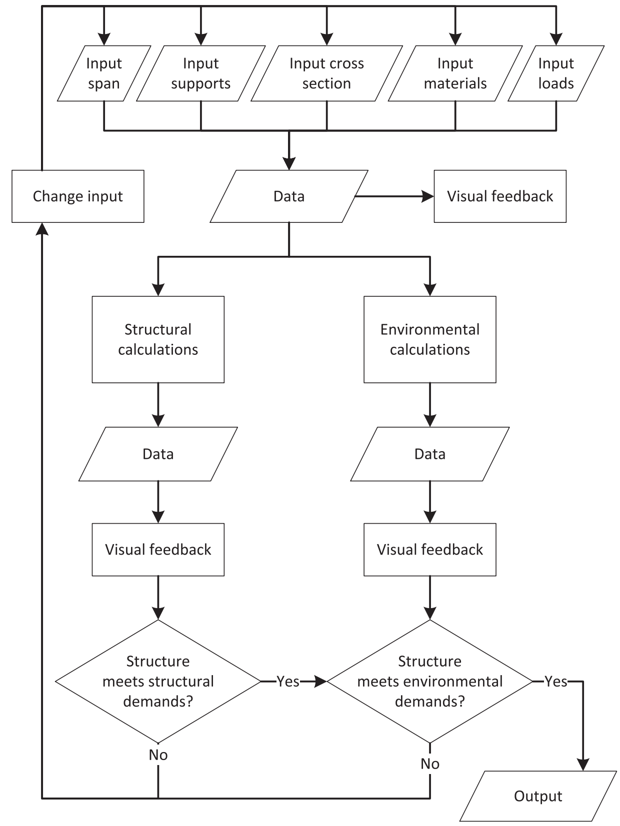

Fig. 1. Scheme of the calculation model.

The Eurocode 2 guidelines for concrete provide some convenient rules to check the structural performance and to generate quantities of steel and concrete. In this example model the Eurocode guidelines are simplified as much as possible, which results in conservative values. However when required the structure could be optimized adding more detailed calculation tools.

2.3. ReCiPe method

In life cycle assessment (LCA) several methods can be used to assess the impact of a substance. Two frequently used methods in scientific LCA research are the CML 2000 baseline method and the Eco-indicator 99 method. The CML method uses multiple indicators at midpoint level [7], while the Eco-indicator includes multiple endpoint indicators that can be combined in a single endpoint indicator [8]. Endpoint indicators represent the ultimate consequences of the environmental impacts for humans and ecosystems. They reveal the 'endpoint' of a possible chain of causes and effects. As more environmental mechanisms are involved, one of the weaknesses of these indicators is a higher level of uncertainty in the results [9]. Midpoint indicators, in contrast, show the potential direct negative impact on the environment, which can be situated anywhere along the chain of cause and effect. Both types of indicator are problem-oriented: the higher the score, the worse the environmental performance.

The CML and Eco-indicator methods have been combined in a new method named ReCiPe, which allows the user to display results at different levels along the chain of effects [10]. In this project the ReCiPe method was used to determine the environmental impacts of the concrete building components. Only the environmental effects for the production of raw building materials have been taken into account. The effects have been normalised to Euro-