# Used building materials as secondary resources – Identification of valuable building material and automized deconstruction

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**Abstract**
*These days, we are constantly expecting more from the performance of the building envelope with regard to both comfort and ecological compatibility. Operational energy has been undergoing significant improvement, which in turn draws attention to the building material: If a standard building does not consume energy in its operation, then it is the building material that impacts the level of environmental compatibility. Designing with used building material offers an opportunity to decrease emissions from extraction, preserve primary resources and reduce landfill. On top of that, the EU waste directive requires all new construction to have a recycling concept for 70% of the building mass (Commission, 2013). This paper deals with a new approach to deconstructing used building elements and re-introducing them in new construction on a regional scale. A well-connected network of stakeholders increases the regional recycling potential. On a technical scale, the deconstruction process needs to be improved so that it becomes more safe and economically competitive. Robotic disassembly shows great potential to simplify the process and restore high valuable recycling. Deconstruction processes can be arranged in a mobile way with a wide range of tools. Such tools can be equipped to relate to the flexible layout of machines, thus allowing individualized adaptation to the building envelope.*

**Keywords**
*circular building economy, sustainable design, resource-efficient building material, stakeholder analysis, robotic disassembly*

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# 1 INTRODUCTION

Sustainability and circularity have become a global topic of social and political interest due to the recognizable effects of climate change. Moreover, against this background of new climate change goals, and a growing population with an ever-increasing need for space and resources, an emphasis is placed on the need for resource-efficient solutions (WBGU et al., 2016).

In order to preserve the natural environment and provide for future generations, the extraction of natural resources has to be minimized. Several countries, such as Germany, are committed to improving their resource efficiency, which aims for a 200% improvement on 1994 levels. (In 2014, 148.7% was achieved. Figures for other countries vary according to the natural resources and economy).

Currently, the motivation to use secondary resources in the built environment is relatively low. Several aspects including cost, liability, and social issues such as customer acceptance and a low level of awareness in relation to preserving natural resources, still restrict circular material flow within the building sector.

By focusing on an industrial region in western Germany as a case study, these obstacles shall be investigated and proven by surveying regional stakeholders linked to the building sector. The Rhenish mining area in western Germany plays a leading role in extracting resources for energy, nutrition and material supply. North Rhine-Westphalia, the county in which the region is situated, is home to 12,544 building industry companies, the highest number in Germany (Destatis, 2015). Only mineral material, and its recycling path towards an equal or higher quality compared to its primary material, were considered in the study.

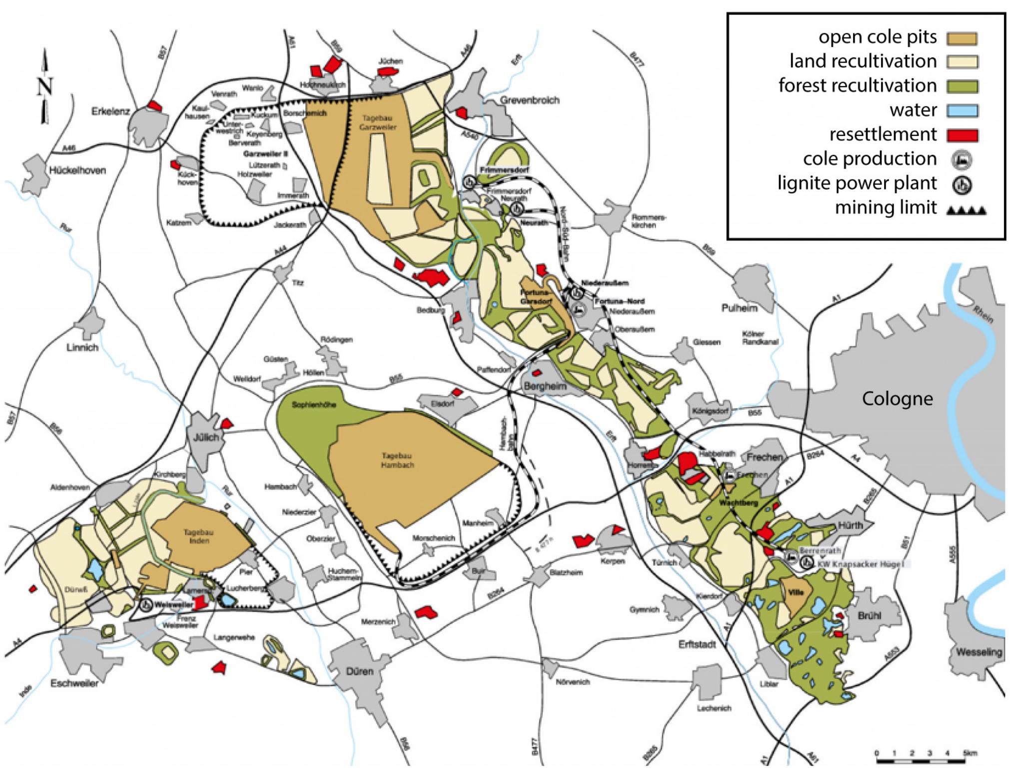


FIG. 1 Rhenish Mining Area, RWE Power 2014

North Rhine-Westphalia has rich resources of gravel, the main component for concrete production. The annual production of 65.5 million tonnes of sand and gravel forms the largest constituent within the regional building sector (Fig. 2), while 15 million tonnes of building waste is also produced in the county annually (IT.NRW 2013).

Looking more closely at the scale of the Rhenish mining area, about 1.5 million tonnes of building waste (largely of mineral origin) is created here annually. An unquantified, though significant, share of this volume results from ongoing resettlement processes, in which buildings are demolished and their inhabitants rehoused, to make way for lignite extraction activities. None of the material resulting from such demolitions has yet been reused or recycled for an equal or higher purpose.

These volumes of building waste can be considered a valuable source of secondary raw materials – and could be referred to as an anthropogenic material stockpile (Schiller, 2015). If systematically managed, this material could serve as a capital reserve for the future.
The reuse and recycling path is specifically developed for each building material, each undergoing an individual process. In addition, it is not only the qualities of the  material itself that indicate its suitability for recycling, but also the construction context of the material.

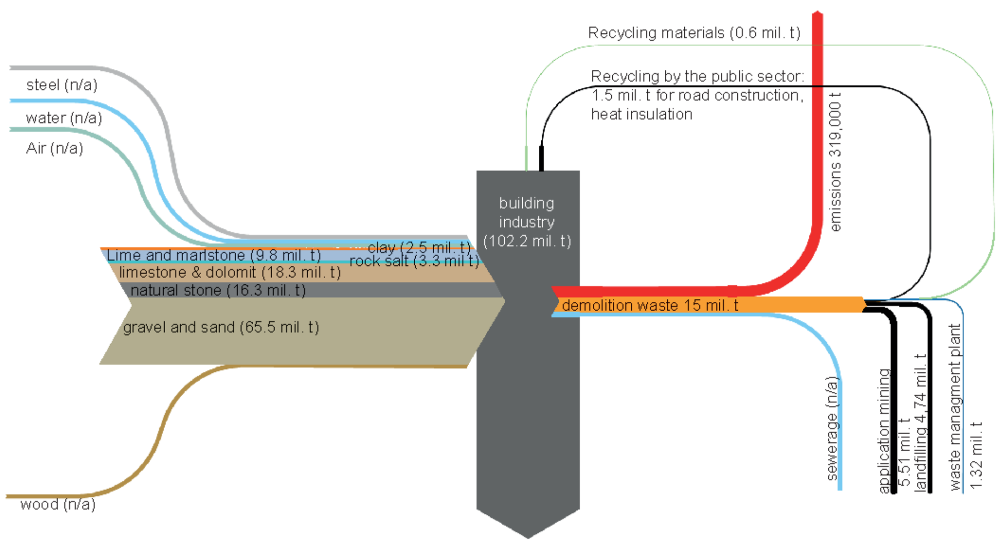


FIG. 2 mineral material flow diagramm, IRR 2015

## 2 METHODOLOGY

The research consists of two parts. The first presents the results of a survey of stakeholders that aimed to identify obstacles and opportunities. Second, the energy dimension of deconstruction is analysed using a method, developed at RWTH by the authors. This analysis demonstrates the relevance of deconstruction (rather than demolition) in relation to the technical obstacles within towns that are to be demolished due to resettlement. The analysis is organized into two main interdependent parts, and results in the categorisation of 12 typical facade constructions.

The reason for the limited focus here on the facade is due to the argument that it is a particularly complex building element.

The embodied energy of the useful material is the benchmark for determining the energy spend on deconstruction. With a higher amount of deconstruction compared to a primary product, the product is more ecologically reasonable.

## 2.1 STAKEHOLDER SURVEY

To identify what potential exists for recycling in the region, a survey of stakeholders from political, industrial, and research backgrounds was undertaken, which analysed their motivations in relation to recycling as well as examining the network of such stakeholders in the region.

The stakeholders were chosen for their relevance (influence on policy, industry and research), using a top-down approach (representatives of industry, policy and research). These stakeholders became discussion partners and, in their function as experts, decisively shaped the results of the series of investigations. For this reason, the selection of experts was targeted at demolition and mineral building material industry representatives, since they were regarded as the qualified leaders in the subject. Representatives from the political level were chosen due to their experience and their field of expertise, while research representatives were chosen based on their relevant scientific publications within this field. Answers were given by multiple choice, but an open discussion allowed the possibility for further elaboration.

Initially, the survey included questions regarding:

1. stakeholder motivation towards a circular building economy
2. general conditions of the circular building economy
3. network (connections between the stakeholders)
4. demands on other stakeholders
5. intentions to act

### 2.1.1 Results

By identifying the main conditions needed for a circular building economy, it became clear that the acceptance of recycling products is important, though the survey results suggested this is absent amongst the target market.

The lack of acceptance can be partly attributed to the insufficient body of knowledge on the composition and origin of the material. Furthermore, the results indicated that statuory regulations negatively impact the use of recycled products.

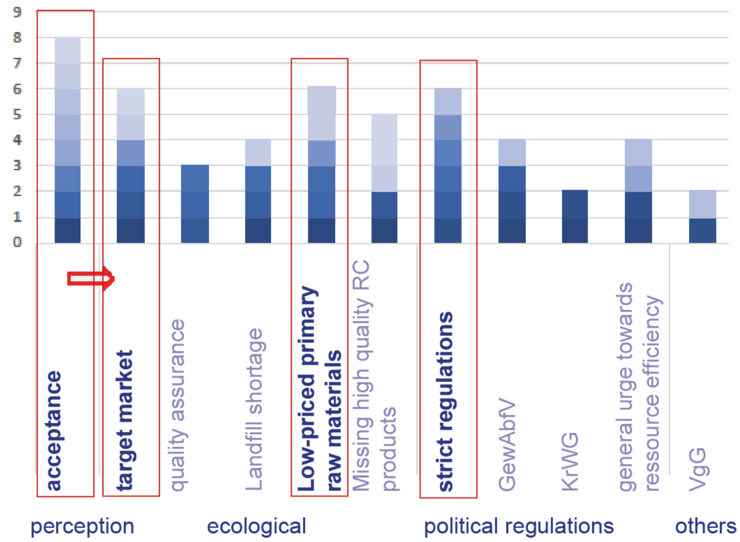


TABLE 1 general conditions of the circular building economy, RB 2016

It was shown that a well-formed and regularly-used network exists between the industrial stakeholders. However, further development is necessary to address the lack of the consumers within the network. This lack confirms the consumer's non-acceptance of recycled building material.

In the future, substituting primary building material in street construction with demolition waste will become more difficult due to statutoryrestrictions (Mantelverordnung), and substituting primary material for high performance concrete is also difficult due to strict regulations (Deilmann, 2014, p.51). However, costs associated with landfilling are set to increase, which will lead to economic advantages for secondary resources.

### 2.1.2 Deconstruction

The Rhenish mining area is characterized by opencast mines and power plants for energy production. Since 1952, mining activities have caused the displacement of 44,064 people (Bund NRW, 2016). Such resettlements of people are ongoing or planned for the near future. The building material produced by the demolition of these places has, up until now, usually been used for landfill.

To reach the goal of upcycling the primary material, its recycling potential needs to be defined, and this depends on defining the quality of the segregated material. The process of extricating the material requires construction site equipment, machine time, transportation etc., and the effort required to do so determines the feasibility of the potential material; the lower the effort to deconstruct, the more sensible it is to do so. (This logic can also be applied to ecological and economical aspects.) The deconstruction phase is therefore of special relevance for two reasons: first, for the architectural planning of future buildings and second, in order to provide circularity.

The number of deconstructable buildings in the Rhenish mining area is growing following the global trend of migration to cities, peri-urban redevelopments and further resettlement plans. As it loses its function, a building's raw material becomes accessible as secondary resource.

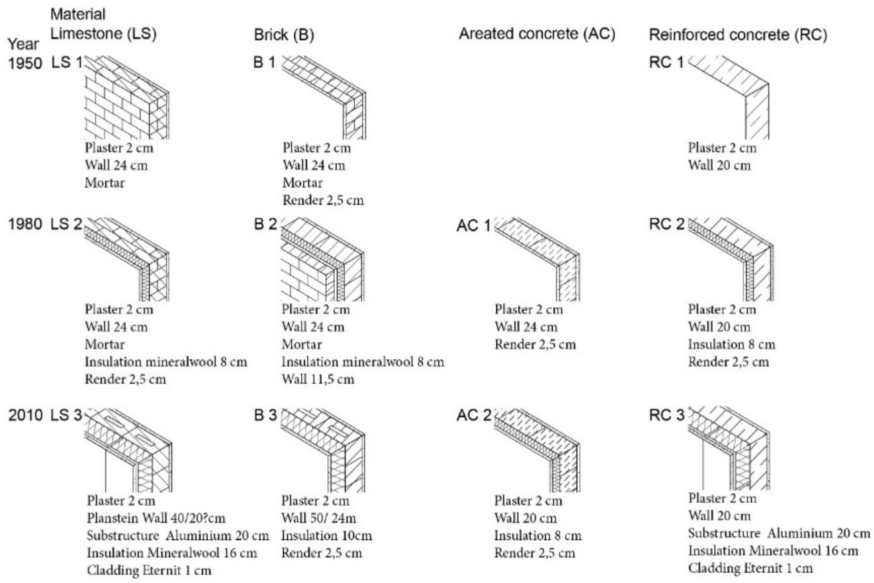


FIG. 3 facade types. RB, 2016

In order to provide a broad overview, regional typical facade types from the 1950s and 1980s are investigated, as these account for the main proportion. The decade in which the facade was built generally indicates the type of construction (Knaack, Hildebrand, Konstantinou, & Wieland, 2013). 2010 is chosen as an additional reference year as significant changes in building insulation took place around that period. The facade types can be put into categories of *no insulation, minor insulation* and *full insulation*.

The major proportion of the chosen facades is made up of mineral materials (insulation and cladding material are exemptions). Only the opaque parts are considered. Four different stone types are shown, including three cladding variations.

The facades have a massive mineral loadbearing shell in common. Limestone, brick and hollow brick are glued together by mortar, while the concrete variants are monolithic and enclose the reinforcement. Ventilated cladding is held on substructure screwed into the wall. Self-supporting cladding (i.e. brick shell) works in a way similar way to that which is loadbearing.

The energy invested in a the production of a building material can be referred to as its ecological value. Similar to economic value, this indicates high responsibility and, in this case, potential to preserve natural resources and limit emissions. According to the bill of quantities, measuring the amount of non-renewable primary energy helps us to understand the capabilities of the substance.[1]

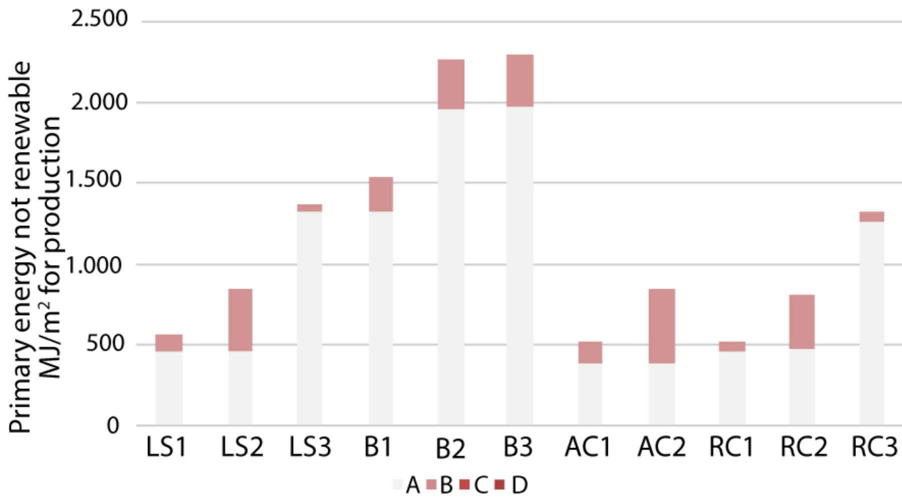


FIG. 4 Non-renewable primary energy used in production, subdivided into the following categories: A) non-destructively detachable, B) destructively detachable (pure material), C) destructively detachable (mixed material same category), and D) critical materials. RB, 2016

In most cases, the load-bearing layer has the highest impact. Naturally, by adding layers (facing shell B2 or cladding on substructure LS3/RC3) greater results are yielded. The stored materials including LS3, B2 and RC3 are of great ecological value.

For obvious ecological reasons, the deconstruction of the product to be reused cannot use more energy than would be used in the creation of a new product. Table 2 shows the embodied energy for reused building elements. This is the maximum output when disassembling a facade element.
The energy embodied in the reusable and recyclable products can be used as benchmark for the energy of the deconstruction.

In most cases, the complexity of the connection details between facade elements indicates the effort required to deconstruct them. Naturally, the more layers or components there are in the facade element, the higher the effort.A facade with insulation that has been glued to its structure requires a higher effort for deconstruction (facing shell LS2, B3, AC2, RC 2), as do smaller building materials like brick demand. Limestone, brick and hollow brick are glued together by mortar and demand a higher deconstruction effort than reusable concrete variants that are monolithic. Ventilated cladding that is held on substructure screwed into the wall (LS3, RC3) can be dismantled with relative ease.

| | LS1 | LS2 | LS3 | B1 | B2 | B3 | AC1 | AC2 | RC1 | RC2 | RC3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **benchmark ($MJ/m^2$)** | 452,8 | 452,8 | 1.317,8 | 1.314,8 | 1.972 | 311,8 | 383,1 | 383,1 | 475,2 | 475,2 | 1.259,9 |
| **effort for destruction ($MJ/m^2$)** | 2,8 | 10,2 | 5,3 | 9,1 | 10 | 7,3 | 3,8 | 9,2 | 0,8 | 7,4 | 2,4 |

TABLE 2 deconstruction results, RB, 2016

Ultimately, it must be ecologically sensible to deconstruct all facade types, and the reused or recycled product should have a lower embodied energy than a new product. It can be assumed that a significant portion of the deconstructed facade elements is not appropriate for direct reuse, in which case recycling with a higher energy input can be considered as an option.

## 2.2 RESULTS OF THE CASE STUDY

The way in which materials are connected defines the purity of disassembled elements and components, and impacts the potential for reuse while contributing to a higher recycling value. Looking at existing building stock, potential methods of deconstruction were seldom considered in their design. The facade types include various types of connections with specific levels of connectivity, ranging from low (non-destructive detachable) to high (destructive detachable or even hazardous waste). These categories were defined following the sorting process on site.

From an energy-use point of view, deconstruction is sensible for all construction types when addressing their ecological dimensions. However, deconstruction is still labour-intensive due to complex disassembly processes. Furthermore, health and safety issues need to be addressed. Deconstruction has a heavy impact on humans due to the following aspects: 1) noise, 2) dust, 3) vibration, 4) debris. Automation addresses a lot of the potential risks, and robotic deconstruction is an option to be considered in order to decrease human health impact and secure safety. Further reasons to favour robotic deconstruction are: 1) limited space, 2) contaminated material, 3) risk of fall/collapse, 4) building height (Motzko, 2016).

# 3 CONCLUSION

The Rhenish mining area indicates what the situation might be at other suburban industrial regions with a high number of buildings that will be demolished in the near future. This building stock can serve as a valuable reservoir of secondary raw materials.

To ensure a reuse of this building material, a well-functioning circularity in the building sector must be secured. To achieve this, all protagonists have to cooperate and communicate well. The exchange of information about the possibilities and advantages of reusing building material is vital in increasing awareness of its ecological impact. By reusing building material, primary resources and energy used for production can be saved. Economic aspects have not been included in this research, but consideration of these is necessary in order to guarantee a market placement of reused building material and this should be investigated in future research. From the perspective of acceptance, it would be beneficial if the industry provided reused and recycled products nationwide. Prototypes increase the acceptance of reused and/or recycled products, resulting in public investors favouring recycled material.

To achieve the goal of recycling building material, all protagonists involved in the building process have to include the principle of circularity in their actions.
In future scenarios, architects and engineers should include the deconstruction phase in their planning, and design for easy disassembly. This significantly increases the potential to make use of the material, energy and capital stored in buildings.

## Endnotes

The data situation allows for a simplified approach; while the facades shown are meant to demonstrate facades from '50s and '80s, the values refer to current data. It is added a 10% security tolerance, values retrieved form Ökobau.dat

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