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Material stocks of the non-residential building sector: the case of the Rhine-Main area

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ABSTRACT

The building sector is known to have the largest inventories of materials in industrialized societies. In comparison to residential buildings, non-residential buildings (NRBs) are much more diverse in function, components and their respective materials. In order to provide insights in material stocks of the non-residential area, this study focused on the case of the Rhine-Main area, a metropolitan region holding extensive stocks of office buildings as well as factory, logistic and other NRBs. The investigation covered analysis of spatial data and examination of single buildings. The structure of the NRB sector was comprehensively characterized in a case-study area as to function and age-classes of existing buildings in terms of building gross volume. The two types "factory" and "commercial/retail and services buildings" accounted for about half of the existing buildings. As to age, about one third of the buildings was found to originate before 1948. This indicates the high importance of renovation activities as a prerequisite for the continuous use of NRBs. Specific material contents of buildings were assessed, showing a large variety. Combining spatial and building related information, a methodological approach was developed which provides area-wide information on material stocks incorporating the allocation to function and age-class of NRBs. This approach may be used for regional estimation of potentials of secondary resources and for Material Flow Analysis in order to estimate potentials and flows of secondary resource.

1. Introduction

1.1. Background

Mineral resources – non-metals and metals – are crucial raw materials for the economy. Today, securing the supply of these resources, notably metals, is a major concern of society. At the same time, environmental impacts from production of primary resources are in the focus of policy, covering the contribution to energy demand and global warming but also to changes of local and regional ecosystems. Against this background, the idea of "decoupling" the consumption of primary resources from economic growth is a major target of international policy (UNEP, 2011). One key strategy is the increased use of secondary resources (e.g. EU, 2011).

The extraction of raw materials during the historical process of industrialization has shifted large amounts of resources from their natural deposits to what is called "anthropogenic stocks" (e.g. Gordon et al., 2006; Müller et al., 2006). Several studies delivered gross estimates on amounts of resources that exist in a society on the country level or on a per capita-basis, respectively (e.g. Fishman et al., 2013). In recent time, also investigations of material stocks resolved for sectors of economy or product groups have been carried out, confirming that the building sector hosts major parts of mineral and other material stocks within society (Schiller et al., 2015). Although these studies indicate overall material inventories, in practice information is needed on a more detailed level to assess technical and economic feasibility of recovery of secondary resources. Hence, it is proposed that for their prospection attention should be given to a micro-level evaluation of selected parts of anthropogenic material stocks (Lederer et al., 2016).

Compared to residential ones, non-residential buildings differ much more in function and technical components, which may contain a higher share of metals and other high-value materials.

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In addition, temporal variations of the non-residential sector are driven by the dynamics of economy so in-use time of its buildings can be expected to be considerably shorter than of residential ones (Schwaiger, 2003). Due to these characteristics, the non-residential sector may be of specific interest for the recovery of secondary resources.

However, specific for the non-residential part of the building sector information on material inventories is scarce although several studies investigated material contents of buildings. Ortlepp et al. (2015) show that most studies focus on minerals and on the residential building sector. Data for NRBs covering information on different kind of metals are provided e.g. by Kleemann et al. (2014), Michel et al. (2012), and by Wittmer (2006). Ortlepp et al. (2015) subsumed metals to one category of materials by using sample information from the Building Cost Information Centre of the German Chamber of Architects. In literature, material inventories of buildings are based on two approaches: in case studies of single real buildings, e.g. Kleemann et al. (2014) and by defining reference buildings, found in literature as 'index building', 'building representative', 'type representative', e.g. Daxbeck et al. (2015), Lichtensteiger and Baccini (2008), Wittmer (2006), and Schwaiger (2003). The so called "matrix-model" was introduced by Lichtensteiger (2006), defined as "ARK-House" method. This classification can be used to assign a real building to its respective type and to investigate frequency of selected types within the building stock based on the evaluation of spatial data.

In our research project, a regional approach for the assessment of material inventories of the non-residential building sector was developed. The research has been carried out in a case study area within the Rhine-Main area in Germany. Basic spatial data for area-wide gross volume (GV) calculations are from land register data referencing the year 2011. This metropolitan region holds extensive stocks of office buildings as well as production, logistic and other NRBs. An approach for comprehensive, area-wide assessment of material inventories of the NRB sector was developed by combining spatial information with information gained from investigation of real buildings. This approach was applied for a case study area (Chapter 3.1). Based on this case study, feasibility and application of this approach for regional prospection of secondary resources are discussed.

1.2. The Rhine-Main area

Located in the western part of Germany the metropolitan area Frankfurt Rhine-Main is one of the leading economic regions in Europe with more than 5.5 million inhabitants (Regionalverband FrankfurtRheinMain, 2015). Its polycentric structure covers about 14 000 km^2, with important cities like Frankfurt am Main (geographic center and main economic driver), Wiesbaden, Darmstadt and Hanau. The economic structure has an outstanding position in logistics, finance, exhibition centers, service industries and science. Due to these facts, the building structure varies a lot. The project region studied combines the area of the so-called "Regionalverband FrankfurtRheinMain" with the area of Darmstadt and its surrounding municipalities (Weiterstadt, Büttelborn, Groß-Gerau). Fig. 1 illustrates the case study area within the project region and its location within Germany. The project region was studied as to general characteristics, available spatial data and buildings for in-depth investigation.

As discussed in this paper, the approach of the study aims at an area-wide assessment of the building stock. To evaluate this approach, a case study area was selected, which was intended not to exceed 100 km^2. The case study area was used to work out the necessary procedures for data analysis and harmonization which can be transferred to analyze the full project region of Rhine-Main or other large regions. The defined smaller case study area functions as a test area to evaluate the methodology and data requirements. At the time of data acquisition, data were only available for some parts of Rhine-Main (among them the case study area). However, as described in Chapter 2.3 a nation-wide 3D-building model is under development and the mapping authority in the state of Hesse plans to release the state wide dataset in 2016.

The finally selected case study area "Frankfurt-East/Maintal" is located within the project region, covering about 70 km^2 including some of the main industrial and commercial city districts in Frankfurt am Main (Bergen Enkheim, Ostend, Fechenheim) as well as some residential areas (Riederwald, Bornheim, Seckbach) and a typical Frankfurt suburban town, the city of Maintal (Fig. 1). Administratively, the case study area is a set of several city districts; as to NRBs it covers several types of commercial and other non-residential zones in order to evaluate the described approach.

2. Material and methods

2.1. Overview

In order to assess material stocks of the NRB sector in a regional, area-wide approach, two perspectives were combined: the "stock-taking" and the "spatial" perspective. The "stock-taking perspective" gathers information from investigations of single buildings. In contrast, the "spatial perspective" is based on existing spatial data. Combining these perspectives is done with geographical information systems (GIS) by means of building typologies which as a result enable a comprehensive mapping of material inventories.

Research covered comprehensive evaluation of literature and statistics, on-site investigations of NRBs and in-depth analysis of spatial data. In a first step, existing typologies of buildings and components in the non-residential sector were reviewed. On this basis, typologies have been derived following common approaches in statistics and practical applications. These typologies have been used to structure the information gained from various sources and to setup a database for storage and analysis of all data gathered during the project.

On-site investigations were carried out for 19 individual buildings, covering building surveys or monitoring of demolition processes, respectively. As to material contents of components, available information has been gathered from literature and additional data was gained from on-site investigation of buildings, contacts with suppliers, and dismantling investigations of single components. For spatial data, several data sources have been merged into a comprehensive spatial database. Analysis of spatial data was used to characterize the Rhine-Main area as a whole and to identify a suitable case study area. For structured evaluation of data, the selected typology of buildings was applied in order to relate spatial GIS based information with building-related information.

2.2. Building definitions and building typologies

2.2.1. Definitions

The research refers to buildings as defined in sec. 2 subs. 2 Building Code of Hesse. Consequently, a building reaches at least one floor above ground level and is covered by an upper horizontal layer – a "roof". The vertical enclosing can consist of walls, parapets, railings and banisters or limited movable door and gate elements. This definition excludes infrastructural elements like bridges or roads. NRBs encompass all buildings either being not intended for dwelling at all or in which less than half of the total floor area is used for dwelling.

The investigation of NRBs aims at identifying material contents per reference unit of a building. Selection of materials was based