IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Material Flows In Buildings' Life Cycle And Regions – Material Inventories To Support Planning Towards Circular Economy

To cite this article: G Schiller *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **290** 012031

View the article online for updates and enhancements.

Recent citations

- Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction
Md. Uzzal Hossain *et al*

Material Flows In Buildings' Life Cycle And Regions – Material Inventories To Support Planning Towards Circular Economy

G Schiller[1], T Lützkendorf[2], K Gruhler[1], I Lehmann[1], K Mörmann[2], F Knappe[3] and N Muchow[3]

[1] Leibniz Institute of Ecological Urban and Regional Development (IOER), Weberplatz 1, 01217 Dresden, Germany
[2] Karlsruhe Institute of Technology (KIT), Kaiserstraße 12, 76131 Karlsruhe, Germany
[3] Institut für Energie- und Umweltforschung (ifeu), Wilckensstraße 3, 69120 Heidelberg, Germany

g.schiller@ioer.de

Abstract. The built environment is the cause of most of the material flows in the anthroposphere and the biggest material storage: Over 90 % of the anthropogenic stock stored in durable goods can be found in the built environment, with non-metallic minerals being the main contributor. In Germany, most of the materials that leave the stock due to demolition or renovation are recovered. In Saxony, a German state, the recovery rate is nearly 99 %, but only 55% of mineral construction and demolition waste is recycled. There is still substantial potential for closing recycling loops. This requires the combined effort of all those actors that influence these material flows – from the investor and constructor of the single building to those responsible for waste management at municipal level and the waste disposal and construction materials industry. However, the information currently available is insufficient to support an effective urban mining. This will be encountered by an ongoing research project that aims to enhance existing informational instruments regarding construction related material flows in the built environment. The project follows a dualistic research approach considering informational instruments at (1) individual building level and (2) at regional level. The objective of the paper is to present an approach on how material inventories can be better aligned with practical information needs. After introducing the overall concept and methodology as well as describing the process of analysing the current state of information flows, first results considering the structure of material in- and outputs and the needs for information of different actors are presented.

1. Introduction

In durable goods, enormous quantities of materials are stored. These materials represent the anthropogenic material storage of a society. The anthropogenic material stock is largely determined by the built environment. More than 90 % of the anthropogenic material storage is located in buildings and infrastructures, with non-metallic minerals accounting for the majority (hereinafter referred to as mineral materials) [1].

In Germany, most materials that leave the building stock due to demolition or renovation are recycled or recovered. In Saxony, for example, the recovery rate for mineral construction and demolition waste

was almost 99% in 2010. However, only 35% of this was recycled, the remainder was reused in surface mining sites or in landfill construction [2]. There is no way to recover these fractions later on. Therefore there is still considerable potential for enlarging the amount of high value recycling.

Studies of the building stock and its dynamics underline the importance of building material in the existing building stock as a resource of the future. The amount of stored materials in Germany's building stock is currently 187 t/capita and continues to grow. The ratio between inflow and outflow in 2010 was 3:1. However, this development is not continuing in that direction. According to calculations by Gruhler and Deilmann [3], the ratio will change to 1:1.6 in 2050. In addition, the composition of material flows will shift (figure 1). It is thus obvious that keeping materials in recirculation in the construction sector is not an easy task. What is needed is detailed data on material requirements and waste generation in selected regions with a high resolution in terms of types of materials.
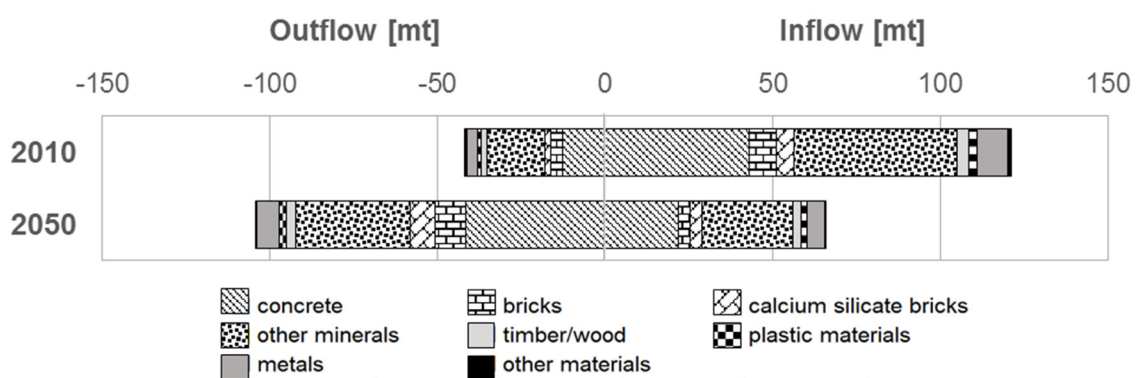

Figure 1. Material flows in the German building stock in 2010 and 2050 (Source: [4] using data from [3] [5]).

Urban mining is thus becoming increasingly important for the supply of (secondary) raw materials in the future. To date, existing recycling potentials remain largely unexploited. A 2010 study reports that in Germany less than 2% of concrete aggregates are replaced by recycling aggregates [6]. It can be assumed that this has not changed much. A significantly higher ratio is possible: approx. 50% of the concrete and brick runoff can be processed into high-quality recycling aggregates, taking into account processing losses. In concrete production, up to 45% of the aggregates can be replaced by recycling aggregates [6]. Bottlenecks are to be expected for certain materials in the future. For example, gypsum has so far largely been obtained from waste materials from exhaust gas purification in power plants. This source will dry up when fossil fuels are phased out. However, gypsum is very suitable for recycling if it is specifically removed from the runoff mass flow [7]. Bottlenecks can also occur indirectly. This applies, for example, to aggregates used as aggregates in concrete. The extraction of these materials leads to changes in the landscape and is associated with costly recultivation measures. In addition, there are increasing regional shortages, e.g. of sand of a certain quality. As a result, the pressure to use secondary resources from urban mining much more consistently is increasing. This is also expressed in the special requirement No. 7 of the European Construction Products Regulation, which requires, among other things, the increased use of secondary materials [8].

So far, among other reasons a lack of information has hindered the effective implementation of recycling concepts in the construction industry. Although there are concepts such as building passes/files [9] and regional material registers [10] that provide information on buildings and the building stock, most of these projects concentrate on available data or only a certain part of the building stock rather than on information required by the actors responsible for decisions along the material chains. However, expanding recycling and exploiting existing recycling potential requires the joint effort of all those who influence these material flows – from the investor and builder of the individual building to those responsible for waste management, the waste and construction materials industry and actors with responsibility for sustainability-oriented cross-sectoral tasks. They have to be provided with information

in such a way that the integration of circular economy concepts into their daily decision making routine is as smooth as possible.

This paper presents a methodological approach to the design of material inventories for buildings and cadastres for regions to meet the information needs of different stakeholders. The focus is on the presentation of the analysis approach with its three elements: (1) occasions/motives, (2) involved actors and (3) used instruments/methods. The ongoing analyses will provide initial insights into the spectrum of relevant actors and their information needs. The discussion and conclusions reflect conceptual conclusions regarding the requirement levels to be addressed and the challenges of information provision at building and regional level.

2. Conceptual approach

2.1. Dualistic approach

The approach is conceptualised as a dualistic research approach along two strands: material inventory for single buildings and material cadastre for building stocks. The two strands differ in the level of scale but at the same time have defined interfaces. The methodology is aimed at achieving a relevant practical applicability of the instruments. To attain this, the development of the project uses a case study approach involving practitioners and the concepts will be tailored to the information needs of the actors and tested on real case studies.

2.2. Occasion-actor-instrument constellation

The basis of the investigations is the systematic analysis of information flows that occur during material-related design and planning decisions. The starting point is formed by occasions (figure 2). We define occasions as selected events in the life cycle of buildings or building stocks that trigger design and planning decisions and administrative actions. Examples are new construction or demolition of buildings or preparation of a waste management plan.
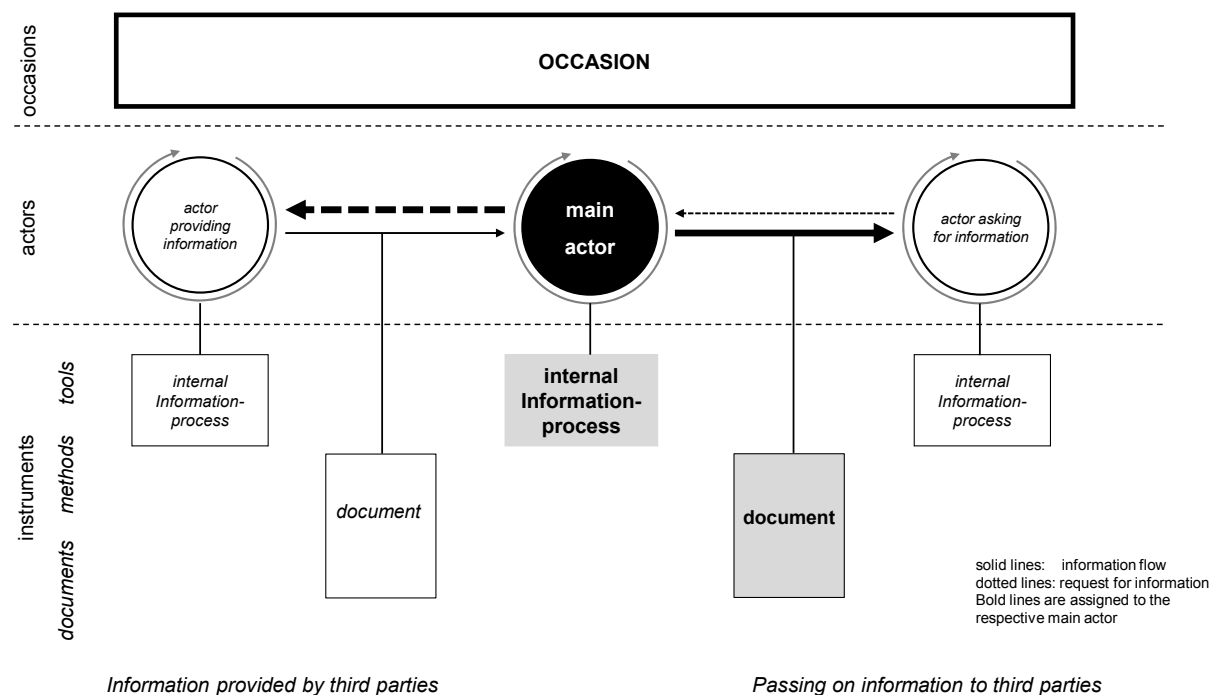

Figure 2. Basic concept of information flow considering occasion/actor/instrument constellations (own illustration).

A certain constellation of actors is addressed at each occasion. In connection with an occasion, which usually also leads to action requirements, a need for information arises among the actors involved. This information serves to prepare and to support decisions or to fulfil design and administrative tasks. The actors take on different roles in an occasion. We differentiate between the main actors who trigger the occasion and other actors involved who provide or request information. In the case of a new construction of a building, e.g. the investor is the main actor, designers and planners provide information and approval authorities are asking for information.

The actors are using different methods, tools and documents to generate, document or exchange information. We summarize this with the term "instruments" and distinguish between internal information processing and the documents exchanged between the actors.

For the "new construction" occasion, for example, the following picture results: A client (main actor) submits a financing application to a bank. In the risk analysis, the bank wants to know whether the building is pollutant-free and recyclable. In order to provide this information, the client asks the architect who delivers the necessary planning documents, which the client forwards to the bank or its experts. The client himself will also check again in an internal process whether the planning results meet his own requirements.

2.3. Material categories

The actors will become active at different points in the material value chain. The spectrum can basically cover the entire value chain from the extraction of raw materials to the management of construction and demolition waste (C&D waste) and the recycling of building elements and secondary materials (figure 3). According to these steps, the materials are grouped differently inside a typology: (1) Raw material groups (linked to the used resources) on the extraction side, (2) building materials in the buildings (linked to products and manufacturers), (3) waste categories in the outflows (linked to waste codes) and disposal categories/recycling options (figure 3).
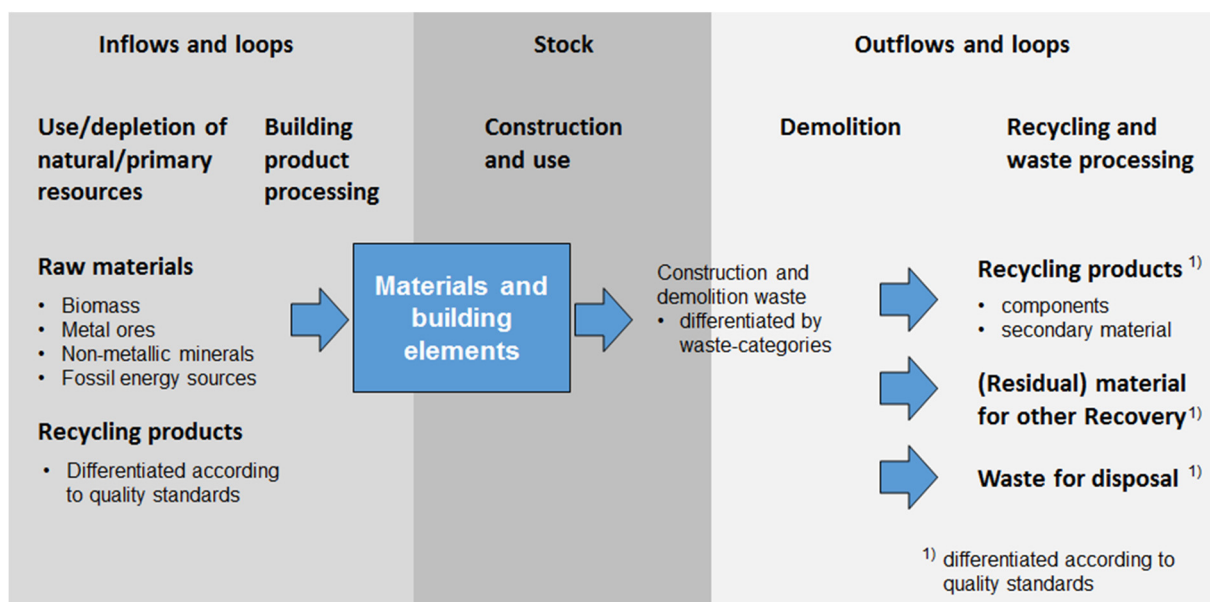

Figure 3. Change of material categories following the value chain of materials and products (own illustration).

An important requirement for building related "material inventories" and region specific "material cadastres" will be to enable linkages to the various material categories and thus to establish consistency between the information needs of different actors.

3. Needs for information of relevant actors

3.1. Information demand related to single buildings

The analysis of information needs is based on the analysis scheme of occasion- actors – instruments. The identification of important occasions, actors and instruments is based on a brainstorming session among experts with reference to the construction and real estate industry and the authors of this article and on literature analyses based on it.

Interviews with representatives of the different actor groups have been conducted to help identify the typical categories of information they are interested in in order to be able to fulfil their specific tasks. Due to the wide range of tasks, areas of responsibility and attitudes encountered in practice, assessments and results may not always be representative.

The following relevant occasions have been identified: financing; valuation/risk analysis; construction planning (new building, reconstruction, deconstruction); certification of buildings; purchase/sale of buildings.

With regard to decisions that are relevant for material issues, a distinction can be made between actors who (a) actively influence the selection of materials, (b) have a professional interest in information on the material composition of buildings or (c) directly or indirectly are affected by material decisions.

This results in a need for information in regard to the selection of materials, the assessment of risks for the environment and health, the assessment of deconstruction and recycling possibilities, the definition of replacement cycles and the dimensioning of a maintenance budget, the determination of life cycle costs or the life cycle assessment, a complete sustainability assessment, the allocation of subsidies or the preparation of reconstruction and deconstruction measures. Typical information needs are listed in table 1.

Table 1. Specific information needs of main actors on building level (own illustration).

Actors typically are interested in:	Construction methods	Type of materials / material groups	Quantities of materials	Qualities of materials	Time of replacement	Kind of compounds	Location of materials inside the building	Type of pollutants	Level of pollution	Potential to recover	Probability for recycling
Actors directly interested in material information – providing and requesting information											
Investor	█	█			█			█			
Owner	█	█			█			█		█	
Architect	█	█	█			█		█			
Developer	█	█									
Building contractor	█	█				█				█	
Building industry	█			█							
Prefab. house industry	█	█						█		█	
Actors directly interested in material information – requesting information											
LCA-Expert		█			█		█				
Sustainability expert					█						
Due diligence specialist					█						
Facility manager					█						
Actors indirectly interested in material information – requesting information											
Portfolio manager					█		█				
Appraisal specialist	█	█									
Banks					█		█			█	
Funding institutions	█									█	
Insurance companies							█				

Table 1 also distinguishes between actors with a direct and indirect interest in material information and between actors providing information and those requesting information. Although the results are still preliminary, the following can already be noticed:

- Actors need either a complete picture or only selected aspects of information on the physical composition of buildings. In the latter case, a complete picture of the actual need for information can only be obtained by looking at all the sub-aspects together.
- For individual characteristics there is a particularly broad interest of many different actors. This applies in particular to construction methods, material types and pollutants. Other characteristics are only occasionally in demand, such as material quantities and qualities. This can be taken as a basis to define requirements regarding the type and scope of information to be provided.
- The information requirements relate to building materials and construction elements. Upstream and downstream aspects such as raw material/resource or waste categories are rarely of interest to the actors at the building level.

However, this information alone is not sufficient to draw conclusions about the content of material inventories planned in the presented approach. The following questions still need to be answered: (a) What is the relationship between the characteristics? (b) How do the characteristics refer to questions of recycling management and resource conservation?

Question (a) will be further explored with regard to the tools, instruments and methods used to generate and disseminate the information. Question (b) is an overarching issue with strong links to actors who have larger stocks in mind. In this respect, this should be discussed in the context of the analyses relating to larger building stocks.

3.2. Information needs related to building stocks in regions
At the level of regional building stock, an expert and literature-based selection of relevant occasions was defined: approval of object-related disposal concepts; plant approval; waste management plans; landfill permit; recycling, backfilling or disposal of C&D waste; using recycling material in building material production; resource planning (regional planning); definition of resource policies and circular economy strategies. Thus, planning and approval processes are in the focus at this level. Based on interviews with thus identified actors, those who are typically involved in these occasions are listed in table 2 as well as the information they are typically interested in.

The focus of the information requirements here is on C&D waste in terms of categories, quantities but also of qualities. Information on upstream and downstream material categories in the value added chain is also of interest. Thus, similar to what has already been observed above, the actors have selective interests, which in sum are condensed into an overall picture. Differentiated information on health risks related to the use of buildings or types of construction or material are not directly relevant here, but can become indirectly significant if they relate to the qualities of the waste categories. The analyses also show that information needs exist above all to support strategic cross-sectional planning tasks. On the other hand, interest in information to support mandatory sectoral tasks appears to be rather low.

Table 2. Specific information needs of main actors on building stock level (own illustration).

Actors typically are interested in:	Construction methods	Type of materials / material groups	Quantities of materials	Qualities of materials	Type of waste category	Quantities of waste category	Qualities of waste category	Type of recycling material	Quantities of recycling material	Qualities of recycling material	Potential to recover	Probability for recycling
Public actors in waste management with responsibility under licensing law												
Local waste authority					X	X	X				X	X
Higher waste authority					X	X	X				X	X
Private actors in the waste management sector												
Demolition company		X	X									
Recycling plants company					X	X						
Open-cast mining company									X	X		
Landfill operator					X	X						
Actors in the building materials industry												
Diff. sectors, e.g. bricks, concrete									X	X		
Responsible authorities for resource policy												
E.g. Sustainability departments	X	X	X	X	X	X	X	X	X	X	X	X
Regional planning		X	X								X	

4. Conclusions and outlook

It can be stated that the interest in the production and use of material inventories is still low and this is to be regarded as an obstacle to the circular economy in the construction sector. Even newer approaches like BAMB [11] will only make a small contribution to improving the situation. It is therefore important to first strengthen the demand for material information and to identify the tools that stimulate and support the management of information on the material composition of buildings and the regional material flow. At the regional level, it is also important to raise the potential for conserving resources by strengthening cross-cutting approaches that bring together different ends along the value chain.

It was found that the information needs of actors operating on the building level are more differentiated than of those on the regional level. For certain information needs a horizontal or vertical comprehensiveness can be observed, meaning that some actors are interested in (nearly) all the identified information categories or that the information in some categories is requested by (nearly) all actors. These findings show which criteria should be focused on when developing the material inventory and cadastre.

There are interfaces between the building level and the regional level. For example, data for the building and deconstruction permit of individual buildings can provide the basis for recording and analysing the development of the regional building stock and its material composition. At the same time, data on individual objects are the basis for type representatives to model the regional building stock. It is important that the granularity of material information can be adapted to the level of observation and can be aggregated or disaggregated.

The next work steps concentrate on the development and testing of specific instruments and data exchange formats for material inventories and regional material cadastres as well as the communication about a scalable material typology/classification.

References

[1]   Schiller G, Müller F and Ortlepp R 2017 Mapping the anthropogenic stock in Germany: Metabolic evidence for a circular economy *Resour. Conserv. Recycl.* **123** 93-107

[2]   Schiller G, Bräuer A, Westphal M, Zinkler S, Friederich I and Kramer-Heinke K 2016 *MinRessource – Nachhaltiges Ressourcenmanagement von mineralischen Primär- und Sekundärbaustoffen [Sustainable resource management of mineral primary and secondary building materials]* (Dresden: Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie)

[3]   Gruhler K and Deilmann C 2016 *Conference Proceedings – Sustainable Built Environment Conference 2016 in Hamburg: Strategies, Stakeholders, Success factors.* (March 2016, Hamburg) vol 1 (Hamburg: ZEBAU) pp 1010–9

[4]   Schiller G, Lützkendorf T, Lehmann I and Gruhler K 2018 *Conference Proceedings – RETROFIT EUROPE SBE19 Conference* (November 2018, Eindhoven) vol 1 (forthcoming)

[5]   Deilmann C, Krauß N, Gruhler K and Reichenbach J 2015 *Sensitivitätsstudie zum Kreislaufwirtschaftspotenzial im Hochbau [Sensitivity study on the recycling potential in building construction]* (Berlin: BBSR)

[6]   Schiller G, Deilmann C, Gruhler K, Röhm P, Reichenbach J, Baumann J and Günther M 2010 *Ermittlung von Ressourcenschonungspotenzialen bei der Verwertung von Bauabfällen und Erarbeitung von Empfehlungen zu deren Nutzung [Identification of resource conservation potentials in the recycling of construction waste and development of recommendations for their use]* (Dessau-Roßlau: Umweltbundesamt)

[7]   Buchert M, Sutter J, Alwast H, Schütz S and Weimann K 2017 *Ökobilanzielle Betrachtung des Recyclings von Gipskartonplatten [Life cycle assessment of the recycling from gypsum plaster boards]* (Dessau-Roßlau: Umweltbundesamt)

[8]   European Parliament and the Council of the European Union 2011 *Regulation (EU) No 305/2011: Harmonised conditions for the marketing of construction products.* (European Union)

[9]   Miller W and Lützkendorf T 2016 *Conference Proceedings – Sustainable Built Environment Conference 2016 in Hamburg: Strategies, Stakeholders, Success factors.* (March 2016, Hamburg) vol 1 (Hamburg: ZEBAU) pp 190–9

[10]   Kleemann F, Lederer J, Rechberger H and Fellner H 2016 GIS-based analysis of Vienna's material stock in buildings *J. Ind. Ecol.* **21-2** 368–80

[11]   BUILDINGS AS MATERIAL BANKS 2018. https://www.bamb2020.eu/ [Accessed 13 November 2018].