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# RESOURCES IN BUILDINGS AND THEIR RECYCLING OPTIONS

K. Krause[1]*, A. Hafner[1], S. Schäfer[1]

[1] Ruhr-University Bochum, Universitätsstraße 150 44801 Bochum, Germany
*Corresponding author; e-mail: karina.krause@rub.de

**Abstract**
In this paper, the material quantities generated from real existing buildings are presented. Location-based information about resources and recycling materials and their potential stock can help to develop concepts for recycling industry to maximize economic benefits and minimize environmental impact. Based on a literature research, the current recycling possibilities of different material groups are pictured. Issues and challenges in the use of recycling materials are also addressed. With the bottom-up analysis of a sample region, a more accurate statement about the material in the building stock is introduced.

**Keywords:**
resource efficiency, implemented materials, quality recycling, demolition waste

## 1 INTRODUCTION

The construction industry is one of the most resource-intensive industries worldwide. 550 m tonnes of mineral materials are installed in Germany, which corresponds to 85 percent of the total domestic extraction.

Therefore, the construction industry plays a key role in the implementation of resource efficiency. If it is possible to make the implemented resource available and to keep the materials in the circular flow, the consumption of resources can be reduced. But there is a lack of reliable data and information of resource and material implemented in buildings and recycling of building materials.

## 2 CONSTRUCTION WASTE IN GERMANY

### 2.1 Waste accumulation and recycling rate

During the deconstruction of buildings significant masses of material are released. The main category are stones, earth and excavated material. Also relevant aspects are the mineral waste from concrete and masonry plus steel from steel reinforcement and steel girder. Approximately 200 m tonnes of construction waste are accumulated per year through the construction, reconstruction and deconstruction of buildings. That is over 50% from the total waste accumulation in Germany in 2012 [1]. This percentage was in recent years at a similar level (s. fig. 1).

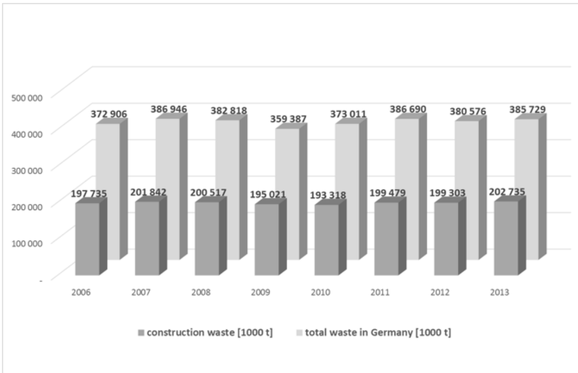


*Fig. 1: waste balance in Germany [1].*

The 200 m tonnes of construction waste split in 110 million tonnes earth and stones, 52 m tonnes mineral waste and 18 m tonnes road demolition waste.

20 m tonnes of the construction waste have been disposed of. This means that nearly 90% of construction waste was recycled in 2012. This recycling rate includes material recycling and thermal recycling. Main recycling options are road constructions and ground work.

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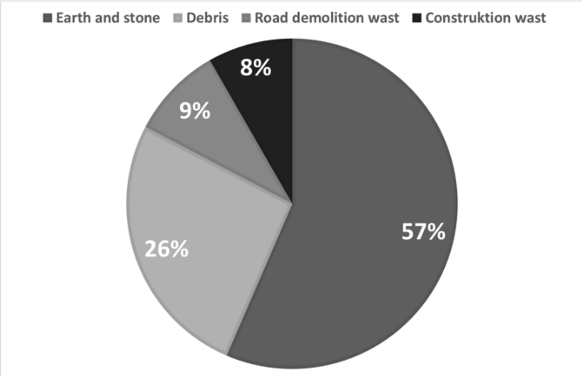


*Fig. 2: categories of construction waste 2012 [1].*

### 2.2 Recycling options of building construction material

The end-of-life options for construction and demolition waste are generally preparation for reuse, material recycling, energy recovery, or filling the landfill. At the recycling facility, there are differences in terms of quality. The level of recycling is divided into three stages; down cycling, recycling and upcycling.

Furthermore, the disposal options, in particular the recycling of selected waste fractions, are briefly explained.

*Mineral construction waste*

In the mineral rubble, it is useful to separate as much as possible from each other, in order to remove possible contaminants in advance like crushed concrete, ceramics, tiles and masonry rubble.

The processing technology determines the quality of the recycling potential. The possibilities for recycling of concrete fractions depend on the structural and environmental requirements in the related application. Possible fields of application are the road construction, earthworks, the production of asphalt and concrete with recycled aggregate and other utilization. Road construction is the most widely used recovery path with more than 50% [2].

Demolition of brick originates from walls and roof tiles. Provided that the bricks can be mechanically cleaned of plaster and mortar residues, it is generally possible to reuse them as a whole. Otherwise broken brick is used as an aggregate for mortars, plasters, sand-lime bricks or as a natural bulk and substructure material for road construction. In addition, recycled bricks may be used as a lightweight aggregate in concrete or as an aggregate in tennis sand [3].

*Timber*

Direct reuse of untreated waste wood as beams, formwork material or wooden paving is in principle possible.

Less than a quarter of the resulting waste wood is recycled for the production of laminated wood mouldings and chipboard. The vast majority will be incinerated in biogas plants and private households for energy recovery [3]. The small percentage of recycled material is partly due to the treatment and coating of wood with wood preservatives, for example, PCP.

*Glass*

In general, the majority of waste glass is melted on as often as desired and used for the manufacture of new glass products [3].

Insulating materials made of glass wool are made of recycled glass up to a limit of 70% and are melted with other ingredients. From waste glass foam glass (plates) can be produced for insulation. Furthermore, expanded glass granulate, which can consist of up to 95% recycled glass, is used as a lightweight aggregate for mineral plasters or lightweight concrete, as well as bulk insulation and sound absorbers [4].

However, these material recycling options can cause an interruption in the glass material cycle due to limited means of disposal of the new insulating materials.

*Polyvinyl chlorid*

Especially polyvinyl chloride (PVC) is widely used in construction as plastic window frames, pipes, cable insulation, flooring and roofing membranes. For the recycling of PVC windows, doors and roller blinds Rewindo GmbH has built a nationwide collection and transport system in Germany [5]. The mostly non-existent purity of PVC composite materials is a problem for recycling.

*Metal*

Structural steel from steel beams, sheets, tubes and rebar have a nearly closed cycle of materials of 99%. 11% of it can be reused directly. This direct re-use avoids re-melting, thus saving energy. The remaining portion is melted down as scrap steel primarily in electric arc furnace and then recycled in high quality new secondary building materials [6].

Copper is also widely used in the building industry. Around 26% of the copper can be found in the construction sector in pipes of plumbing and heating systems, in alloys and claddings. Copper can be recycled any number of times [7].

*Insulating material*

The significant proportion of these materials is mineral wool, in particular glass wool and rock wool, and rigid foam insulation made of expanded polystyrene (EPS) for thermal insulation composite system [8][9].

The annual amount of waste of mineral wool products is estimated at approximately 100,000 tonnes. The majority consists of old carcinogenic KMF. Although a higher recycling rate of new KMF is generally possible, currently the majority is landfilled, as described below [8]. Unpolluted rock wool waste can be recycled [10].

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Expanded polystyrene (EPS) is composed of approximately 98% air, 2% polystyrene and belongs to the group of foamed plastics [11]. The problem with the recycling of EPS is partly due to the transport cost which arise due to the low bulk density of the EPSs and the lack of economic efficiency of existing treatment processes. Further difficulties arise from the frequent processing of EPS in thermal insulation systems and the use of flame retardants compounds. In this way, the clean separation is made more difficult. Therefore, the main part of the EPS-waste is incinerated. Only small amounts are processed as grist for equalizing screeds, Poroton brick or polysyrol recyclate for injection moulding [12].

*Material made of gypsum*

Gypsum is used due to its good processability and its low-energy production, in the construction industry as plaster, dry screed, or as plasterboard in interior design. Theoretically, any gypsum can be recycled many times, because the starting material is chemically identical to the hardened end product. For a practical application the plaster must be sorted, which is hardly to be found, because the plaster is usually a part of the overall construction waste [3].

Possibilities of separation and treatment processes for gypsum waste are described in [13] and [14].

## 3 RESOURCES IN BUILDINGS

### 3.1 Building stock in Germany

For a forward-looking material process management of materials in the construction it is necessary to have information of the existing material and its quantities. In Gruhler et al. [15], a building material calculation program was developed, which calculates the housing stock and documents material and energy characteristics of building types. There are ten multi-family houses (MFH) built between 1880-1990 and eight single-family homes (SFH) built between 1960-1990. The types of buildings have been selected, so that these reflect the totality of the existing building stock in Germany. System boundary is the outer dimensions of the building, extensions (balconies) are not considered. Basement are included in the calculation.

Here concrete and bricks are summarized as mineral materials. The existing storage in building is described in the material intensity. The material intensity is defined as the quotient of the material warehouse and a typical building area or a typical building volume. For the results shown here, the gross external area (GEA) according to German DIN 277-1 is selected as a typical building area. Figure 3 shows the material intensity of different MFH and SFH in t/m² GEA. Gruhler et al. comes to the following conclusions: MFH have a material intensity in t/m² main usable area (MUA) of average 2,2 t/m² MUA, the traditional types of buildings are always more intense than the industrially erected. SFH have an average of 2.8 t/m² MUA a 0.6 t/m² MUA (27%) higher material intensity as MFH SFH are more material intensive than double or detached SFH. The number of floors, has a large influence on the material intensity in MFH [15].

### 3.2 Material intensity in new buildings

Own calculations are based on real-built buildings. They have been carried out on the basis of design drawings and mass calculations. This bill of quantities is also the basis for the performance of life cycle assessment (LCA) of the buildings. In LCA the materials are studied for their effect on the environment. In this study the mass investigations are used to make a statement about the included resources in buildings.

The studied buildings are SFH and MFH. The SFH have a maximum of three storeys. In the MFH, number of floors vary between three and eight. The construction type's massive wood construction, timber frame, conventional (reinforced concrete, EIFS, brick) and hybrid constructions were calculated. Hybrid structure is understood as a combination of mineral load bearing structure and wooden facade.

The year of construction of the buildings is maximum of five years back, so all have a high energy standard. The system boundary of the investigations are the floors above ground. Basements, balconies and outdoor facilities were not taken into account. Altogether we calculated 16 SFH (8 wooden, 8 mineral buildings), and 27 MFH (6 wooden, 13 hybrid and 8 mineral buildings).

Figure 4 shows the amounts of materials in SFH houses per m²/GEA. The largest share is the mineral fraction. Even buildings, where the primary structure is made of wood, show a high proportion of mineral materials although no basement is included. The comparison of the masses of SFH shows in buildings of conventional design twice as much mineral material as in wooden structures. Wooden structures contain twice as much of renewable materials. The same results show calculations of MFH. On average, new mineral buildings (MFH and SFH) show a material intensity of 1.2 t/m² GEA.

Wooden buildings have a lower material intensity of 0.6 t/m² GEA for SFH and 0.8 t/m² GEA in MFH. Hybrid constructions have a value of 1.0 t/m² GEA. The results show that the quantities and composition of material is critically dependent on the construction.

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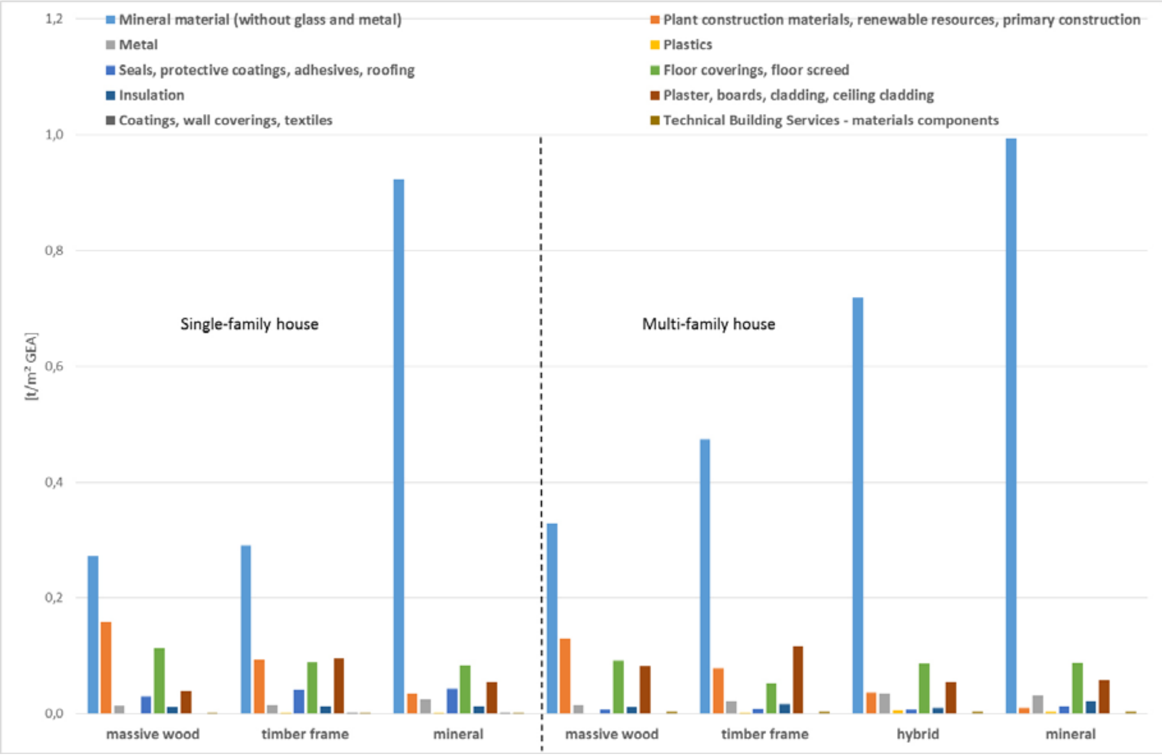


*Fig. 3: mass of resource in buildings. Adapted after [15].*

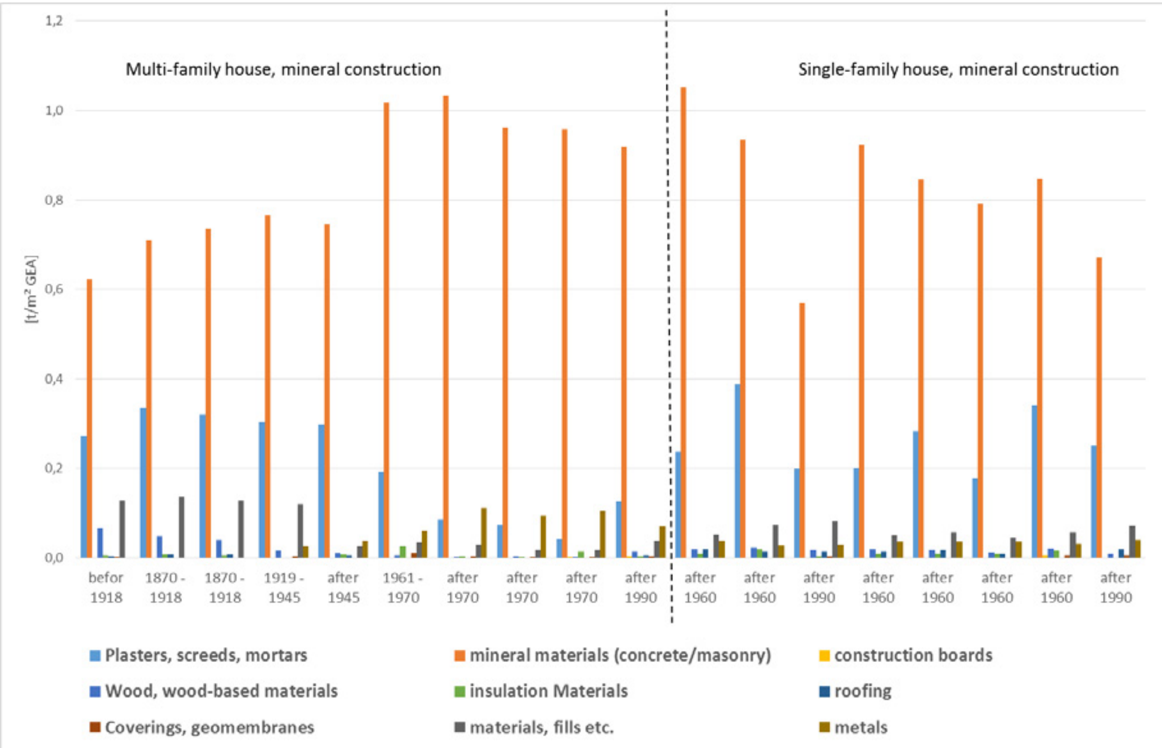


*Fig. 4: average mass of material in SFH and MFH.*

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### 3.3 Material quantities of a new residential quarter

The city of Munich is currently planning a new residential quarter on a former military conversion site with 1800 units and a floor area of approximately 254.000 m². The goal is to develop strongly needed affordable housing and at the same time to address issues of energy efficiency and environmental impact with innovative approaches. The development plan for the new quarter is shown in figure 5 and shows a wide variety of buildings. The southern part of the quarter will be designed as an „Eco-City". In this part – outlined by the red line - around 500 flats are to be built. Framework for the „Eco-City" is innovative energy supply with renewable energies, buildings in plus-energy-standard and building with wood, a mobility concept and shared facilities. The „Eco-City" contains small terraced houses, free standing four story-buildings and 5-7 multi-story residential buildings.

*Fig. 5: new residential quarter in Munich [16].*

It is assumed the entire northern part will be erected in a conventional mineral design.

In the part of the "Eco-City" 25% of floor area is assumed to massive timber constructions and 43% in timber frame construction. 32% of floor area is expected to be realized in a hybrid construction, which has been accepted here.

From the calculated values (s. fig 4) average values are made for the construction types massive wood, timber frame and conventional-mineral. Hybrid structures will be considered in the MFH additionally. The calculated buildings can be classified to the planned buildings types. The SFH meet the small terraced houses with a maximum number of 3 floors. The MFH meet free standing four story-buildings and 5-7 multi-story residential buildings.

By assigning the calculated average values of real buildings to the planned building development in floors and GEA the expected material stock of the new residential quarter can be determined. In figure 6 the calculated material quantities in tonnes for the investigated area are shown.

An area of 30 hector (subdivided in approx. 53.000 m² floor area of wooden construction and 201.000 m² floor area of mineral construction) with the building typologies described above includes approximately 200,000 tonnes of material resources.

The result shows the proportion of predominantly mineral material. Despite an increased proportion of wooden buildings as usual, the mineral materials dominate. The mineral materials have a 80% share of the total material usage.

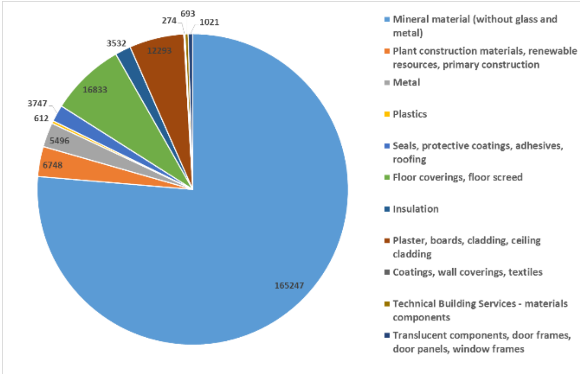


*Fig. 6: mass of resource of a new residential quarter in tonnes.*

### 3.4 DISCUSSION

The presentation of results of existing buildings from own LCA calculation and transmission on new planned buildings shows that a unified planning tool for material documentation is useful.

The calculations also show a material intensity of 0.9 t/m² GEA for SFH and 1.0 t/m² GEA for MFH of mineral material in mineral constructions (s. fig. 4). Investigations by [15] show a material intensity of 0.6 t/m² GEA for SFH and 0.9 t/m² GEA for MFH by consideration mineral materials of buildings after 1990 (s. fig. 3). The comparison of the own mineral material quantity calculation and quoted literature values indicate a comparable level. The differences may be caused by variations in the considered elements or in the definition of material categories. Future arrangements for system boundaries should be developed for a consistent documentation of materials. Depending on the material type and construction type material intensity varied. The choice of reference area is crucial for the assessment of buildings. It offers different interpretations [15].

## 4 SUMMARY

It could be shown that the building industry is one of the most resource-intensive industries, but also high rates of recovery or recycling are realised. They are available for almost all materials of the demolition in building. Quality recycling is complicated for complex materials, inseparable

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materials and critical compounds or it is even entirely prevented. To facilitate future technical conditions for an efficient and high-quality use of materials, data on the size and composition of the existing anthropogenic raw material storage are required. Investigations by [15] for the existing material storage in buildings were shown.

Based on own LCA calculations, possible material stock of new buildings was calculated, and extrapolated for a planned housing estate. It has been shown that the choice of construction material has an influence on the material intensity. Wooden buildings have lower material intensity than conventional constructions. But the proportion of renewable materials is twice as large compared to mineral material construction. This has a big influence in the consideration of energy efficiency and environmental impacts. The exact values of environmental impact will become even more evaluated.

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