Quantifying Life Cycle Environmental Benefits of Circular Steel Building Designs

development of an environmental assessment tool for reuse of steel members in building designs for the Netherlands

by

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Abstract

The re-use of building components and structural elements is an underdeveloped practice which could be an important strategy in the global paradigm shift towards a circular economy. Steel is one of the most important structural building materials which combines incredible strength, favourable mechanical properties and excellent durability characteristics. It is practically infinitely recyclable and raw materials required for the production of steel are abundantly available in the Earth's crust. This makes steel one of the most interesting sustainable engineering materials. However, the production process requires vast energy investments and produces considerate environmental pollution. To make steel an increasingly sustainable material and a frontrunner in the global transition towards a circular economy, significant investments and process improvements are necessary. The global environmental challenges of the 21st century demand rapid and far-reaching changes from the steel industry but it also poses opportunities for creative thinking and development of alternative strategies. The re-use of structural steel elements could offer great potential in reducing both the embodied environmental impact of construction works as well as the vast waste streams that result from demolition. There is general consensus on the technical feasibility of this circular alternative across academic literature and the idea enjoys widespread scientific support. Actual implementation is however limited, presumably due to the existence of several multi-level barriers. A diversity of actors along the value chain have indicated that various attitudinal, financial, structural, operational, technological and legislative barriers are preventing widespread adoption. Although some of the identified issues are of a practical nature, various perceived barriers have been identified which were found to be rather subjective. It is to be expected that providing additional information on the risks and opportunities, and by quantitative demonstration of the potential benefits of re-use, several of these perceived barriers could be alleviated. This thesis aims to integrate the potential use of circular steel elements in the structural design process for steelworks as a sustainable alternative to the use of new steel. The developed method allows structural design & engineering professionals to assess the environmental impact of structural steel frameworks with increasing accuracy. Furthermore, it improves the current practice by making the design process reuse-inclusive. It thereby provides design professionals with a tool to assess and communicate the possibilities of improving a design with regard to their inherent sustainability. It was found that the currently prescribed 'fast-track' LCA method, aimed at quantifying the embodied environmental impact of building structures, is highly sensitive and the current method could be leading to large inaccuracies and spread of misinformation. Two dominant national LCIA methodologies have been extensively compared and a sensitivity analysis has been performed for a variety of data resources. It could be concluded that the prescribed national data for steel products contained in the NMD is unverifiable and inconsistent with other resources. This raises serious concerns with regard to the accuracy and reliability of currently used 'fast-track' LCA methods for the Netherlands. It was calculated that the specific LCIA method used and the selection of modules included in the assessment can cause deviations of the estimated shadowprice up to approximately 424%. Subsequently, a tool was developed based on the CML methodology to validate the potential deviations that

could arise from selecting a specific data resource. The application analyses and evaluates structural steel frameworks with regard to their inherent environmental impact. Furthermore it allows the engineer to select and substitute new steel elements with remanufactured counterparts found in a circular steel database. A case study was performed for four different scenarios. Both the LCIA method as well as the considered modules were consistent for all scenarios. From the results it could be concluded that the estimated shadowprice is also highly sensitive to the specific data considered. It was indicated that the input data can lead to deviations of the shadowprice of up to approximately 281%. Furthermore, it was calculated what the potential benefits of reuse would be. It was calculated that substituting 25% of the required steel could lead to reductions of approximately the same magnitude by eliminating the required process for production and cutting the transportation requirements. From the results of this thesis it could be concluded that there is serious inconsistency and limited transparency among the various data resources used for quantifying the environmental impact of steelworks. It is to be expected that the actual shadowcosts deviate significantly from the estimations provided by current assessment methods used in the Netherlands. Failure to accurately quantify the impact of primary building products could lead to significant errors as these materials have a relatively large contribution to the total impact of a building structure. Subsequently, this could lead to misinterpretation of LCA results thereby providing a misleading message for policy- and decision makers. However, it was also illustrated that the remanufacturing and reuse of structural steel profiles could offer significant environmental benefits and has the potential to significantly cut the environmental impact of structural steel framework constructions.

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