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Reducing the environmental impact of concrete and asphalt: a scenario approach

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ABSTRACT

In this paper, measures are evaluated to reduce the environmental impact of concrete and asphalt. Several composition scenarios are designed for these materials and are evaluated based on their environmental performance using life-cycle assessment (LCA). The effect of low-energy production techniques and the application of secondary materials are quantified. The ReCiPe endpoint assessment method is used in order to compare the scenarios. The evaluated concrete-mixes point out that the highest potential for improvement can be realized through application of alternative cement types. The scenarios show a maximum reduction of 39% in environmental impact. The most substantial impact reduction in asphalt can be realized through application of warm-mix asphalt (WMA) instead of hot-mix asphalt (HMA). This yields a reduction of about 33%.

1. Introduction

The construction sector can substantially contribute to a sustainable management of natural resources and materials. The building industry is one of the largest material consumers, responsible for 24% of global material extractions (Bribían et al., 2010). Apart from depletion, this extraction leads to:

- damage to landscape and disruption of ecosystems;
- damage to health by contamination of the indoor- and outdoor environment during production, processing, maintenance, and demolition of building materials caused by emissions, dust, and contact allergens;
- contamination of soil, water, and air by emissions from building materials during use phase.

The impact of reducing material consumption can be very large, since building activities of the construction industry consume about 40% of materials entering the global economy and generate roughly 40–50% of the global output of greenhouse gases and the agents of acid rain (Asif et al., 2007; Anink et al., 1996).

The objective of this study is to gain insight in and improve upon the environmental impact of two building materials: concrete and asphalt. Their influence on the environment is substantial because of frequent application in construction and relatively large individual environmental impact.

In 2009, according to Eurostat the *cement* industry in the European Union is responsible for 38.5% of the total European CO_2 emissions from industry (Vatopoulos and Tzimas, 2012). Understanding the environmental impact of cement manufacturing is therefore becoming increasingly important (Huntzinger and Eatmon, 2009). Reusing industrial by-products is considered as the most promising strategy to curb CO_2 emissions in cement plants.

Working with *asphalt* at high temperatures also produces considerable amounts of greenhouse gas emissions, as well as other chemical pollutants that affect air quality (Rubio et al., 2013). In recent years, new technologies significantly reduced the

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manufacturing temperature of hot asphalt mixes (Rubio et al., 2012). According to Oliveira et al. (2013) the warm-mix asphalt (WMA) technology can reduce the energy required during the manufacturing process and also leads to a decrease of emissions from asphalt plants (Prowell, 2007). Most of the research on WMA so far has focused on analysing its performance and economic benefits because of its reduced energy consumption (Kristjansdottir, 2006; Zaumanis, 2010). Until now, however, the environmental impact of WMA compared to hot asphalt mixes has not been quantified.

In this study, the ReCiPe endpoint assessment method is used as a basis for the quantitative evaluation of environmental performance of concrete and asphalt. It uses three perspectives (Egalitarian (long term focus), Individualist (short term focus) and Hierarchist (balanced in between)) to reflect visions on environmental impacts. Both for concrete as well as asphalt several alternatives are examined. These are distinguished by the extent to which they use secondary or recycled material. These alternatives are evaluated via ReCiPe from each of the above three perspectives. The paper is completed by proposing alternative compositions of concrete and asphalt that significantly reduce environmental impact.

The outline of this paper is as follows. Life-cycle assessment is discussed in Section 2. An overview of existing assessment methods is provided in Section 3. Subsequently, the assessment method used in this study is described in Section 4. The improvement potential of initiatives proposed in literature to reduce the environmental impact of concrete and asphalt is translated into scenarios, which are evaluated from three perspectives in Section 5. Finally, Section 6 states the conclusions, while suggestions for further research are given in Section 7.

2. Life-cycle assessment

Life-cycle assessment (LCA) is "a methodology for evaluating the environmental load of processes and products (goods and services) during their life-cycle from cradle to grave" (Ortiz et al., 2009, p. 29). This cradle-to-grave analysis (Pandey et al., 2011) is generally used for the assessment of individual products, wherefore 'bottom–up' data of specific processes is needed (Ozawa-Meida et al., 2013). It includes all stages of producing a product, from raw materials, through producing, distribution, consumption/use, to the stages of disposal. A life-cycle approach identifies energy use, material inputs, and waste generated from the time raw materials are obtained to the final disposal of the product. Looking at the entire life-cycle helps to ensure that minimizing impact in a single stage does not simply create more impact at another stage in the life-cycle. A core challenge of LCA is the comparability of different product studies, due to different methods and assumptions. A standardization process can help in this respect (Peters, 2010). Furthermore, it is a time- and resource-consuming method (Larsen and Hertwich, 2009).

An LCA consists of four stages (Ortiz et al., 2009; Rebitzer et al., 2004):

1) Planning: goal definition and scoping. It provides a description of the product system in terms of the system boundaries and the functional unit.
2) Inventory analysis (LCI): a methodology for estimating the consumption of resources and the quantities of waste flows and emissions caused by or otherwise attributable to a product's life-cycle. It involves collecting data for each unit process regarding all relevant inputs and outputs of energy and mass flow, as well as data on emissions to air, water, and land.
3) Impact assessment (LCIA): indicators for analysing the potential impact of resource extractions, wastes, and emissions. The result of the LCIA is an evaluation of a product life-cycle, in terms of several impacts categories, such as climate change, toxicological stress, noise, land use, etc.
4) Improvement analysis: identification of significant issues. Findings are evaluated to reach conclusions and to formulate improvement recommendations.

In this research four life-cycle stages are distinguished, which have to be assessed for an LCA. The first stage consists of extraction and processing of raw materials. The second stage comprises manufacturing and assembly of a product. Third, the impact of the use phase is determined. Fourth, the impact of reuse, recycle or disposal of a product is accounted for. Transport and distribution are included as fragments in all life-cycle stages, since every stage requires movement of goods.

In the material composition scenarios compared in this paper the main difference occurs in the first two stages. The use phase is assumed to have comparable environmental impact in all scenarios discussed.

This research focuses on step 3 and 4 (LCIA and improvement analysis) of the LCA. An impact assessment of concrete and asphalt scenarios is described. Based on the results, alternatives for the reduction of environmental impacts can be proposed. Software packages for mainly step 2, the inputs and outputs of energy and mass flow, as well as data on emissions to air, water, and land are used.

3. Environmental impact assessment methods

In LCA-type models, two main methods in describing impacts can be distinguished (Bare et al., 2000):

- at the level of *midpoint* impacts, e.g., covering issues such as climate change, ozone layer depletion, human toxicity, acidification, and abiotic resource depletion;
- at the level of *endpoint* impacts, e.g., covering issues such as damage to human health, damage to ecosystem health, damage to resource availability, and damage to the man-made environment.

Midpoints are considered to be a point in the cause-effect chain of a particular impact category, prior to the endpoint, at which factors can be calculated to reflect the relative importance of an emission or extraction in a life-cycle inventory (e.g., decrease in quality of ozone layer defined in terms of ozone depletion). Characterizations of environmental impact at the midpoint generally are completely inclusive of the endpoints, which are a result of the midpoint category. Midpoint models generally enjoy a higher level of scientific consensus than models conducted at the endpoint or damage levels (Bare and Gloria, 2008; Bare et al., 2000). Midpoint environmental impacts are measured through category indicators or in LCA terminology: 'impact categories'. Examples of impact categories are climate change, ozone depletion, human toxicity, eutrophication, etc.

Endpoint methodologies use midpoint impact categories in order to assess damage on human health, ecosystem and resource depletion. Harm as a result of climate change, ozone depletion, as well as other (midpoint) categories is linked to one or more of the damage categories. Endpoints are those physical elements which society determines as great importance for protection. Hence, the endpoint method (or damage approach) is a characterization method or model that provides indicators at the level of Areas of Protection (ecosystem quality, human health or resource