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Sustainable management of excavated soil and rock in urban areas – A literature review

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A B S T R A C T

Construction in urban areas implies use of construction materials from quarries and excavation of soil and rock. From a resource perspective, there could be benefits from using excavated soil and rock as a construction material. The aim of this paper is to describe the material flow and management practices of urban excavated soil and rock from the perspective of resource efficiency. A conceptual model for the urban flow of excavated soil and rock was developed and a literature review concerning the management of excavated soil and rock was conducted. The conceptual model was subsequently used to clarify the different perspectives of the scientific literature and knowledge gaps. Conclusions drawn are that there is little knowledge about the quantities and the fate of excavated soil and rock in urban areas. Current research is focusing on the waste flows of construction material and little is known about the overall management practices of excavated soil and rock. Clearly, excavated soil and rock are often disposed at landfills and the recycling rate for high quality purposes is low. There is a need to evaluate the potential for an increased use of excavated soil and rock as construction material. However, the overall efficiency of urban construction material management can only be evaluated and improved by also including construction materials produced in quarries.

1. Introduction

The need for resource efficiency and reduction of climate impact from urban areas is crucial for a global sustainable development. Ongoing urbanization and growth of cities will likely lead to significant increases in the demand for natural resources such as water, land, energy, and mineral resources (Huang et al., 2010). Urban areas emits about 80% of the global CO_2 emissions (Heinonen and Junnila, 2011) and is responsible for about 80% of global energy consumption (Grubler et al., 2012). In rapid growing cities, the construction sector has shown to be one of the major sources to CO_2 emissions (Weber et al., 2007). In order to reduce climate impact from construction, there is a need to improve resource efficiency and increase the reuse of construction materials (Blengini and Garbarino, 2010; Eras et al., 2013; Gangolells et al., 2014; Huang and Hsu, 2003; McEvoy et al., 2004; Miliutenko, 2012; Simion et al., 2013; Toller et al., 2011).

The use of natural resources for construction in urban areas was described by Wolman (1965) as one of the components in the metabolism of cities. The metabolic requirements of a city was defined as all the material and commodities required to sustain the city's inhabitants, such as food, water, clothes, durable goods, electric energy, and construction material. A metabolic approach can be helpful to evaluate the sustainability in urban management of construction materials. A methodology for material flow analysis where material flows are structured and quantified, gives a better understanding of the metabolism (Huang and Hsu, 2003; McEvoy et al., 2004). Such methodology has been used in other research fields such as for biomass, phosphorus and energy to describe sustainability, self-sufficiency and resource security (Chowdhury et al., 2014; Decker et al., 2000; Rosado et al., 2014; Welfle et al., 2014).

Construction of buildings and infrastructure require use of construction materials, earthwork, transportation and management of large volumes of materials such as aggregates and

Abbreviations: C&D, Construction and Demolition.

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excavated soil and rock. This paper is mainly focusing on the metabolism of excavated soil and rock which consist of all materials generated when digging/blasting in the ground for urban construction purposes.

Depending on local geological conditions and anthropogenic activities, excavated material can be rock, stones, gravel, sand, clay, organic material and materials from previous constructions or industrial activities. The quantities of excavated soil and rock can be considerably big and hauling and handling costs high. In infrastructure projects, on-site handling and hauling of excavated soil and rock and construction material from quarries, i.e. quarry material, can be up to 30% of the total project cost and generate significant amounts of CO_2 emissions. Optimization of the management in projects has large potential to reduce both costs and climate impact (Kenley and Harfield, 2011). The management alternatives of excavated soil and rock vary between construction projects. Lafebre et al. (1998) and Eras et al. (2013) has described possible management alternatives for excavated soil and rock as 1) use on-site 2) use in other projects 3) pretreated before use in other projects 4) store for later use, 5) use as landfill cover or dispose at landfill.

Other parameters affecting management possibilities are geotechnical properties, geo environmental properties, availability of recycling facilities, landfills and quarry materials (Chong and Hermreck, 2010; Wilburn and Goonan, 1998).

It is important to notice that geotechnical properties are basis for what functions can be achieved. Particle size, density, water absorption, hydraulic conductivity, deformation properties and bearing capacity are some of the most important aspects that have to be considered. Also, geo environmental properties such as PH value, organic content, total concentration and leachate concentration set the conditions for what material can be acceptable at the project site (Arulrajah et al., 2013). There is an increasing awareness of the possibilities of reusing materials such as soil and rock for construction purposes. Laboratory tests and field studies proves that excavated soil and rock, brick, glass, concrete, asphalt and ceramics can be used beneficially for civil engineering purposes and hence replace quarry materials (Arulrajah et al., 2012; COWASTE, 2014, 2014; Gabr and Cameron, 2012; Kreft-burman et al., 2013; Mohammadinia et al., 2013; Rahman et al., 2014; Taha and Nounu, 2009).

This paper is one of the outcomes from the research project "Optimass". The project aim for "Optimass" is to provide conditions for a more sustainable management of soil and rock in dense city regions. The idea in both the "Optimass" project and this paper is that there is a potential to reduce environmental and economic costs by coordinating the soil and rock material produced in quarries and material excavated due to construction. In this paper this is done in a regional context.

The aim of this paper is to describe the material flow and management practices of urban excavated soil and rock. Focus is on excavated soil and rock due to construction and resource efficiency. This study will look at all materials as potential resources regardless of the specific material properties. This is done even though the geotechnical and geo environmental conditions and hence environmental risks affects the potential use of excavated soil and rock. In this study the primary focus is to reveal the quantities of material flows in urban regions from a resource perspective.

The paper is based on a literature review. The aim is also to identify knowledge gaps and needs of future research. For this paper, the research questions are:

- What is the knowledge about the flow of urban excavated soil and rock?
- What are the benefits of using excavated soil and rock in construction?

2. Methodology

The methodology of this study consists of a literature review in the research field of soil, rock and sustainable management. The purpose of the review is to give a presentation of literature related to the research field and the different perspectives on soil and rock. A model illustrating the urban flow of building materials was developed and used to clarify different types of scopes and material flows described in the scientific literature. Information was collected by using key words for the types, names, processes and objects significant to the flow of excavated soil and rock in urban areas and the methods relevant for describing its sustainability. The results were analyzed and conclusions drawn are presented in this paper.

2.1. Conceptual model for construction material flows

A conceptual model for construction material flows was developed and is presented in Fig. 1. The model can be applied at different spatial system levels, from project level to transnational level to illustrate how construction materials are managed. The model illustrates the demand, supply, stock and internal flows of construction materials for a system.

The demand for construction materials can be met by either domestic sources within the system or by imported sources which are illustrated with blue/dashed boxes. Sources can come from natural extraction such as production in quarries or residues from construction or industry. Construction materials are used domestically in the system or exported from the system and are illustrated with red/bold boxes. The construction material that is used domestically ends up as stocked material of two types: active stock and inactive stock. The active stock represents material that is typically used and cumulated in buildings, roads and other constructions while the inactive stock is material that has been permanently taken out of use and serves no purpose. The latter is usually construction and demolition (C&D) waste ending up at disposal sites (Johansson et al., 2013). In the considered system, there is also a flow through, i.e. external material passing through the system. The conceptual model was developed with inspiration from previous work on construction mineral flows by McEvoy et al. (2004), the work on biomass demand by Welfle et al. (2014), the work on urban material stocks by Johansson et al. (2013), the work on regional management of building materials by Frostell et al. (2009).

2.2. Applying the conceptual model to excavated soil and rock

In this paper, the flows in Fig. 1 are referred to as flow $A - L$. Construction in Fig. 1 was defined as all types of construction activities including demolition. Flow *A* refers to the demand and use of material in applications where excavated soil and rock can be used. Typical applications are in roads, e.g. as sub-base where crushed rock can be replaced (Arulrajah et al., 2012; Kreft-burman et al., 2013). Flow *B* corresponds to the supply of extracted material from domestic sources such as sand, gravel and rock that are usually produced in quarries. Flow *C* is the excess excavated soil and rock generated at the construction site which is sent away as waste to a building material supplier. The building material supplier processes the material before it is used in construction (flow *D*) or sends the material to landfill (flow *E*). Flow *F* is excavated soil and rock generated at the construction site which is either needed on-site for use in construction or needed in other construction projects, as described by Eras et al. (2013). The use of flow *F* materials is often preceded by some kind of treatment, for example crushing and sorting.

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