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Determining Resource Conservation Potentials in the Recovery of Construction Waste and Formulating Recommendations on Their Use

Summary

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Abstract

The utilization of waste materials represents an important contribution to the protection of natural resources. This especially holds true in regard to high-grade recycling, which envisions to use wastes as secondary material and to achieve the closest possible product cycles and which, consequently, has become a major goal for waste management in the European Waste Framework Directive (2008/98/EC, Article 11) as well as in the current working draft of the German Recycling Act (KrWG, § 8), which is based on the said directive. The construction industry is of particular significance due to the mass flows it creates and the potentials it incorporates to get materials return into the resource cycle.

For future mass flows in the construction industry, the development of the building stock is of decisive importance. This development will mainly be determined by demographic and economic conditions. At present, these conditions are subject to great changes. Thus, in Germany it is expected that there will be enormous spatial and temporal disparities in regard to the development of building stock in the up-coming years. Based on the fact that recycling cycles of building materials are faced with distance limits, the material flow balances as well as the volume potential for the high-grade usage of construction waste in building construction vary greatly at the regional level.

Objective

The aim of the present study is to explore the medium (year 2020) and long-term (year 2050) expected potentials of high-grade recycling of mineral construction waste**.** Here the question is answered, especially in regard to the mass construction material of concrete, as to what extent recycling "from building construction back into building construction" could occur and what resource conservation potentials this would make accessible. The main subjects under consideration are the aggregates in the concrete used for constructing buildings. To this end, there is an accounting of the mass flow which focuses on juxtaposing the deployable, future amounts of suitable construction waste recyclates with the need for aggregates and the amount of corresponding gravel materials that can be substituted by recycled building rubble.

Development of a Material Flow Model

The quantification of recycling-relevant material flows is done via regionalized model calculations, using a material flow model developed expressly for this purpose. For medium-term considerations, regionalization takes place at the level of districts, which have been summarized on the basis of their areal specify. As for long-term perspectives, regionalized statements can solely be made in regard to the differentiation between Eastern and Western Germany.

The material flow model consists of several model components which are based on each other, in which recycling-relevant material flows are calculated and are later transferred as initial values to subsequent model components (Figure 0-1).

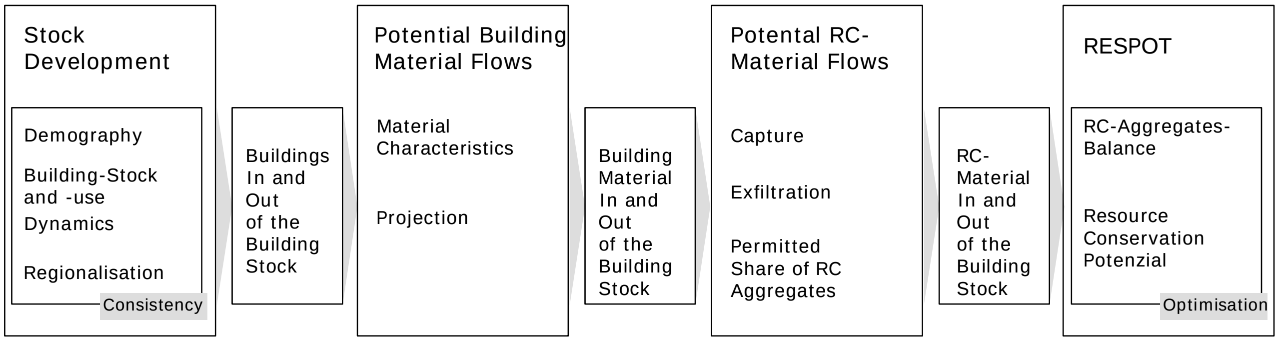

Figure 0-1: An Overview of the Material Flow Model "Resource Conservation Potential"

The model component "stock development" serves to illustrate possible future development of the building stock (in and out of the residential and commercial building stock) at the regional level. The assessment of regional changes in housing stock relies on the aggregated projections of Banse and Effenberger (2006). These assessments are projected in accordance with the relevant parameters used for de-scribing the housing supply, housing demand as well as any resultant insights into the utilization of building stock at the level of area typology. On the other hand, the procedure employed for the field of commercial building is based on hypothetically formulated statistical values of the development of building stock. According to them, the housing stock will continue to grow in the medium term in Western Germany and in districts in Eastern Germany characterized by tendencies towards suburbanization. However, in Eastern Germany, there are mainly found area types (AT), in which the housing demolition figures exceed the number of new building being built. In the long term, the demolition of the housing stock will exceed new construction almost every-where (Table 0-1).

Table 0-1: Assumptions for the Increase (New Buildings) and the Decrease (Demolition) in the Building Stock

Housing Stock Changes in 2020 (1000 apartments / year)									
	Ger-many	Western Germany				Eastern Germany			
		Total	AT1	AT2	AT3	Gesamt	AT4	AT5	AT6
New Buildings	204	187	51	25	111	17	3	9	5
Demolished Buildings	113	63	23	10	31	50	11	35	4
New/Demolished	1,8	3,0	2,2	2,5	3,6	0,3	0,3	0,3	1,3

AT1: urban centers; AT2: districts with a low dynamic, AT3: districts with a greater dynamic, AT 4: urban centers, AT 5: sparsely populated and often peripheral, AT6: countryside districts with tendencies towards suburbanization

Housing Stock Changes in 2050 (1000 apartments/ year)			
	Germany	Western Germany	Eastern Germany
New Buildings	107	94	13
Demolished Buildings	282	232	50
New / Demolished	0,4	0,4	0,3

For commercial building stock, it is assumed that it will increase in both Western and Eastern Germany (Table 0-2).

Table 0-2: Assumptions for the Change in Stock of Commercial Buildings

Changes in the Stock of Commercial Buildings in 2020 (1000 buildings/year)									
	Germany	Western Germany				Eastern Germany			
		Total	AT1	AT2	AT3	Total	AT4	AT5	AT6
New Buildings	36,0	31,0	8,8	5,7	16,5	5,0	0,8	3,4	0,7
Demolished Buildings	16,2	13,9	4,0	2,6	7,4	2,2	0,4	1,5	0,3
New/Demolished	2,2								

AT1: urban centers; AT2: districts with a low dynamic, AT3: districts with a greater dynamic, AT 4: urban centers, AT 5: sparsely populated and often peripheral, AT6: countryside districts with tendencies towards suburbanization

Changes in the Stock of Commercial Buildings in 2050 (1000 buildings/year)			
	Germany	Western Germany	Eastern Germany
New Buildings	26,0	23,0	3.1
Demolished Buildings	11,9	10,5	1,4
New/Demolished	2,2		

The subject-matter of the model component "Potential Building Material Flows" is to convert the previously estimated development of building stock for various area types into building material mass flows. The focus here is on recycling-relevant building material[11]. To this end, a calculation method is used, which is based on the material characteristics of typological buildings. For residential buildings, material characteristics of typological buildings based on existing studies can be formulated. For commercial buildings, the values here are determined hypothetically on the basis of data concerning construction activity.

On the basis of the amount of recycling-relevant construction materials, the model component "Potential RC Material Flows" calculates the volume of supply of recycling aggregates which can be recovered from the outgoing construction waste flows via reprocessing as well as the usage amount of recycling aggregates, which could be incorporated under the current standard and control requisites into the concrete under demand by the construction industry. The calculating of the supply side is based on estimates regarding the proportion of recycling-relevant fractions of concrete and brick from the outgoing construction waste as well as estimates concerning the proportion of unsuitable components segregated in the process of material reprocessing. The limits of technical practicality represent the primary references for that. With currently available technology (for assumptions see Table 0-3) approximately 48 % of the outgoing quantity of recycling-relevant building material can be made available as RC aggregates for building construction purposes. In the concrete of ordinary buildings, a maximum of 25 % - 32 % of the total volume can be incorporated in the form of RC aggregates in accordance with effective technical regulations depending on the concentration of brick tile parts.

[11] Recycling-relevant building material: concrete an bricks of the output-material-flow (used to produce RC-aggregates) as well as concrete of the input-material-flow (where RC-aggregates can be added)

Table 0-3: Basic Assumptions Regarding the Recovery and Use of RC Material

Recovery of RC material from the outgoing construction mass flow	20 % capture loss 40 exfiltration during reprocessing	
Use of RC-GK in concrete for new structures	In relation to the volume of GK in concrete	In relation to the total volume of concrete
	45% volume in delivery type L* and L1 35% volume in delivery type L2	32% volume in delivery type L* and L1 25% volume in delivery type L2

Volume percentages (RC-concrete chippings: RC-crushed brick) in the delivery types: L *: 100:0, L1: 90:10, L2: 70:30; The volume fraction of aggregate in the concrete is set at 72%.

The model component RESPOT balances the calculated supply and the usable quantity of recycled aggregates and thus determines the actual usable amount of RC-aggregates in building construction under given constellations of the housing stock development. The resource conservation potential corresponds to the volume of natural gravel material, whose use in the production of concrete for buildings may be waived on account of this substitution. The maximum technical substitution potential, which could be achieved under the assumption of unlimited avail-able quantities of recycled aggregates, provides a reference value that has been used for benchmarking the above findings. If the RESPOT falls below this reference value, optimization scenarios can be simulated with the model and thus approaches for the improved exploitation of resource conservation potentials derived. Such optimization may for example include adjustments of the deployed type of re-cycled aggregate, depending on the prevailing supply-demand conditions in the area type structures or alternative assumptions for the recovery and usage rate of RC-material).

The model calculations show that in assuming building stock developments as have been established in the medium-term for Western Germany, the potential demand for recycled aggregate cannot be met by the available supply. The dynamic of new building construction, in part, greatly surpasses the demolition intensity in the corresponding area types. Seen in relation to high-grade recycling, there thus exists a lack of appropriate RC materials from building construction. In contrast, for large parts of Eastern Germany, where the regions mainly exhibit a comparatively low new construction rate and a high level of demolition activity, an excess of recycled aggregate can be observed if the analysis is strictly limited to high-grade recycling using and recycling material only in the field of building construction. One exception to this are the “countryside districts with tendencies towards suburbanization,” in which in a weakened form similar changes of housing stock development can be observed compared to that in Western Germany. If the potential resulting from the application of technical and normative limits as well as from the expected material supply at regional level is used for high-grade recycling, then in 2020 a volume of 4.1 million m³ /year of natural gravel may be substituted by recycled aggregates. An additional 1.8 million m³ potentially recoverable aggregates cannot be accommodated by building construction for purposes of high-grade recycling. These reserves are mostly located in Eastern Germany (Table 0-4).

Table 0-4: Resource Conservation Potential and Future "Storage Sites" in 2020

Reference year: 2020	Germany	Western Germany	Eastern Germany
Substitutable amount of natural gravel in the concrete on the basis of the demand for new construction, (RESPOT) [million m³ / year]	4,1	3,6	0,6
Quantity of deployable recycled aggregates, which through lack of demand cannot be incorporated into building construction ("storage sites") [million m³ / year]	1,8	0,5	1,3

With an exclusive focus on the use of recoverable RC material from mineral construction waste being used as aggregates in building construction, incongruent tendencies will develop in Germany in the medium-turn: in some regions there would be surplus amounts of RC material for high-grade usage while, simultaneously, in other regions there would be a shortage of them.

These regional disparities cannot be resolved because the recycling of construction materials is only economically feasible in strict spatial boundaries. Rather, they require a regionalized approach, as is illustrated by this study. Only then is it meaningfully possible to capture and exploit the potentials for recycling in building construction in an adequate manner.

However, recycled aggregates from mineral C&D waste with different amounts of concrete and brick elements can be used. The permitted share of the various material components is currently regulated in Germany by DIN 4226-100, which sets the requirements for aggregate delivery types. Depending on the delivery type used, certain admixture amounts of recycled aggregate in concrete are allowed from an engineering perspective. With an increased brick proportion in the recycled aggregate, the maximum admixture level decreases in the concrete. Without special authorization, currently the highest substitution level that can be achieved by using recycled aggregate is one in which at least 90 % of its weight consists of re-cycled concrete parts. However, this presupposes having the adequate local avail-ability of suitable concrete material from demolition activities. But if the available RC concrete material is not sufficient enough to allow for the maximum technically permissible substitution level in the concrete under demand, then it can be advantageous in regard to maximizing resource conservation to make use of recycled aggregates with a higher brick content, even though the permissible admixture amount per unit of concrete would be reduced by doing so. This potential reserve can be detected in the area types that are characterized by a clear lack of recycled aggregate in the medium-term.

The compositions of recycled aggregates that are permitted to be used in concrete have a considerable influence in the medium-term on the resource conservation potential that can be achieved through high-grade recycling Whether a better exploitation of the resource conservation potential can be brought about through the use of variously composed aggregates, is dependent on the ratio between the available supply of recycled aggregates and the amount that can be incorporated resulting from the demand for concrete. This ratio varies greatly at the regional level in the medium-term.

In addition to the exertion of influence on the input-side, for example by deliberately raising the use of mineral materials that do not stem from concrete in the re-cycled aggregate and ways of increasing the admixture rates, optimizations in the collection and processing of outgoing construction waste represent obvious starting points for further increasing the resource conservation potential through high-grade recycling.

The model assumptions for the recovery of sorted concrete and brick fractions and for the producibility of suitable recycled aggregates through the exclusion of unsuitable material content (see Table 0-3) meet the ambitious limits of technical feasibility in light of contemporary conditions. Here achieving a further optimization would at present be associated with a disproportionately high amount of effort and would possibly also increase the risk of a drop in the quality of RC-materials generated. As a starting point for further increasing the achievable resource conservation potential, these points of intervention are thus of secondary importance for the time being.

Seen from a long-term perspective, the relations between the material output from existing buildings and the material input into the building stock will be shifting. From the emerging demographic dynamics it can be derived that in 2050, particularly in housing, the number of buildings being demolished will clearly exceed the number of new buildings being built almost everywhere. Possibly, the commercial building stock will continue to grow in the long-term but only with a much lower momentum when compared with the medium-term perspective. This will reduce in the long-term the maximum level of resource conservation potential that can be achieved in building construction through high-grade recycling. Both in the Eastern and Western parts of Germany, the technically imposed upper limit of the substitution of concrete additive can be achieved with the potentially available RC material. The model calculations reveal that the achievable resource conservation potential for the year 2050 is 3.3 million m³. This represents a decrease of about 20% in comparison with the corresponding value from the year 2020. At the same time, in the long-term this would - in terms of high-grade recycling - represent an oversupply of recycled aggregate nationwide. This is estimated for 2050 to be 6.2 million m³/year, thus representing an increase by a factor of 3.4 as compared to the value reported for the year 2020.

Table 0-5: Resource Conservation Potential and Future "Storage Sites" in 2050

Reference year: 2050	Germany	Western Germany	Eastern Germany
Substitutable amount of natural gravel in concrete on the basis of the need for new building (RESPOT) [m. m³/year]	3,3	2,9	0,4
Amount of deployable recycled aggregate, which due to a lack of need cannot be incorporated into building construction ("storage sites") [m. m³/year]	6,2	5,0	1,2

In the long-term, the maximum technical resource conservation potential via high-grade recycling with the recycled aggregate obtainable from mineral construction waste is fully achievable. The attention is shifting to the growing amount of avail-able RC-materials, which as a result of declining construction activity cannot be incorporated in building construction.

Quantifying the achievable resource conservation potential clearly indicates the necessity of granting spatial and temporal aspects a special status in the interests of the broadest possible implementation of high-grade recycling. Spatial and temporal disparities characterize the future building stocks. The emerging heterogeneous view here illuminates the significant differences, which will have been adequately taken into account on the path leading to high-grade recycling. The model presented thus makes a contribution to the regionalized predictive modelling of relevant material cycles. The system limitations for the interpretation of the achievable resource conservation potential still appear to have been made in too restrictive a manner, though. Among others, an emphasis is placed on recycling material flows in building construction in the strict sense of the word by examining construction waste flows out of the building stock, their collection and processing, the demand for building materials in building construction and the quantity of recycled aggregate to be introduced. Associated raw material sources and deployment areas, which greatly determine the framework for the achievable resource conservation, could not be taken into consideration. This concerns above all additional types of raw material which affect the supply side of building material -for example, the available amount of primary aggregates - but also the considerably wider range of possible options for RC usage. Here, exist dependencies in regard to the studied approach of high-grade recycling, which may be subject to similar spatial and temporal disparities. Moreover, the building construction sector, which above all is focused on more demanding types of concrete but with them on a rather limited spectrum of concrete applications only, is giving high-grade recycling only a significantly narrowed perspective. In terms of quantity, however, interesting fields are also offered with concrete applications in the area of civil engineering as well as in the fields of road, sidewalk, sewer and pipeline construction. Here, the demand for the high-grade utilization of RC-material can be met, often probably in an even easier way.

Against the backdrop of long-term disparate developments, the strengthening of planning security will gain in importance in the form of an extension of the spatially and temporally differentiated knowledge basis. This requires the consistent further development of appropriately formulated analysis approaches, taking into account all those sources and options which have a significant influence on the framework for high-grade recycling.

The present study focuses on the use of recycled aggregate in building construction. Here, among other things, the importance of the ratio of concrete and brick to be incorporated in the recycled aggregates becomes evident. Especially the proportion of brick components in the recycled aggregate significantly affects the substitutable amount of natural gravel in accordance with authorized practice. This aspect, however, should not only be considered in terms of the maximum amount of raw material substitution to be achieved in the context of high-grade recycling. It is therefore short-sighted to reach the conclusion that, when there is sufficient availability of recycled concrete, incorporating brick components should be refrained from to the greatest possible extent so as to achieve the maximum technical substitution amount. Here, among other things, it is important to remember that there is a restricted number of ways to utilize scrap bricks with many fields of civil engineering such as road base construction nearly ruled out while this does not hold true for recycled concrete.

The recycling of used brick in building construction becomes more important in the extended perspective and broader look on things.

Here, for instance, mention can be made of initiatives in Saxony, where the Ministry of Finance is currently assessing to what extent the passive house standard in public buildings can be implemented while also incorporating, for example, the recovery of brick chippings. Contrary to the hitherto prevailing trends of constructing thin but high-strength and insulated wall structures, it will be investigated whether adequate functional properties can be achieved just by using higher-dimension wall sections that provide lower strength requirements for the building materials, which would thus allow for an even greater use of brick recyclates while, simultaneously exhibiting better insulation properties.

With the available technology and developed technical processes, there exists considerable potential for the improved recycling of mineral C&D waste in building construction. In practice, however, little use has been made of it. In addition to regional disparities in the available amount of and the need for recycled aggregate, this can also especially be attributed to a lacking knowledge basis and poor acceptance regarding the use of recycled matter for applications in building construction. Evidence for this was provided by the numerous discussions with experts which took place in the context of the project. Additionally, mention can be made of the work currently being carried out on behalf of the German Federal Environment Agency on these issues (UBA, 2008b). These studies indicate that, although "the recycling of mineral waste already plays a major role today, [...] there are still many measures that need to be taken in order to improve the acceptance and the market position of recycled products in a lasting manner" (UBA 2008b: 101). Efforts are proposed here for creating new markets for high-quality applications, highlighting the value of recycling, con-serving natural resources involving the complete chain of actors, internalizing external costs, having public authorities adopt a pioneering and exemplary role, establishing clear legal requirements in terms of guarantees as well as ensuring quality within the entire material cycle. It has also been deemed just as necessary to strengthen know-how and competence in praxis via well-communicated, application-oriented education and research. This is supported by findings obtained in the course of the present study, according to which the subject matter of the use of recycled aggregates in concrete has so far not been a consistent part of the relevant technical education and the dissemination of viable ways of carrying out high-grade recycling is hence not sufficient.

<u>The broadening of the knowledge base on the level of immediate actors and an in-creasing acceptance thus represents one of the central challenges in the context of a strategy for promoting high-grade recycling.</u>

In this context, particular attention should also be paid to supporting the context of justification. Thus, it should be illustrated in an understandable manner that through the use of RC material in building construction, these materials would not be withdrawn at the same time from other fields of application such as, for instance, road construction and backfilling and there, once again, they have to be compensated by natural materials. Even issues of adverse effects (e.g. due to increased requirements for cement in the use of secondary aggregates in concrete construction) must be given further attention.

An extended quantification in accordance with the approach that incorporates other sources and utilization options as mentioned earlier provides an important entry point here. In addition to the field of building construction, it must also incorporate in particular the recycling alternatives in the field of civil engineering. Increasing material outputs in building construction and declining investment activity in the field of civil engineering could lead here to volume ratios that might significantly strengthen the position of high-grade recycling. In this context, it is also important to analyze critically the extent to which RC materials used in the aforementioned manner by civil engineering can be constructively justified. Possibly, civil engineering and road constructions along with their high recycling quantities are distracting from the fundamental issues focused on resource-conserving construction and restructuring of technical infrastructures. The same applies to the reclamation of mining areas, which has already been referred to in (UBA, 2008b).

An enhanced accounting approach enriched by other relevant aspects will have to place more emphasis on the free interchange of recycled aggregate between building construction and civil engineering. Recycling should be seen from a macroeconomic perspective, taking into account all possible forms of applications, before optimizing the raw material substitution in accordance with specific applications.

The question of the ecological importance of high-grade recycling is certainly a complex issue to discuss. These arguments presented about the environmental consequences resulting from a potential increased demand for cement, which can-not be excluded in light of current practical realities, weigh heavily. Simple estimates of a reduced amount of new land being used from surface mining activities for providing raw materials are only of limited help to rebut this. A full accounting of the environmental impacts in the sense of an environmental performance evaluation could help make the discussion more objective and better address existing shortcomings. Close attention here should be paid to the use of appropriate indicators, by which the different impact categories are to be represented. The special significance and challenge then lies in interpreting to be expected. Under no circumstances should it rashly be concluded, on the basis of an environmental effect profile that does not admit an unambiguous recommendation in favour of high-grade recycling, to reduce the efforts being made in this direction. It is important to re-member that the technological developments beneficial to high-grade recycling are still comparatively "young" and that these technologies are yet at an early stage of development. Experts still see here considerable opportunities for development in regard to RC utilization and also in regard to the production of building materials with secondary materials. Accounting disadvantages in comparison with the already established and optimized approaches, which are typical for technologies in early stages of development (see also the history of the development of solar technology), shall not necessarily lead to the premature termination of ongoing developments. It is rather more often the case that learning curve effects contribute significantly to the establishment of technologies for reducing the eco-balance effects.

The results of an ecologically balanced analysis can give valuable clues as to the direction in which efforts of technological development of reprocessing technology and the technology of producing building materials should be directed so as to possibly reduce existing ecologically balanced disadvantages of recovering construction waste in the field of building construction in comparison with conventional primary building material applications and additional recycling options.