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Capture and Control of Material Flows and Stocks in Urban Residential Buildings

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Capture and Control of Material Flows and Stocks in Urban Residential Buildings

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Abstract. To promote the circular economy and resource efficiency in the construction industry, information on material flows and stocks is needed. The work presented describes a holistic and dynamic model for the determination of material flows and stocks in urban areas triggered by the construction of residential buildings. In addition to the classification of material stocks (raw material cadastre for residential buildings), it is of central interest to identify future waste streams in order to forecast potential secondary raw materials, determine recovery strategies and control mechanisms. Furthermore, the supply of exploitable fractions must be matched with demand to identify the degree of self-sufficiency of selected areas in order to reduce the use of primary resources and necessary transports. The model developed in this work is validated on the basis of the district of Munich / Freiham, one of the largest urban developments in Germany. In this case study it has been shown that under certain conditions a self-sufficient supply of steel (from 2036 onwards) and recycled aggregate for the production of recycled concrete (from 2031 onwards) for residential building construction can be achieved.

Keywords: Urban mining, material flows, material stocks, residential buildings, urban systems, building materials

1. Introduction

Closing the loop - the *EU Action Plan for the Circular Economy* aims at transforming Europe's economy into a more sustainable one [1]. The construction industry, one of the most resource intensive industries, uses around 40 % of worldwide material resources and produces around one quarter of the total CO_2 emissions [2]. To promote the circular economy and resource efficiency in the construction industry, information on material flows (e. g. raw materials, building materials, waste, etc.) and the material composition of the building stock is needed. Through this knowledge for example, the occurrence of potential secondary raw materials (e. g. recycled building materials) can be forecast. Furthermore, systematic recovery and utilisation strategies can be identified and further developed (material flow management).

This work describes the development of a holistic and dynamic material flow model for the determination of the material composition of the housing stock (material cadastre) and the associated material flows triggered by urban housing. The model developed in this work was validated on the basis of the district of Munich / Freiham, one of the largest urban developments in Germany.

2. Methodology

Material characteristics at building-, component- and material level were combined with geometric data from 3D city models to represent the current condition (material cadastre / material stock model) (figure 1). This information serves as the basis for further calculations within the dynamic material flow model (figure 2).

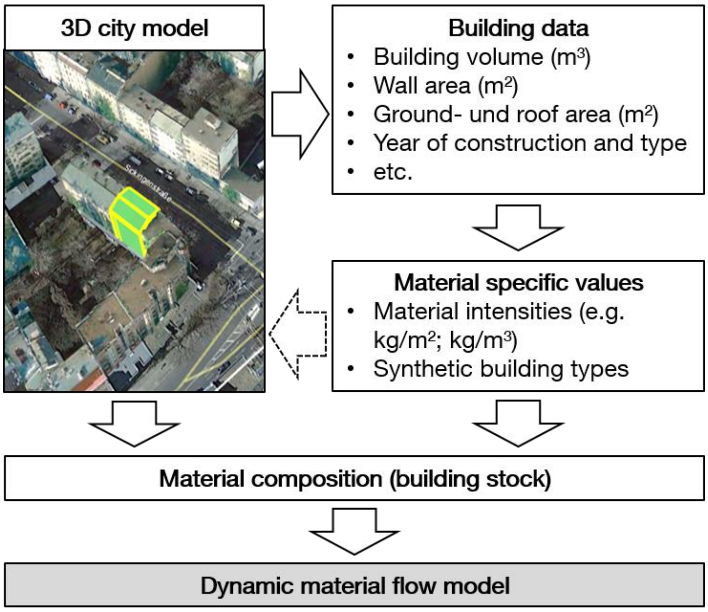

Figure 1. Construction of material cadastre

Based on the material stocks model and the parameters within the individual modules of the calculation model in figure 2, predictions on future material flows could be made. The year of construction and the building type was known and taken from the 3D city model. This helped to account for the distribution in material compositions of the different building groups. By knowing the year of construction the dynamic changes and development of the examined building material stock could be calculated on an annual basis. By applying a normal distribution on the year of construction a timespan for a potential release of materials from the stock through refurbishment or demolition could be identified. The material demand was calculated on a similar basis. Calculations performed in the dynamic material flow model include the following:

- proportion of recyclable masses from building stock
- construction waste
- system losses
- materials required for new construction, renovation and refurbishment
- materials released by building demolition
- dynamic change in material composition of building stock
- degree of self-supply
- others

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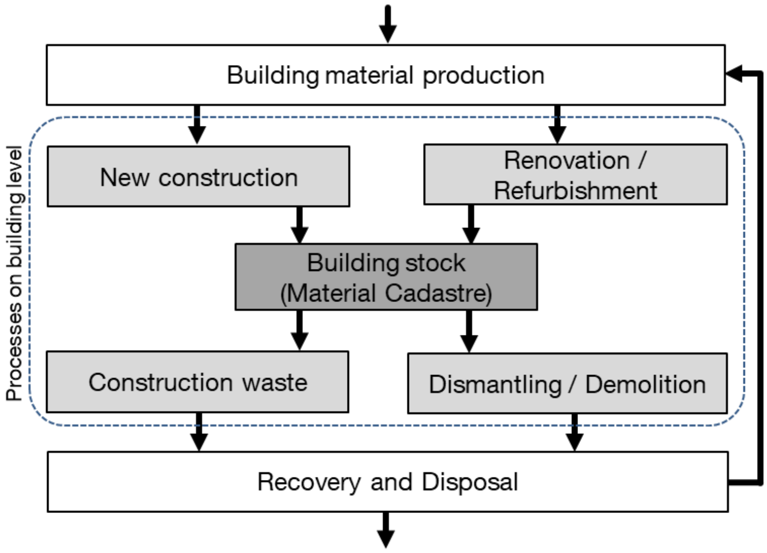

Figure 2. Overview of dynamic material flow model

3. Results

The model developed in this work was validated on the basis of the district of Munich / Freiham. It has been shown that around 2.2 million tonnes of building materials are currently bound within the residential building stock within the focus area. Of these, around 48 % are concrete and 24 % bricks. Approximately 5 % of the examined stock consists of metals, with a current equivalent value of approximately € 20.4 million (table 1). About 50 % of the total mass is bound in apartment buildings of the age groups 1958 - 1968 (31 %) and 1969 - 1978 (19 %).

Table 1. Material composition of the residential building stock within the focus area

	SFH[a]		MFH[b]		Total	
Material group	Mass (t)	(%)	Mass (t)	(%)	Mass (t)	(%)
Plaster, screed, mortar	89,473	17%	258,800	16%	348,273	16%
Concrete	218,039	41%	823,406	50%	1,041,445	48%
Building blocks (e.g. bricks)	137,306	26%	381,159	23%	518,466	24%
Construction panels	1,443	0.3%	6,298	0.4%	7,741	0.4%
Timber-based materials	13,244	2.5%	11,380	0.7%	24,625	1.1%
Insulation materials	6,762	1.3%	14,240	0.9%	21,002	1.0%
Roof coverings	5,413	1.0%	3,622	0.2%	9,035	0.4%
Coverings, membranes	1,448	0.3%	4,465	0.3%	5,913	0.3%
Diverse materials, filler	36,334	6.9%	68,640	4.1%	105,275	4.8%
Metals	22,302	4.2%	87,987	5.3%	110,289	5.0%
Total	532,065	100%	1,659,998	100%	2,192,063	100%

[a] Single-family homes
[b] Multi-family homes (e.g. apartment buildings)

The development of the material composition of the focus area is shown in figure 3. The first exponential rise in material agglomeration was around 1947. This was due to the need for living space after World War 2. The second peak occurred at around 1965, which was due to the urban expansion policy of the city of Munich. During this time, a large number of concrete apartment buildings were constructed which still shape the cityscape and represent a large proportion of the material stock within the focus area.

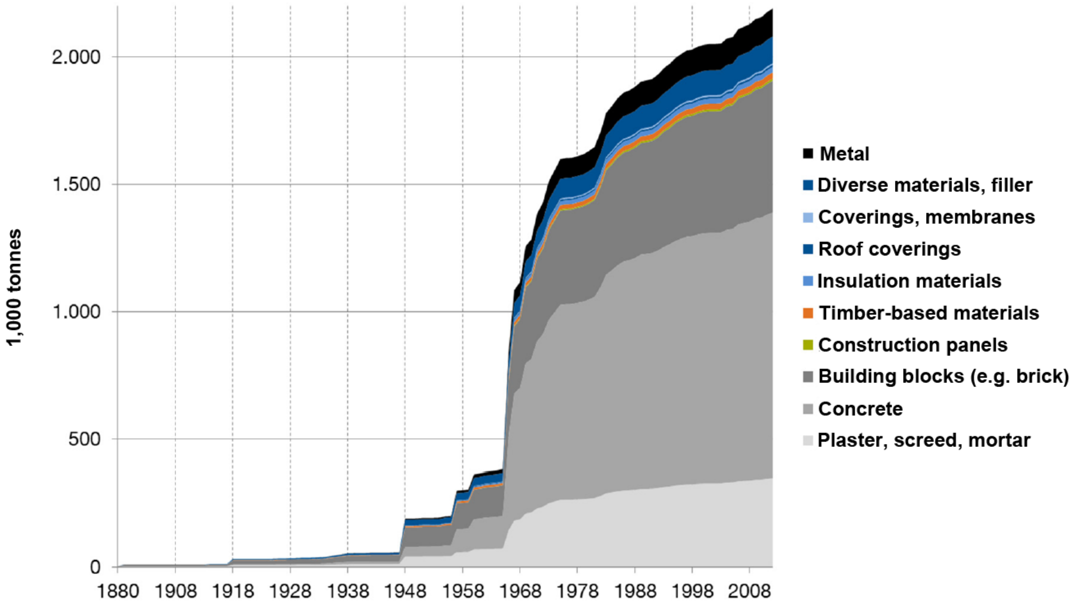

Figure 3. Development of the material composition of the residential buildings within the focus area

On the basis of the material stock, future material flows have been calculated and the potentials of mass balances (self-sufficiency of urban spaces with materials) were demonstrated. This indicator represents the proportion of useable secondary raw materials (including system losses) released from the building stock at a certain time in proportion to the material demand for building purposes. The material balance sheets are shown on the example of steel and concrete (figure 4 and figure 5). The two distinct demand-peaks (steps) for both material types are due to material demands for a further two-step city expansion projects. Phase one has currently started the green-field construction process to provide living space for around 8,000 inhabitants until 2024. Phase two is currently in the planning phase aiming to provide space for an additional 12,000 people until 2030. After 2030 the construction of new buildings is based on the replacement of existing buildings (brown field development) and renovation measures. Under the chosen conditions, it is possible to achieve a self-sufficient supply of steel from about 2036 for the construction of housing within the focus area and from about 2031 with recycled aggregate for the production of recycled concrete.

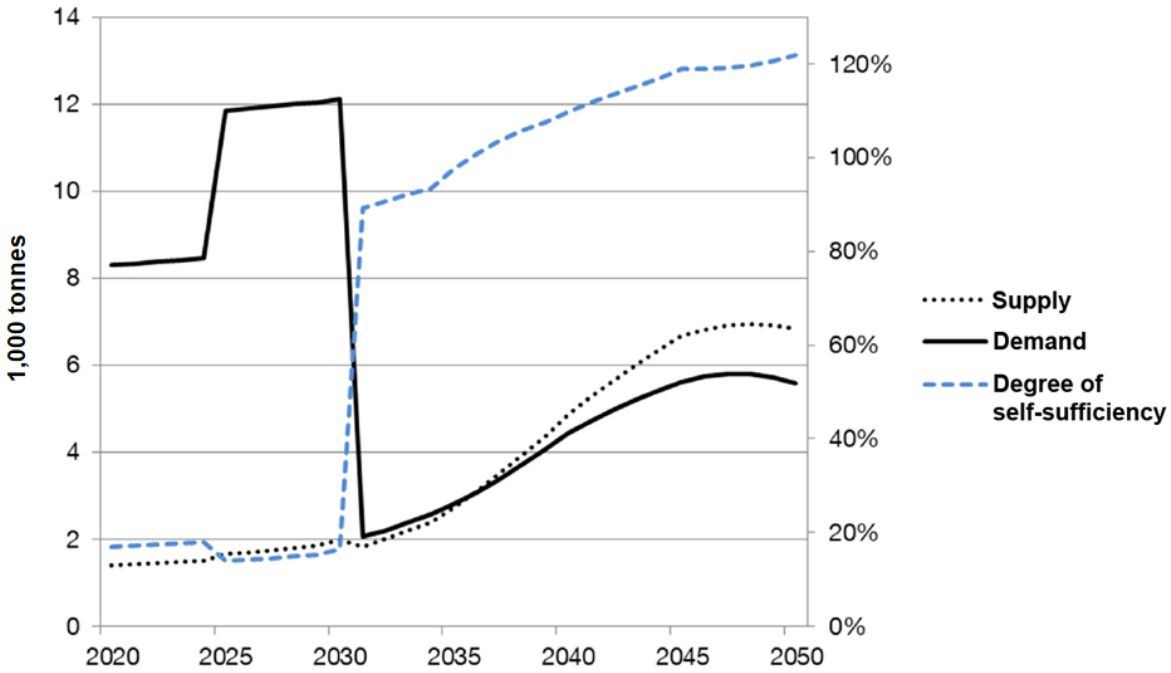

Figure 4. Potential degree of self-sufficiency with steel for residential buildings within the focus area

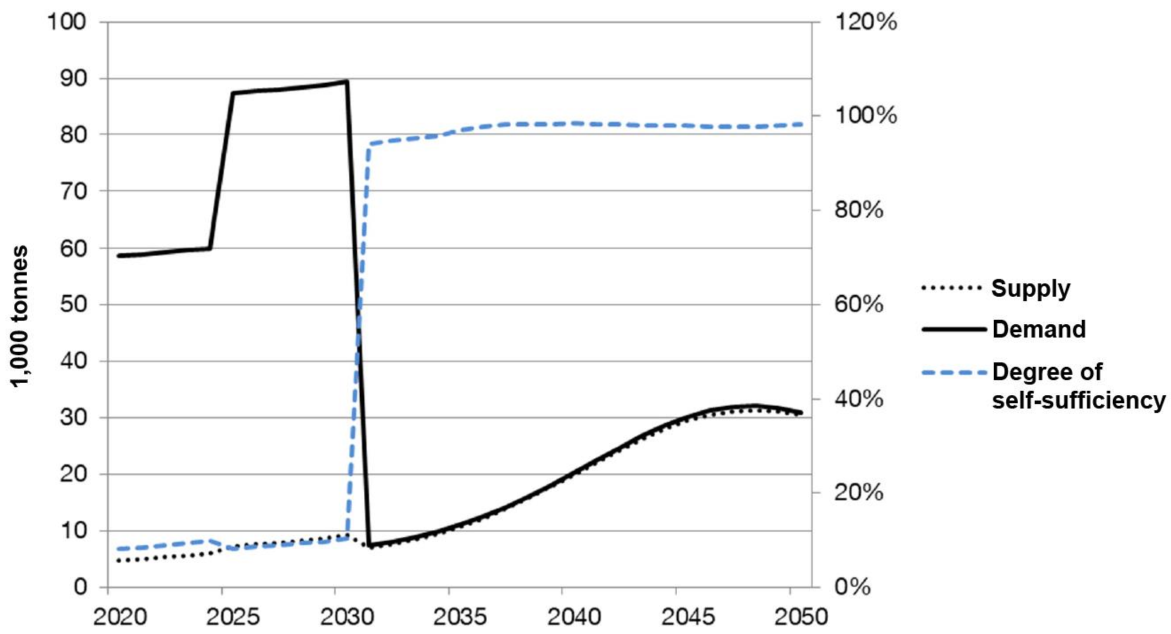

Figure 5. Potential degree of self-sufficiency with recycled aggregate for the production of recycled concrete within the focus area

4. Conclusion

By knowing the whereabouts (geographical and temporal occurrence and demand) of materials, a targeted use of secondary raw materials from the building stock can be enforced. Systematic material flow management (e. g. high-quality on-site recycling) in urban areas has a high potential to increase the share of secondary resources and to reduce the use of primary resources and transports. In order to put these measures into practice, a common data space (e. g. continuously updated database on material composition of buildings) is needed to optimize the exchange of information between the different actors along the value chain and to coordinate the supply and demand for materials.

5. References

[1] European Commission 2015 *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Closing the Loop - An EU Action Plan for the Circular Economy*

[2] Becqué R, Mackres, E, Layke J, Adam N, Liu S and Managan K 2016 *Accelerating Building Efficiency - Eight Actions for Urban Leaders* World Resources Institut (WRI). Washington, DC

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Heinrich M 2019 *Erfassung und Steuerung von Stoffströmen im urbanen Wohnungsbau - Am Beispiel der Wohnungswirtschaft in München-Freiham* PHD-Thesis at the Technical University of Munich, Germany.

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