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Demolition Waste an Analysis of Composition and Financial Value based on a Case Study in Vienna

A Master's Thesis submitted for the degree of "Master of Science"

> supervised by Ass. Prof. DI Dr. Johann Fellner

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Vienna, 9 October 2013





Affidavit

I, KATRIN LEPUSCHITZ, hereby declare

- 1. that I am the sole author of the present Master's Thesis, "DEMOLITION WASTE - AN ANALYSIS OF COMPOSITION AND FINANCIAL VALUE BASED ON A CASE STUDY IN VIENNA", 83 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
- 2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 09.10.2013

Signature

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ABSTRACT

The following thesis aims to elaborate on the composition and financial value of building materials after demolition. The theoretical part presents the current situation on the management of construction and demolition waste in Austria and Europe by addressing relevant legal regulations, norms and guidelines. It provides relevant information on the establishment of secondary markets for recycled building material, namely building components exchange. Additionally, strategies and issues as well as economic aspects regarding the reuse of construction and demolition material are identified. Results of the first part show that the political and legal framework comprising an end-of waste status as well as a product-status declaration clearly set the stage for the establishment of a market for recycled construction and demolition material.

The second section of the thesis constitutes a case study based on data recorded at in-house investigations of a retirement home building in Vienna. The data collection was carried out by the 'Christian Doppler Laboratory' on 'Anthropogenic Resources' of the Technical University of Vienna. Within the framework of this research project methodologies for the exploitation of secondary resources are elaborated by several PhD students. During the in-house investigations, 14 materials were identified according to major quantity with concrete accounting for the biggest mass. Based on interviews with recycling experts, possible recycling and disposal paths of the selected material streams will subsequently be exhibited in a recycling scenario. In order to determine the value of primary and recycled construction material, prices of raw and recycling materials are investigated with the intention of juxtaposing primary and secondary resource value of the building. The results of the case study reveal that the primary value is 17 times bigger than the secondary resource value. However, this conclusion cannot be generally applied and varies according to building types and demolition processes. Even though disposal costs are taken into account, the secondary value of the house's building materials is still positive, but only when labour, transport and processing costs are excluded from the calculations. Furthermore, steel, concrete, copper, aluminium, glass and scrap metals prove to be the most profitable material streams.

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1. Introduction

Just as everyday products have an expiry date, buildings also come to reach an end-of-life status. However, their lifespan is longer and their waste streams occur in unproportionally enormous masses. In addition, end-of-life building materials require a different waste management system than municipal solid waste because they entail different recycling and disposal routes. Yet, the reuse of building materials represents enormous potential for the sustainable use of resources and resource efficiency, not only because of their massive material quantites, but also due to their valuable composition.

In regard to sustainable use of raw materials, an efficient management of building materials can make considerable contributions to sustainable development. The concept of sustainable development refers to international and environmental efforts expressed in various political reports: 'Our Common Future' by the United Brundtland Commission, the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 and the Agenda 21. The targets set in these political discussions are referred to implementing sustainable development in everyday life in order to 'satisfy present needs without entailing the risk that future generations will no longer be able to satisfy their own needs'.

As far as resource efficiency is concerned, the recycling of secondary building material directly complies with the objectives of the 'Flagship Initiative under the Europe 2020 Strategy – A Resource Efficient Europe'. This initiative aims at creating a framework for policies to support a resource-efficient economy, limit the environmental impacts of resource use and creating new economic opportunities (European Commission, 2011).

Construction and Demolition Waste, hereafter named 'CDW', is the biggest waste stream worldwide with excavated material, accounting for around 60%. Corresponding to the aformentioned international politics, it is obvious that CDW is not only of local, but also of international concern, offering an immense potential of waste prevention (Jeffrey, 2011: 3). Therefore, the benefits that resource-efficient CDW management may entail for humankind and the environment are the motivation behind this thesis. The aim is to contribute specific knowledge on the composition of demolition waste and its financial value in order to point out options for sustainable, resource-efficient and profitable handling of dismantled building material.

According to the EU Waste Framework of 2008, 70% of the mineral building material shall be recycled by 2020. In Austria, currently more than 70% of CDW are returned to the recycling process. However, the recycling rates are relatively high in the civil engineering part of the building, compared to recycling rates for the building construction itself which only reach 40% so far (Daxbeck H., 2011: 1). Thus, Austria is required to increase the recycling rate of building engineering to 30% according to EU law.

Regarding terminology, construction and demolition waste are grouped together. However, construction and demolition waste differ in their material composition which results from either construction or demolition processes. In this thesis, the main focus lies on demolition waste because demolition projects often produce 20 to 30 times more waste material per square meter than construction projects (Jeffrey, 2011: 3). The following thesis not only comprises a description of the general state of the art of the treatment of CDW, but also a case study which represents the analysis of composition of demolition waste and its financial value after the dismantling of the building.

1.1. Research Questions and Objectives

Resultedly, the research questions of this thesis are as follows: 'What is the composition of demolition waste' and 'What is the financial value of building materials after demolition?'. The questions are based on the hypothesis that building material entails a financial value after demolition given the precondition of a proper dismantlement. It is a current practice in Austria to carry out demolition processes stepwise in order to avoid contaminations of materials which would negatively affect recycling rates and value of recyclable materials. Both research questions are based on a case study in which a retirement home in Vienna is investigated. The theoretical part of this thesis builds the framework for the hypothesis and leads to the research questions, illustrating general practice of building materials in Austria. Hereby, the objective is to disclose information on what efforts regarding recycling construction materials have already been taken on a political and economic level. The focus lies mainly in Austria because the case study is carried out in Vienna. However, in order to illustrate the legal European situation, which affects countries also in a national level, the status-quo on CDW management in Europe is outlined. The legal and political situation on the dealing with construction and demolition waste builds the foundation of the general use of CDW- derived recyclables and is therefore of great importance for the case study.

The first research question sets the stage for the second by identifying the building's major material streams. Hence, 14 construction materials were chosen to be investigated. After the selection of 14 material streams based on major quantity, their primary and secondary financial value was examined. The objective is to identify the most profitable material streams after demolition. By disclosing the specific quantity and the referred value of each material stream of the house, the potential resource value of the building can be identified. However, the aim is to present the primary value of the 'raw' building materials as well as the secondary value of the building's secondary resources. Therefore, there is a permanent focus on the 14 selected material streams throughout the whole thesis.

Another objective is to show how much revenue can be achieved by selling materials stemming from demolition projects. However, there are still difficulties regarding the general acceptance and image of the use of recycled building material. The aim of this thesis is to challenge this negative image and present information on the sustainable use of building materials for both the wrecking company and the people reusing recycled building waste in order to reach the target of a closed material cycle in the building industry.

1.2. Methodology and Structure

The thesis constitutes a theoretical part and a practical part illustrated by a case study. The aim of the theoretical part is to give an overall state of the art of the general use of demolition waste based on relevant legal documents. Moreover, it shall disclose the main informative foundation for the practical part of this thesis.

The first part comprises a literature survey of legal documents, guidelines, information retrieved from relevant homepages, reports on demolition wastes and journals. In chapter three, the current state of the art regarding management of recyclable building materials in Europe and Austria is exhibited by elaborating on the legal and political situation. Afterwards, economic aspects on the reuse of building materials and a potential secondary market are shown. The sources for the economic background information are retrieved from journals and homepages.

The case study, which constitutes the second part of the thesis, investigates the composition of the building's material. It shall identify the most profitable waste streams of the building based on their quantites. Unlike the literature study from the first part, the case study is based on data recorded in the building when it was not yet dismantled by doctoral students working for the Christian Doppler Laboratory for

'Anthropogenic Resources'. Thus, the information on material masses are based on in-house-investigations. The data recorded in the building was transferred to excel files and then demonstrated in more detail to localise the material streams.

Furthermore, a recycling scenario of the building is assumed in order to take the value of recycled material and disposal fees into account. The scenario is based on information gained during telephone interviews with recycling experts and the manager of the Austrian Construction Materials Recycling Association. Subsequently, prices of primary building materials were researched online on webpages of construction companies selling building materials. Secondary or recycling prices were more difficult to find online. Therefore, recycling experts provided me with average values on recycling materials. In order to illustrate common recycling paths of selected materials, books and online journals were consulted. Lastly, the fifth chapter sums up the results of the case study and confirms the hypothesis that building material entails a financial value after demolition.

2. Current Situation of Waste Management in Austria

The following chapter outlines the situation of waste management in Austria with a specific focus on construction and demolition waste. First of all, relevant definitions which are applied in Austrian regulations dealing with waste management are listed below. Afterwards, the Waste Management Act is explained as the centre for Austrian legislation in terms of waste. Followingly, figures on the general total waste generation as well as on the use and consumption of CDW in Austria are illustrated. In order to provide a deeper understanding of CDW, its types and composition of materials are listed. The indication of quality standards is closely linked to the differentiation of CDW and recycled building products and is therefore also relevant for this chapter.

2.1. Definitions

"*Waste* means any substance or object which the holder discards or intends or is required to discard" (European Commission, 2008: 9).

"Waste Management means the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer of broker" (European Commission, 2008: 9)

Hazardous waste means waste which displays one or more of the hazardous properties, such as explosive, oxidizing, flammable, toxic, etc. (European Commission, 2008: 9)

Construction Waste is the waste generated during construction processes. Its composition is therefore predictable because the construction manager knows exactly what materials are brought onto a site. Examples are damaged materials, excess materials left over at the end of a job, intermediate waste products and packaging waste (Symonds Group, 1999: 35).

Demolition Waste is the waste generated during demolition processes consisting of various composite and unsegregated materials, such as concrete, cement, bricks, roof tiles, insulation materials, etc. (Symonds Group, 1999: 26).

Excavated Material is non-contaminated light and tight soil which is excavated during earthworks, building construction or civil engineering works (Land Oberösterreich, Abteilung Umwelt- Anlagentechnik, 2006: 5).

Mineral Materials are defined in the landfill directive and comprise concrete, clinker, bricks, gypsum-based mortars and plasters, chimney bricks and fireclay from private households, gravel, sand, limestone, asphalt, bitumen, glass, fiber cement, asbestos-cement, tiles, natural stones, broken natural materials, and porcelain. In mineral construction and demolition waste, only 10 volume percent of metal, synthetics, wood and other organic materials such as paper and cork may be contained to be designated as mineral fraction (Österreichischer Baustoff-Recycling Verband a, 2013).

Inert Waste is waste which does not underlie any major physical, chemical or biological changes and does neither pollute surface-, nor groundwater (Österreichischer Baustoff-Recycling Verband a, 2013).

"re-use means any operation by which poducts or components that are not waste are used again for the same purpose for which they were conceived" (European Commission, 2008: 10).

"recovery means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfill that function, in the plant or in the wider economy." (European Commission, 2008: 10)

"recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations." (European Commission, 2008: 17)

Primary Raw Materials are geogenic resources which are introduced into the anthroposphere within their first use or application (Lichtensteiger, 1998: 31).

Secondary Raw Materials are resources taken from the anthropogenic cycle which can be reused after processing or recovery. An example for secondary raw material is recycled building materials, mostly stemming from concrete demolition, crushed asphalt and bricks (Lichtensteiger, 1998).

Recycled construction and demolition material is defined as secondary raw material that is produced from demolished building materials such as concrete demolition, demolition of bricks or asphalt (Land Oberösterreich, Abteilung Umwelt-Anlagentechnik, 2006: 8)

Demolition is the process of breaking down a building whose demolition waste is forecast to be landfilled without previous treatment for reusability (Pisti, 2011: 11).

Selective Demolition is the process where reusable and hazardous components are removed from a building before it is crushed with recycling intentions (Pisti, 2011: 11).

Deconstruction is the process of dismantling a building so that all of its parts can be reused (Starke, 2013).

Landfill is a facility which is foreseen for the long term deposit of waste taking into account hygienic, hydrogeological, soil mechanics and ecological aspects in order to prevent negative impacts on the environment (ÖNORM S 2005, 1998: 2).

*Excavated soil landfill*¹ is a facility for the deposit of not contaminated excavated material (ÖNORM S 2005, 1998: 2).

¹ Bodenaushubdeponie

*Construction debris landfill*² is a facility for the deposit of mineral waste streams which mainly arise from construction, demolition and renovation processes (ÖNORM S 2005, 1998: 2).

2.2. Waste Management in Austria

Waste management in Austria is regulated by the Waste Management Act from 1990³ which has been established after a period of a radically increasing generation of waste due to industrial development. It was introduced for the sake of sustainability and its main aims are to avoid negative impacts of waste, such as emissions that are negatively affecting humans, animals and the environment, in order to spare resources and to support waste management which is not presenting any harm to future generations (Abfallwirtschaftsgesetz, 2011: §1 (1)). Waste management shall be carried out according to the following five-level hierarchy: prevention, preparation for recovery, re-use through recycling, recovery such as energy recovery and disposal (Abfallwirtschaftsgesetz, 2011: §1 (2)). This national law on waste management entered into force in 2002 and is adapted according to EU law. An important component of the waste regulation in Austria is the electronic data management. It acts as tool to document toxic waste streams and to deal with their compulsory registration. Yet, more specified waste management regulations, such as quality standards or the collection and treatment of waste, are dealt on a federal level in Austria (Lebensministerium, 2011).

According to § 8 of the federal law on waste management, the Federal Minister for Agriculture, Forestry, Environment and Water Management has to adopt a federal waste management plan every six years which shall be the base for the realisation of the aims implemented in the Austrian waste management regulation (Abfallwirtschaftsgesetz, 2011: §8 (1)). The federal waste management plan comprises information on the general and prospected future waste situation of the country and its industrial installations connected to waste management systems (Abfallwirtschaftsgesetz, 2011: §8 (3)).

In 2009, Austria produced around 54 million tons of waste, including primary and secondary waste. The latter one results from the treatment of primary waste and consists mainly of ash and slag. According to Table 1, the greatest waste flow is

² Baurestmassendeponie

³ Abfallwirtschaftsgesetz

excavated material with around 23 million tons. Construction waste also accounts to the top biggest waste streams in regard to quantity with 6,8 million tons in 2009.



Figure 1: Waste Flows in Austria

(Bundesministerium für Land- und Forstwirtschaft, 2011: 18)

Forecasts for 2016 predict an increasing trend towards more waste generation of approximately 56 million tons. Hence, excavated material is expected to rise from 23 million tons to 26 million tons and construction waste is predictated to increase from 6,80 to 7,40 million tons within seven years (Bundesministerium für Land- und Forstwirtschaft, 2011: 23).

2.3. Data on Use and Consumption of CDW in Austria

According to the Waste Management Act, materials resulting from construction activities, shall be reused if it is ecologically and technically feasible and does not entail excessive costs. If a reutilisation does not make sense, neither ecologically nor economically, the waste shall be disposed at minimum impacts (Abfallwirtschaftsgesetz, 2011: §16 (7)). Excavated materials are the major share of total quantity of waste generated and a consequence of both, increased construction

activity of the Austrian Federal Railways and the varying quantities of contaminated soils resulting from sporadic primary events. Waste streams from construction activities have also increased dramatically over the last few years. This is due to the developments in civil and structural engineering in Austria (Bundesministerium für Land- und Forstwirtschaft, 2011: 18).

All in all, construction and demolition waste represent an enormous stock of resources, more specifically, secondary resources. However, the varying composition of residual building material represents a problem for its efficient re-use. Nevertheless, determination of the current consumption of building products is difficult because of the lack of data quality as well as the confidentiality of data. Yet, a material flow of 100 million tonnes per year is approximated in the Austrian construction industry. In more detail, around 100 million tonnes were accounted for the total material-use in 2005 and about 105 million tons in 2007. The following table shows rough estimations on the consumption of single materials in 2005 and 2007 respectively (Daxbeck H., 2011: 22f).

| MATERIAL | 2005 | 2007 | UNIT |
|---|--------|--------|--------------|
| natural stone <i>i.e. sand and gravel</i> | 54,73 | 55,75 | million tons |
| mineral material <i>i.e. bricks, cement and</i> <i>concrete</i> | 34,79 | 36,99 | million tons |
| glass | 0,002 | 0,001 | million tons |
| steel | 0,77 | 1,03 | million tons |
| aluminium | 0,13 | 0,16 | million tons |
| synthetics | 0,38 | 0,44 | million tons |
| wood | 8,62 | 9,68 | million tons |
| others | 1,03 | 0,84 | million tons |
| TOTAL MATERIAL CONSUMPTION | 100,45 | 104,89 | MILLION TONS |

Table 1: Material Consumption in Construction Industry

(Daxbeck H., 2011: 23)

Compared to the consumption of building material, in 2007, more than 7,8 million tonnes of construction and demolition waste (without excavated material) were recorded. At the same time, it was documented that 553 000 tonnes of building materials were landfilled due to their inhomogenous composition (Daxbeck H., 2011: 5). The total mass of the building stock in Austria consists of greatly various building materials whose composition and application also depend on construction time. In general, more than half of it is made of cement-bound construction material, such as concrete and mortar etc.. On the other hand, the second major material fraction comprises bricks, roofing and flooring, accounting for about 20% in terms of quantity (Daxbeck H., 2011: 9). Today, the complexity of buildings and their materials represent new challenges for recycling since new products, such as liquid wood or transparent cement are composite materials consisting of specific synthetics which are not easily recyclable and difficult to separate. However, the purer the composition of material, the easier it is to recycle and the higher its value.

Even though a rough overview on the generation and consumption of construction and demolition waste is in place, there is no existing literature on the composition of historic building material stock in Austria. So only assumptions on the composition of materials and potential risks of hazardous substances can be made (Daxbeck H., 2011: 8). Furthermore, the Federal Ministry of Environment records the data received from the federal provinces which have not followed a unique style of data records. Moreover, companies are not obliged to send their data and therefore there is a lack between waste generation and its record to be expected. Hence, waste generation might be underrepresented in the Federal Waste Management Plan. In order to improve data quality, in 2010, the Electronic Data Management (EDM) was established by the Federal Ministry of Agriculture, Forestry, Environment and Water Management with the aim of documenting Austrian waste generation. Nevertheless, it will still take some time to reach this goal (Daxbeck H., 2011: 7f).

2.3.1. Types of CDW

Usually construction and demolition wastes are grouped together and not treated separately in literature. However, the materials resulting from these waste streams can differ greatly. In the main, construction waste, resulting from construction processes, contains more modern and cleaner building materials than demolition waste. Demolition waste arises from demolition projects that often produce about 20 to 30 times as much waste material as construction projects. It is often contaminated with paint, adhesives and dirt. Therefore, proper recycling of demolition waste

requires the separation of these pollutants (Jeffrey, 2011: 3). The singularly treated term 'construction and demolition waste' covers a wide range of materials which are subdivided into following categories in terms of origins and nature:

"(i) waste arising from the total or partial demolition of buildings and /or civil infrastructure;

(ii) waste arising from the construction of buildings and/or civil infrastructure;

(iii) soil, rocks and vegetation arising from land levelling, civil works and/or general foundations;

(iv) road planings and associated materials arising from road maintenance activities." (Symonds Group, 1999: 7)

According to the European Waste Catalogue, member states should be encouraged to adopt following classifications. The code of the materials indicated in the catalogue is to find within the parenthesis:

"Concrete, bricks, tiles, ceramics, and gypsum based materials (EWC code 17 01 00);

wood (EWC code 17 02 01); glass (EWC code 17 02 02); plastic (EWC code17 02 03); asphalt, tar and tarred products (EWC code 17 03 00); metals (including their alloys) (EWC code 17 04 00); soil and dredged spoil (EWC code 17 05 00) insulation materials (EWC code 17 06 00) mixed construction and demolition waste (EWC code 17 07 00) Hazardous components of construction and demolition waste should be identified." (Symonds Group, 1999: 7)

2.3.2. Quality Standards of CDW

Processing of demolition waste to reusable secondary raw material products requires consistent quality standards. The Austrian Quality Control Association for recyclable CDW⁴ is dealing with quality requirements and the allocation of quality labels. On the other hand, the Austrian Association for Building Material Recycling⁵ has established several directives on recyclable building material which clarify the standards and procedures in terms of transition of building waste into new recycled products including specific product criteria. These directives are not legally binding and serve as guidelines. However, as a consequence of the Construction Product Regulation, harmonised norms are legally required to apply (Daxbeck H., 2011: 6). As for instance, the ÖNORM B 3152⁶ for aggregates is binding in its harmonised form for the determination of environmental compability. Furthermore, the Federal Ministry for Agriculture, Forestry, Environment and Water Management determines the state of the art in the Austrian Act on Remediation of Contaminated Sites which makes it binding in respect to the relevant state of the art definition. Hence, it depends on definitions made in related enforceable enactments in order to identify the guideline's legally binding nature (Car, 2013).

In terms of weight, 80% of demolition waste in Austria are processed in recycling plants belonging to the Association for Building Material Recycling which are then quality-certified products. Yet, 50% of the processing plants are operated by the Association for Building Material Recycling. Besides certified materials, there are various companies which do not have quality labels for their recycling material (Daxbeck H., 2011: 6).

The qualification for construction and demolition waste to become a recyclable building material requires certain quality standards. In order to qualify, an independent institution or external inspection has to sample all fractions for hazardous components and confirm the criteria of quality standards. Regarding chemical and physical parameters, such as pH for instance, and threshold values, the material is categorised according to following quality classes: A+, A and B (Land Oberösterreich, Abteilung Umwelt-Anlagentechnik, 2006: 15f).

⁴ Österreichischer Güteschutzverband für Recycling-Baustoffe (GSV)

⁵ Österreischischer Baustoff-Recycling Verband (ÖBV)

⁶Title: Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction - .Rules for the implementation of ÖNORM EN 13242

| A+ | Applicable for the usage in hydrogeologically sensivitve areas without topcoat in unbound condition |
|----|--|
| A | Applicable in bound or unbound condition with covering layer in hydro-geologically sensitive areas or unbound without topcoat suitable for use in hydro-geologically sensitive areas |
| В | Applicable for use in bound or unbound condition with suitable topcoat in non- hydrogeologically sensitive areas as additive |

Table 2: Definition of quality standards of CDW

(Land Oberösterreich, Abteilung Umwelt- Anlagentechnik, 2006: 19)

The quality standard C indicates that the materials may be considered for construction purposes within a landfill for non-hazardous waste (Hirnschall, 2013).

The precondition for recovery is clean separation of waste on-site at the demolition site and subsequent reprocessing according to state of the art technology. Hence, recycled building materials have to meet following quality criteria for their reuse: They have to be free from contamination by harmful substances and they have to fulfill certain chemical parameters and threshold values (Land Oberösterreich, Abteilung Umwelt- Anlagentechnik, 2006).

The quality classes A+ and A are indicators for the transition from waste to product, but for the official declaration of the end-of-waste feature, a legally binding, national standardised regulation regarding specific quality requirements and quality assurance have to be introduced. Currently, the Federal Ministry of Life is working on a regulation of an end-of-waste declaration which shall establish a clearly comprehensible categorisation of product declaration (Österreichischer Baustoff - Recycling Verband d, 2013: 8f). So far, the directive – in the 8th edition from 2009 – of the Austrian Construction Materials Recycling Association is the base for the production of recycled building materials. According to this directive, which is approved by the Federal Ministry, recycled CDW can be provided with the CE-label and applied as market product. Yet, the end-of-waste status is replaced by the

status of a quality product (Österreichischer Baustoff - Recycling Verband d, 2013: 22). In individual cases, one can always refer to § 6 of the Austrian Waste Management Act which defines the end of waste status (Land Oberösterreich, Abteilung Umwelt- Anlagentechnik, 2006: 10).

The Austrian Quality Control Association for recyclable CDW remains the national independent institution fulfilling its main task of ensuring the quality of recycled building materials and labelling its products with the quality mark for recycled building materials (Österreichischer Baustoff - Recycling Verband d, 2013: 8).

Besides quality standards, more specifications exist for the indication of recycled building materials, such as material description giving information on content of components and grades (S, I, II, II, IV) revealing application areas (Hirnschall, 2013: 28ff). The quality standards as well as the aforementioned indications are especially relevant for the fields of application of recycled building materials, such as building concrete and asphalt. These fields comprise road building, embankment construction, construction of storage slots, filling material for trenches, construction material for sports grounds and additives for production. However, the use of recycled building materials is not permitted in groundwater protection areas and groundwater fluctuation zones (Land Oberösterreich, Abteilung Umwelt-Anlagentechnik, 2006: 19).

3. State of the Art regarding Management of Recyclable CDW

The following chapter provides information on the management of CDW in Europe and more specifically in Austria. It is conducted based on a literature survey of legal sources as well as reports of relevant projects, journals and information found in the internet. A political, legal and economic overview points out the framework circumstances in terms of management regarding recycled building materials.

3.1. Status Quo in Europe

The building industry is the biggest consumer of resources in Austria as well as in Europe. Therefore, an environmentally sound and resource-efficient management of this economic branch can have massive impacts on resource efficiency. To be more precise, Europe produces approximately 450 million tonnes of CDW per year (Del Rio Merino et Gracia, 2010). Hence, CDW is one of the most voluminous and heaviest waste streams in the EU and accounts for 25 to 30% of all waste generated in the EU. Given its composition of concrete, bricks, gypsum, wood, glass, metals,

plastic, solvents, asbestos, excavated soil etc., numerous materials, which have a high resource value, can be recycled. In European terms, CDW arises frrom activities, such as the construction of buildings and civil infrastructure, total or partial demolition of building and civil infrastructure, road planning and maintenance. However, different definitions are applied within the EU. Therefore, a cross-country comparison and unified legislation is cumbersome. CDW is considered as a priority waste stream by the European Union, but the level of recycling and re-use of CDW varies greatly among European countries. However, CDW can pose particular risk to the environment and recycling if not separated at source or if hazardous fractions are not removed immediately after demolition.

The EU has been conducting many studies on the management of CDW in order to establish operational definitions of concepts and to perform a quantitative and qualitative analysis of the present situation of CDW. In addition, the Joint Research Center has issued a 'Technical guide to Life Cycle Thinking and Life Cycle Assessment' for waste experts which is aiming at environmental sound management and go together with the waste hierarchy. The EU has also issued several policies and standards of which some will be mentioned here. The Waste Framework Directive, for instance, proposes a high level of resource efficiency and recycling and stipulates that member states shall achieve a 70% recycling rate of non-hazardous CDW in terms of weight by 2020 (European Commission, 2012). The average recycling rate for EU-27 accounts for 47% at present. Denmark, Estonia, Germany, Ireland and the Netherlands fulfil the 70% of the Directive's target recycling rates. Austria, Belgium, France, Lithuania, and the United Kingdom have reached 60% to 70%; Latvia, Luxembourg and Slovenia vary between 40% and 60%. Cyprus, Czech Republic, Finland, Greece, Hungary, Poland, Portugal and Spain account for less than 40%. Yet, no data was available to estimate recycling rates in Bulgaria, Italy, Malta, Romania, Slovakia and Sweden (Hestin, 2010: 7). All in all, the main European policy drivers concerning CDW are the Revised Waste Framework Directive (2008/98/EC) and the Directive 99/31/EC on landfill. Yet, there are national policies and standards in terms of waste framework policies, CDW waste policies, secondary raw material regulation, building standards and landfill regulations (Hestin, 2010: 9-11).

Especially regarding the recycling of CDW, the European Construction Products Regulation⁷ is worth to acknowledge. It was established in 2011 and enters into force with 1st July 2013 and then substitutes the Construction Products Directive was the legal basis for the CE marking. From this date on, the regulation – unlikely a directive – is directly binding for all member states. Therefore member states don't have to effectuate them in national law anymore because it is automatically binding. The regulation is already in force since 2011, but producers and consumers are given two years for the adaptation until the 1st July 2013 (WKO, 2013). The aim of the Construction Products Regulation is to ensure reliable information on construction products. Hence, it seeks to achieve more clarification of the basic concepts and of the use of CE marking, the simplification of the procedures and increased credibility for the whole system (European Commission, 2013 ; Glass For Europe, 2013).

To conclude, it shall be mentioned that the re-use the majority of especially mineral building materials entails multiple benefits because once they are crushed to a suitable size and contaminants are removed, it can be used as valuable aggregate which is needed for the production of concrete. This way, the need for quarried stone can be massively reduced by substituting natural aggregates in concrete production with recycled waste. If, for example, 20% of the natural aggregates are replaced with aggregates recovered from concrete, the resulting concrete may be even of higher quality, given the precondition that the 20% substitutions are not exceeded. However, the separation of contaminated material during the demolition process is a must to ensure high quality and prevent contamination and increasing costs (Del Rio Merino et Gracia, 2010).

3.2. Status Quo in Austria

In Austria, 80% of CDW are recycled in plants of the Austrian Construction Materials Recycling Association. 50% of the processing plants are lead by the members of the Austrian Construction Materials Recycling Association. In terms of figures, following table presents an overview of recylced building materials in Austria and their recycling paths.

⁷ Bauprodukteverordnung

| TYPE OF WASTE | RECYCLING PATH | OCCURRENCE [T] | RECYCLED [T] | RECYCLING RATE [%] |
|--|---|-------------------|-----------------|--------------------------|
| building rubble | aggregate for the production of concrete, backfilling | 3 300 000 | 2 000 000 | 60,60% |
| concrete demolition | pipe construction, filling of trenches, road construction | 2 000 000 | 1 900 000 | 95% |
| bitumen, asphalt | aggregates for asphalt production, construction of roads, parking lots | 1 040 000 | 900 000 | 86,50% |
| construction waste | sorting and material or thermal recovery | 220 000 | 30 000 | 13,60% |
| wood arising from construction or demolition | re-use as construction material or thermal recovery | 238 000 | no figure | no figure |
| asbestos | landfill | 35 910 | no figure | no figure |
| TOTAL | | 6 833 910 | 4 830 000 | 70,70% |

Table 3: Recycled CDW and Recycling Paths for Austria

(Daxbeck H., 2011: 6)

The Austrian Construction Materials Association is the 'center' of practice of all Austrian institutions dealing with recyclable building materials. It acts nationwide and across intdustrial sectors by holding meetings every two to three months to bring involved stakeholders together. Yet, it publishes guidelines for the use of recycled building materials which are constituted by specialized working parties consisting of company experts and external professionals.

The Association was established in 1994 by 14 enterprises with the aim of representing the interests of the construction material recycling industry. Now, it comprises 73 members and the number of plants for the recycling of construction and demolition material is also increasing. Its target groups include private and

public customers, federal authorities, provinces, municipalities, special associations and the Life Ministry. Therefore, its membership is open to a great variety of stakeholders, not only of economic, but also of legal and political nature. The tasks of the Construction Materials Association imply the promotion of relevant research projects, taking part and act in matters of plant approvals, providing information material and advertising brochures and safeguarding the interests of construction material recycling enterprises in environmental legislation. It also keeps an updated catalogue of companies and plants, as well as a list of selling prices of recycled building materials. The Association offers the opportunity to its members to be included in Austria's only recycling plant register, to become a member of the Austrian Recycled Construction Materials Quality Insurance Association and to obtain the quality label for recycled construction material. Furthermore, they are provided by up-to-date information as well as documents. Members have the chance to present their company brochures on exhibitions stands of the stakeholder meetings which are organised on a monthly base (Österreichischer Baustoff-Recycling Verband b, 2013).

The Austrian Construction Materials Recycling Association has established an online information platform - called 'Recycling Börse Bau' which is a recycling exchange institution – for the promotion of the reuse of mineral building materials which shall bring together supply and demand. This online tool has been created with the cooperation of the Federal Chamber of Economy, the Federal Ministry of Economics, Family and Youth, Life Ministry as well as with the support of several Austrian provinces. This exchange platform does not deal with these materials, but communicates the information at which place and time a certain material is available or needed. It entails advantages such as a nationwide information platform, overview on available recycling materials, increased market efficiency by bringing together supply and demand, cost savings through reduced transport routes, improvement in communications, daily up-to-date information and is available free of charge for a wide range of stakeholders, such as builders, public contractors and their consultants, as well as architects, civil engineers, building contractors, recycling, landfill and transport operators etc. (Österreichischer Baustoff- Recycling Verband c, 2013).

3.3. Relevant legal Documents for the Reuse of CDW in Austria

The legal framework on the use of demolition waste as well as technological preconditions set the stage for and determines the treatment of demolition waste and finally the economic viability for marketable recycled building materials. It comprises national laws, regulations, acts, norms and guidelines with differing legal character and various sources. In this chapter, the most important legal regulations and directives are outlined. However, the list is far from being exhaustible and shall serve as an overview to show what kind of policies and standards exist. These documents present the achievements of collaboration between policy makers and experts from the construction sector with the common aim of the sustainable treatment of CDW.

The following regulations about the treatment of CDW are fixed in federal law Gazette⁸ and acts and shall be taken into consideration when dealing with CDW.

3.3.1. Regulations

The *Waste Management Act*^{θ} came into force in 2002 and was revised in 2010. It points out the goals of waste management according to their priorities and determines the definition of waste. That is of major importance in the building sector because materials arising from construction work should not be considered as waste because of the missing intention to discard it.

The *Waste Documentation Ordinance*¹⁰ entered into force in 2004 and obliges the holder of waste to maintain written records regarding type, amount, origin and retention of waste. In terms of the building sector, the contractor or the building owner are obliged to fill in a document on the CDW generation.

The *Waste Catalogue Regulation*¹¹ came into effect in 2004 and serves as a uniform list to differ hazardous and non-hazardous wastes. It overtook the types of wastes from the European Waste Catalogue in 2009 and serves as a complement to the ÖNORM S 2100.

8 Bundesgesetzblatt

⁹ Abfallwirtschaftsgesetz

¹⁰ Abfallnachweisverordnung

¹¹ Abfallverzeichnisverordnung

The *Remediation Act*¹² imposes tax on residual waste for a longterm storage or deposit of wastes, such as landfilling, the filling of pits and the transport and deposit of waste outside of Austria. Hence, it constitutes the legal framework for the financing of residual wastes. The price in terms of tax for the deposit of waste is included in the price for landfilling and has to be paid by the operator of the landfill. Therefore, landfilling of CDW is taxed according to the Remediation Act. In 2012, new prices were fixed. The premium for excavated material and CDW and mineral wastes arising from construction works accounts for 9,20€ per ton and the landfilling of hazardous waste costs 29,80€.

Regulation on the Separation of CDW¹³

In 1990, a volontary agreement on the use of recycling materials was reached between the professional organization of building indusry and the ministry of economic affairs. Its goal was to increase the recycling rates. This agreement lead to the Regulation on the Separation of CDW which was approved in 1993 by the ministry of environment. According to this Regulation, the contractee of demolition projects is obliged to give recycling priority over landfilling even if that would create 25% additional costs. This regulation imposes the separated collection and recycling of recyclable CDW. It imposes the building-owner to take the responsibility for the compliance of seperation and recycling obligations and to conduct a waste audit form about specific amounts of certain types of substances.

The Landfill Directive¹⁴ entered into force in 2008 and clarifies the state of the art of equipment and operational mode in terms of landfilling. It differs between four types of landfillings, such as landfill for excavated material, landfill for CDW, landfill for residual waste, landfill for large-scale waste and inert waste landfill.

Classification Ordinance of Hazardous Waste¹⁵ is in force since 2000, but is partly replaced by the Waste Catalogue Regulation (Österreichischer Baustoff-Recycling Verband a, 2013).

¹² Altsanierungsgesetz (ALSAG)

¹³ Baurestmassentrennverordnung

¹⁴ Deponieverordnung

¹⁵ Festsetzungsverordnung gefährlicher Abfälle

3.3.2. Norms

The following norms have recommendational character and are created by the Austrian Standard Institute ¹⁶ which is a neutral and independent service organisation. It provides a platform for the development of norms, rules and standards since 1920 without being a federal authority or ageny. Many stakeholders take advantage of this platform including companies, federal authorities, science and consumers. The contents of the rules and standards are designed by a committee and applied in practice. The Austrian Standards Institute is a member of the European Committee for Standardisation (CEN) and the International Organization for Standardisation (ISO) and coordinates Austrian expert's participation in the development of european and international standards. It develops standards within a complex process involving experts from economy, administration, science and consumer organisations. These professionals establish the contents of standards in committees and working groups according to an internationally approved method (Austrian Standards Institute, 2013).

ÖNORM B 2251 on demolition work and works contract contains regulations on proceedings and contract issues for the execution of demolition works of buildings. In case of the involvement of pollutants, ÖNORM 192130 is to be applied. Furthermore, ÖNORM M 9406 serves as complement in case of the asbestos bound material. The regulation B 2251 describes several methods of demolition in detail (ÖNORM B 2251, 2006: 3f).

ÖNORM S 2100 is on the list of wastes and contains its application fields, criteria for the assignment of waste streams, as well as more specific information on packaging waste, hazardous waste and demolition and construction waste. This regulation is established with the aim of summarising waste streams according to the Waste Management Act 2002 (ÖNORM S 2100, 2005: 2f).

ÖNORM B 2110 about general conditions of contract for works of building and civil engineering construction is about work contracts concerning construction activities. It outlines general conditions of contracts for construction work and aims at giving unambiguous descriptions and definitions related to it. Yet, it clarifies rights and obligations of clients and contractors related to construction works (Baudatenbank BDB, 2013).

¹⁶ Österreichisches Normungsinstitut

ÖNORM S 5730 is about the investigation of constructions on pollutants and other injurious factors. It gives instructions on the structured approach, data collection, documentation, the formulation of building pollutant survey and gives information on legal certainty issues (ÖNORM S 5730, 2009: 2f).

ONR 192130 on the investigation of pollutants in buildings before demolition contains definitions, type, origin and causes of hazardous materials in buildings and discloses methods for the investigation of pollutants. Due to increasing knowledge on building materials and its containing pollutants, renovation, maintenance and demolition costs as well as expenses on rebuilding can be better estimated (ONR 192130, 2006: 2f). However, this document does not represent a standard, but is cosidered as an ON Rule.

ÖNORM M 9406 deals with the handling of products containing weakly bound asbestos and comprises normative references, definitions as well as security measures. Therefore, this regulation gives a foundation on general minimisation of the risk in terms of dealing with material which is weakly bound with asbestos. It finds application in regard to renovation and demolition of buildings and the treatment of the materials. According to this standard, material containing asbestos shall be removed and further treated in order to avoid the release of asbestos fibres which is hazardous to human health (ÖNORM M 9406, 2001: 2f).

ONR 22251 on standard text for service specifications in the field of building construction in conformity with ecological requirements has the aim to provide text templates for the compilation of specifications to support the creation of legally compliant tenders. The norm was written in cooperation with the Austrian Construction Materials Association, the City Administration of Vienna and edited by the Committee of building services (ONR 22251, 2010: 1ff).

Currently, there is a new norm (ÖNORM B 3151) on recylcing-oriented deconstruction being prepared. Its aim is to separate single materials during demolition processes in order to achieve high class recycling in terms of quantity and quality. This goal shall be attained by the exploration of potential contaminants before demolition, the creation of a deconstruction concept, the removal of all contaminants and separation of the main fractions during mechanical dismantling. Fields of application of this norm are buildings, civil engineering, line construction, such as roads and airside structures, such as parking lots (Starke, 2013: 2ff).

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3.3.3. Guidelines

Besides regulations and norms, the Austrian Construction Material Recycling Association provides a wide range of instruction sheets in regard to the use and treatment of building materials:

Use of excavated soil material (2012),

Recycling of asphalt – guideline for recycled building materials (2009),

Guideline for the mobile treatment of mineral construction waste and excavated soil material (2008),

Directive for flowable, self-compacting filling-material with recycled, crushed material (2007),

Leaflet - Interim storage for mineral construction waste, and concrete (2006),

Directive for the treatment of contaminated soils and components (2004),

Leaflet – flowable and self-compacting filling-material with recycled, crushed material (2003)

Leaflet – recycled building materials for trenches (2001)

Leaflet – working with contaminated soils and contaminated mineral construction waste (1999) (Österreichischer Baustoff-Recycling Verband a, 2013).

Besides the aforementioned documents, there are numerous guidelines made publicly available through RUMBA¹⁷ which is a demonstration project providing downloads on instructions for the environmentally sound management of demolition, construction and renovation of buildings in the internet. Its goals are to reduce the freight transport related to construction sites, presorting at demolition sites, development of framework conditions for environmentally sound construction site logistics. RUMBA is financed by the EU- Life Programme and by project partners (RUMBA, 2013).

Overall, it can be stated that there are a lot of features as well as guidelines in Austria fostering the cooperation of various stakeholders in the construction industry to promote environmentally friendly management of construction and demolition sites as well as the recycling of CDW and further efforts are taken in order to improve the legal framework for the re-use of recycled building products.

¹⁷ RUMBA – Richtlinien für umweltfreundliche Baustellenabwicklung

In the chapter above, three categories of regulatory framework types are differentiated. On a European level, there are five categories of policies and standards influencing the management of CDW which however correspond to Austrian establishments. The five types are:

- waste framework policies on a national level to which the Austrian Waste Management Act corresponds to,
- CDW policies including obligations regarding the management of CDW, specific policy or legal documents addressing the issue of CDW which correspond to Austrian regulations,
- landfill regulations that manage the control on landfilling which is covered by the Austrian landfill regulation
- secondary raw materials regulation and standard which clarify standards on quality of secondary materials from CDW and are equivalent to Austrian norms such as also
- Construction and demolition sites regulations and standards: requirements for buildings specifically addressing CDW (Bio Intelligence Service, 2011: 24).

3.4. Secondary Markets as Prevention Measure for CDW Generation

Secondary markets are an option to pursue the waste hierarchy's first priority: waste prevention. They have the function to merchandise usable products which would be otherwise disposed. However, in some cases reparation might be required. For commodities which are sellable without maintenance work, four different market facilities can be differentiated: second-hand shops, exchange markets and exchange meetings, donation projects and second-hand department stores (Salhofer et al., 2000: 110). Secondary construction materials markets comprise diverse stakeholders, such as suppliers, industries and end-users of building material. Yet, they have a potential to open up new economic opportunities, new job markets and revenue streams due to valuable substances in building materials (Macozoma, 2002: 1).

3.4.1. Builiding Components Exchange and Best Practices

Especially exchange markets for building components have a huge potential to prevent waste generation which is connected to demolition projects. According to Austrian approximations, 15% could be reused, 65% recycled, 15% thermally recovered and only 5% of related waste streams could be landfilled as special or

hazardous waste. Dismantling of certain building components and mounting them in for reuse offers a series of advantages: valuable raw materials are preserved, building waste is reduced and new jobs are created.

For instance, in 1995, a great network of 20 building components exchanges and stores has been developed in Switzerland. They supply used and repaired commodities in stores or via internet for sell. A virtual storage is created online where vendors can offer objects for procurement already before demolition. Hence, the building components exchange¹⁸ forms a platform for suppliers and clients. The reusable commodities comprise not only removable and reuseable building components and construction materials, such as sanitary facilities, stair rails, parquet flooring, doors, windows, sinks or single furnaces, but also bulk material, wooden beams, roof timberings and roofing tiles. In building supplies stores, recycling products such as insulating materials, protection films, building bricks are already very common and most suitable selling products include floor coverings such as solid parquet, stairs made of wood and steel, inner doors, bricks and roof tiles, wood and steel breams. Historical windows and parquets are usually sold in antique shops. Overall, by reusing these commodities, costs related to demolition and construction can be reduced and recycled materials are usually less expensive (Energieinstitut Vorarlberg, 2011).

In order to illustrate an example of a well working secondary market for building materials, the Swiss umbrella association and building component exchange 'Bauteilnetz Schweiz' is worth to be acknowledged. It promotes the reuse of building materials and was established in 1996 and counts 80 members today. The aims of this organisation are to prolong the life time of valuable building components, save construction costs, reduce CDW and energy consumption and create jobs. As an umbrella association, the 'Bauteilnetz Schweiz' supports its members in their activities with information tools, such as a central database or practical guidelines. It does not only act as an information agency and reference contact in regard to reuse of building materials on a national level, but also forms partnerships with authorities and economy (Bauteilnetz Schweiz a, 2013). Additionally, the online shop 'UseagainSyngenta' deals with second-hand building components and used furniture. In this way, building wastes and disposals could be prevented and social projects in Switzerland and Eastern Europe were supported. From March until

¹⁸ Bauteilbörse

August 2012, the project 'UseagainSyngenta' was carried out with various subcontractors, such as diverse building components exchanges, dismantling companies, craftsmen, aid organisation and transport companies. The result revealed that 41% of the materials were reused which means that more than 1000 parts were lead to an appropriate re-use via internet within three months. The objects were offered at the homepage useagain.ch and then directly delivered to the clients. In case customers were not satisfied with their purchase, spare parts were made available. Not only for that reason, but also because the Syngenta could cover added costs with their revenue, the project was considered successful (Bauteilnetz Schweiz b, 2013).

Similar to Switzerland, in Germany, the 'bauteilnetz Deutschland' is a nationwide cooperation project with longterm experience in terms of communication, logistics and presentation regarding the reuse of building materials. Members include individuals as well as working groups consisting of architects, planners and engineers. Areas of specification of the organisation are public relations efforts, establishment of an internet information platform and of a catalogue of building materials in order to promote and consult exchange markets for building materials. So far, eleven exchange networks for building materials are active in different locations in Germany. The German Federal Foundation for Environment¹⁹ promotes the development of such networks for building components since 2006 and is now financially investing in the related project 'Development of sustainable tools for a conscious management of building components'. The 'bauteilnetz Deutschland' was awarded for the UNESCO Decade Project 2009/2010 and again in 2010/2012. It pursues its aims of waste prevention, energy and CO2 saving by the creation of new workplaces in new networks, awareness raising, expansion of the range of tasks for demolition companies to improve dismantling methods, definition of quality standards and the creation of regional cooperation communities. Thereby, the goal of a targeted deconstruction approach in planning and building processes should be achieved and well- preserved objects such as heaters, wood panels, bricks and tiles, garden fences, doors etc. should be open up for market economy. In this way, social, environmental and economic benefits can be achieved (Dechantsreiter, 2013).

¹⁹ Deutsche Bundesstiftung Umwelt

In Austria, only one exchange market exists, namely the 'Recycling Börse Bau'²⁰, which was already mentioned in chapter 3.2.. However, this is not equivalent to the Swiss or German example (Energieinstitut Vorarlberg, 2011).

3.4.2. Problems of Secondary Markets

Even though the building industry is a local business and establishments of related markets are to be solved locally and individually, common features regarding importance of single factors and general problems can be identified and are illustrated in the follwing chapters.

Secondary construction materials arise from construction sites, demolition sites and disaster sites. Their quantity, quality and availability however, depend on various stakeholders involved in the life cycle of CDW. Several studies in South Africa have revealed fundamental problems relating to CDW management:

- Lack of accuracte and up-to-date information on CDW quantities, their source, type and location which causes difficulties to plan,
- Constraints on site such as tight time schedule, labour costs due to extra efforts required in material recovery and space limitations for effective waste material separation and storage for reuse and recycling purposes,
- Construction processes, such as mass demolition, commingled waste storage on construction sites are not suitable for secondary material recovery,
- Control of the source of material supply which means availability of required materials of the right quality,
- Legislation in respect to responsibility, law enforcement and accountability,
- Illegal dumping and
- Lack of knowledge, misconceptions, low awareness levels and negative perception towards secondary materials (Macozoma, 2002: 2).

A further issue was identified by an American construction lawyer working in a deconstruction management firm and is managing the architectual salvage and the upcycled material reuse and resale side of the business. According to Mark Rabkin's experience, 'building deconstruction' or 'comprehensive dismantlement of building components' is the most effective way to preserve the embodied energy of the materials that comprise the built environment. On the other hand, the biggest

²⁰ Recycling Exchange for Construction Activities

disadvantage of 'construction in reverse' is the extra time and labour required by the process. To overcome this drawback compared to traditional demolition, many deconstruction firms are non-profit so that they provide a tax deduction to the property owner for the appraised value of any materials salvaged for reuse. However, the Deconstruction Management, Inc. (DMI) is a for-profit body that provides management of deconstruction contractors and directs the reuse, resale and redirection of reusable materials. The industry's primary goal is to identify potential consumers of reclaimed building materials, hence creating projects and retail stores selling building materials. The Deconstruction Management, Inc. is working to simultaneously expand deconstruction opportunities where potential buyers can connect with sellers of reclaimed building materials, hence bringing supply and demand together (Hill, 2011). This entity's task is similar to the above mentioned networks for exchange of building compenents. Overall, a well working secondary market of building components requires a good network or institutions which reveal information on supply and demand of CDW by bringing purchasers and suppliers together.

3.4.3. Considerations for Secondary Market Improvement

The implementation of secondary markets could be the key to successful CDW minimisation. The most critical success elements to stimulate secondary markets are waste material supply, secondary material industries and end markets which are equally important and therefore have to be balanced. Whereas waste material supply includes factors such as the availability of building stock for CDW material supply, techniques for waste material recovery, CDW quality control, storage facilities, the location of secondary industries, the cost of waste material supply. Secondary industries comprise the vital factors of availability of secondary market infrastructure, such as recycling companies, stores etc., consistent supply of good quality CDW, demand for secondary building materials and technical and financial support for reuse and recycling. The third element covers the aspects of public demand for secondary materials and products, quality and performance of secondary materials, the price of secondary materials compared to virgin materials and products, availability and supply of secondary materials and products.

A market development plan should bring these success elements together and enhance market improvement of secondary markets of building components. This plan should outline the strategy, implementation process, time frame and the role players to be involved. First of all, a lead agent should act as a lobby group for sector development and as a central voice for all affected stakeholders (Macozoma, 2002: 4) In the case of Austria this would be the Austrian Construction Materials Association and the 'Recycling Börse Bau', in Germany the 'bauteilnetz Deutschland' and in Switzerland the 'Bauteilnetz Schweiz'. Secondly, government support plays a crucial role as stakeholder since it can endorse techniques, strategies and financial support at national, provincial and local levels. Thirdly, the establishments of partnerships between the various stakeholder involved in the life cycle of CDW is of vital importance. This is due to the fact that CDW is not only related to waste management, but also to sectors such as the construction industry, roads and housing. Overall, through partnerships, networking and communication, successful CDW programmes can be planned and implemented appropriately by the government. Financial support shall stimulate secondary markets through research purposes, the implementation of pilot projects, skills development and the acquisition of assets. Last, but not least, legislative support and the creation of a strong regulatory framework can be a very strong industry development instrument. The components are the promulgation of a sectoral waste act, the increase of fees at landfill sites, the imposement of high taxes on raw material purchase, prohibition of the disposal of CDW in landfill sites, tightening of laws on illegal dumping and the introduction of heavy punitive measures for non-compliance. These measures refer to chapter 3.3. where the Austrian regulatory framework is broadly illustrated (Macozoma, 2002: 5).

3.4.4. Strategy for Enhancement of a Market for recycled Building Material

Results of an Austrian study²¹ on the sustainable re-use of building materials were concluded in a national strategy to promote the use of recycled CDW. This strategy encompasses four corner stones of promotion: improve quality, boost the market, improve acceptance and rise awareness. They all respond to various stakeholders invovled, are closely linked to each other and their factor of success depend on a strong regulatory framework.

Thus, the improvement of quality strengthens the market for recycling products. The promotion of acceptance for secondary material products is dependent on improved quality and awareness. However, the regulatory framework, which is an external factor influencing all cornerstones, is a decisive precondition for quality improvement

²¹ Project EnBa

on a national and regional level. It sets norms and regulations on deconstruction methods and investigation on contaminants (Daxbeck H., 2011: 42).

Promoting the market for recycled building materials requires the availability of marketable products. For this, a comprehensive definition on the product status of recycling material shall be established in order to guarantee the ecological safety and technical suitability of recycling products. Complementarily, a regulation on end-of-waste-status has to be implemented.

The awareness of waste flows in the construction sector is strongly dependent on knowledge transfer in planning offices and on construction sites. Architects and planners should be informed on the limited availability of landfill volume and the improvement of quality of recycled products. Other than that, this awareness regarding material flows in CDW management and life cycle approaches shall be communicated in the relevant fields and educational insititutions (Daxbeck H., 2011: 42f).

Due to the fact that quality improvement for recycled material is the starting point, there is also an international need for technical standards, appropriate performance specifications on quality of specific products. Therefore pressure should be applied to the participants of the RILEM and CEN working groups to resolve issues on uncertainties surrounding technical specifications (Symonds Group, 1999: 23).

RILEM, founded in 1947, is a non-profit association under the English title International Union of Laboratories and Experts in Construction Materials, Systems and Structures. Its mission is to advance scientific knowledge related to construction materials and to encourage transfer and application of this knowledge world-wide. Their mission is carried out by the collaboration of leading experts in construction and science including academic members, industrial members, such as firms and enterprises. Its activities range from the production of technical recommendations adapted in research and used by international standardisation bodies as basis for their work as well as the establishment of journals and the organisation of workshops and symposia (RILEM, 2011).

Similarily to RILEM, CEN, the European Committee for Standardisation was created in 1975 as international non-profit association based in Brussels. It is the greatest provider of European Standards and technical specifications in all areas of economic activity except for electrotechnology and telecommunication. These
standards have a unique status because they are also valid on national level in all 33 member states. Hence, with one common standard, a product can reach a wider market with lower development and testing costs (European Committee of Standardization, 2009). Within this context, CE marking is vital to be mentioned. It is established by the CEN and indicates that the product complies with essential requirements of relevant european environmental, health and safety legislation. Furthermore, CE marking ensures free movement of products within the EU and EFTA (Wellkang Tech Consulting, 2013). The achievement of scientific working groups elaborating on quality improvement and internationally renowned quality labels, such as CE are of major importance for the quality assurance of products. They would also increase the acceptability of recylced building materials which are labelled accordingly. Yet, the acceptance of recycled building material is vital for a good image of its re-use and is a consequence of qualitative and legal framework conditions.

3.4.5. Critical Reflections on Building Components Exchanges

As aforementioned, building components exchanges offer a unique service by registering and passing on second-hand components after demolition or deconstruction of a house. At the same time, these initiatives aim to reduce waste disposal and create long-term jobs by dismantling, transporting, cleaning, presenting and selling the components.

However, building components exchange is only a niche market in Germany among secondary markets for price-concious people eager to self-building and fans of historic building components. Therefore, it can be assumed that the establishment of a market for antiques is much easier than for regular building components, such as sinks and heaters. Other than that, professional building components must be certified according to expensive tests in order to obtain a permission to be applied. This certification for used building components is rather limited (Petzet, 2012: 173,177). Furthermore, problems and efforts, such as logistics, transport, storage, non-destructive deconstruction and reinstallation are not conditions supporting the re-use of old building components. The costs related to these additional efforts of especially bulky parts often exceed the recylcing value (Petzet, 2012: 182). Hence, the recycling of buildings regarding regular building parts, such as sinks or heaters, is not a common use at the moment. Nevertheless, architectural salvage is considered to be a profitable market. The reclamation or reuse of architectural materials of homes, churches or commercial properties may include aged barn

wood flooring, handcrafted decorative hardware, furniture, marble fireplaxes, claw foot tubs or ornate radiators (Clean Air Council, 2013). However, a secondary market for regular commodities, such as doors, windows, mirrors, sinks is still not yet established.

3.5. Economic Aspects on Recycled Building Material

In this chapter, basic economic considerations related to the use of recycled building materials are pointed out taking into account decisions affecting the demand and applications of specific recycled materials.

3.5.1. Economic Considerations affecting Demand of Recycled Products

In the 1990s the Dutch model 'CUR' was created with the aim for the establishment of a quantified assessment of costs of selective demolition and re-use of secondary aggregates versus landfilling of unsegregated CDW. This model refers to factors which drive decisions and factors which determine a material's value. Within this context, two key decisions have to be considered: the potential user's decision whether to use primary aggregates or CDW derived aggregates and the demolition manager's decision whether or not to separate the CDW flows for individual treatment, use or disposal. In fact, these decisions on separating waste streams and on recycling their material are generally market-led. So the market demand for CDW derived aggregates, which is the largest recoverable component, determines the nature of the recycling process. However, besides economic forces, also legal requirements on the separation of CDW play an important role.

This model only considers the aggregate fraction and deals with factors which drive decisions and a material's value. Two key decisions are to be considered: the potential user's decision whether to use primary aggregates or CDW derived aggregates and the demolition manager's decision whether or not to separate the various CDW streams for individual treatment, use or disposal. The whole process is market-led. The market demand for CDW derived aggregates which is the largest recoverable component determines the nature of the recycling process.

In the main, the following formula expresses the economic considerations which might lead a construction company to select CDW derived aggregates rather than primary materials and can be considered as an indicator for demand due to cost differences:

Qp + Tq > Er + RCp + Tr

Qp = Price of newly quarried product at the quarry gate based on market forces
Tq = Cost of transport from quarry site depending on distance
Er = Any extra costs created by using CDW derived aggregates, such as cleaning costs, additional storage costs at the location where the aggregates are used
RCp = Price of recycled product at the recycling centre gate
Tr = Cost of transport from recycling centre to site depending on distance

Overall it can be stated that the choice for recycled products is very much dependent on price differences. So if the costs of newly quarried products and the linked costs of transportation exceed the additional costs which are bound to the technical efforts of recycling, the price of the product and the transportation costs, clearly new products are favoured over secondary materials. It can be assumed that the recycling products are cheaper than the primary ones as well as that the transport costs might be the same. Thus, the additional costs of recycling materials are the decisive factor for demand. They are associated with separate demolition, materials sorting, cost of labour and machinery and vary from site to site which makes assessment of the decision making process on different sites difficult (Symonds Group, 1999: 17ff).

3.5.2. Applications of Recycled Building Material as Indicator of Demand

The demand of recycled building materials is a precondition for the existence of a market for recycled CDW. Hence, applications of reused CDW determine the success factor for the end market of secondary materials and the establishment of the viability of these materials. Nevertheless it is of major importance to acknowledge that even if all CDW was re-used or recycled, the quantities would not cover the demand for construction materials. Therefore primary materials will continue to play an important role in order to respond to the demand for the foreseeable future (Symonds Group, 1999: 23). However, the reuse of CDW entails positive impacts and should not be neglected. Recycled aggregates and sand, for instance, have a wide variety of uses on construction projects. Thanks to waste

recycling systems, materials produced out of CDW have an ever growing market due to extensive research into properties of these materials and due to efficient handling systems that bring new and improved recycling equipment to the market (CDE Global, 2013).

Concrete: is a construction material used for any type of building or infrastructure due to its physical and aesthetic properties. It is the second most consumed substance in the world after water with a worldwide consumption between 21 and 31 billion tonnes in 2006. In buildings it is used for foundations, floors for ground or upper floor levels, structural frames, external and internal walls, roof tiles and garden paving (Bio Intelligence Service, 2011: 40). Re-used concrete can be applied in road construction as aggregate base and aggregate subbase, surfacing in gravel roads, base for building foundations and fill for utility trenches (Macozoma, 2002: 6). In terms of economics, the limited production costs of concrete do not encourage reuse and recycling. However, economic benefits include the proximity and quantity of available natural aggregates, reliability of supply and quantity of CDW, government procurement incentives, standards and regulations requiring different treatment for recycled aggregate compared to primary material and taxes and levies on natural aggregates and on landfill (Macozoma, 2002: 52).

Bricks, tiles and ceramics are an inorganic, non-metallic solid produced by the action of heat and subsequent cooling. They are used in buildings as structural products, for external and internal walls, for external wall cladding, as pavers, water/ sewage pipes, floors and roof tiles. Due to their density, they cause lower variation in temperature and moisture, therefore they are cooler in summer and warmer in winter which makes them to a favourable building material. Re-used bricks can be recycled to products filling the road, to produce tennis sand and serve as aggregate in concrete. However, the low costs of bricks, tiles and ceramics produced from raw materials are not encouraging the development of recycling (Bio Intelligence Service, 2011: 55,63).

More than 50% of the worldwide *wood* supply is available for the industrial use since the other half is used as firewood or the production of charcoal. Wood is used in a variety of products in the construction sector, such as roof structure, building framework, wooden floor and terrace, wood beams to sustain construction frameworks, kitchens and doors (Bio Intelligence Service, 2011: 86). If reusable wood is processed to timber, it is used as mulch, composting bulking agent, animal bedding and fuel (Macozoma, 2002: 6). However, the economic barriers for its reuse are the competition between energy and material revocery and its potential contamination with hazardous substances (Bio Intelligence Service, 2011: 85).

Glass can be recycled into low-grade glass production, such as glass reinforced concrete. It can enter non-construction recycling markets, but also be used in road surfacing (Macozoma, 2002: 7)

Scrap metals are mostly melted down and then recycled into new structural sections for use in framing, roofing material and can consequently be recycled to machinery tools, cars and other non-construction related products (Macozoma, 2002).

Regarding other recyclable materials, such as *paper and plastics*, they are usually recycled by traditional non-construction related industries into secondary products (Macozoma, 2002: 7).

3.6. Recycling Criteria for Building Material

Overall it can be stated that the political framework is the precondition for quality improvement of recycled CDW material which is again the main factor for the market establishment of scondary building materials. Recycling criteria for an environmentally-sound and economically efficient management of recycled CDW comprise the establishment of a suitable regulatory framework, quality assurance, improvement of acceptance among various stakeholders in the private and public sector. This should be achieved by efforts in public relations, promotion of research and development regarding designs for recycling and life-cycle approaches and knowledge transfer (Daxbeck H., 2011: 32). In terms of economics, not only the establishment of a market for CDW recyclings and the economic properties of the specific materials play a major role, but also landfill regulations and higher landfilling fees make the recycling of building materials, such as aggregates, economically viable. Within this context, political regulations on penalties related to dumping are to be established in order to avoid illegal dumping activities (Symonds Group, 1999: 20). Thus, all in all, policy regulations are the determining factor for the appropriate reuse of building materials because wihtout a suitable framework for the building industry, such as minimum quotas for the application of recycling material, the general acceptance of recylced building materials and their successful market establishment are not guaranteed.

3.7. Summarising Graphs

The sources of the following charts were taken from all the afore-mentioned literature indications and summed up according to the elaborated results of the theoretical part.

| REGULATIONS legally binding | NORMS technical standard | GUIDELINES advisory instructions |
|--|--|--|
| Waste Management Act (adapted according to EU framework directive) | ÖNORM b 2251 on demolition work and works contracts | Guideline on the use of excavated soil material |
| Waste Documentation Ordinance | ÖNORM S 2100 list of wastes | Guideline for recycling asphalt and recycled building materials |
| Waste Catalogue Regulation | ÖNORM S 5730 investigations of constructions on pollutants and other injurious factors | Directive for filling-material with recycled, crushed material |
| Remediation Act | ONR 192130 on the investigation of pollutants in buildings before demolition | Leaflet – interim storage for mineral construction waste, and concrete |
| Waste Balance Ordinance | ÖNORM M 9406 handling of products containing weakly bound asbestos | Directive for the treatment of contaminated soils and components |
| Regulation on the separation of CDW | ONR 22251 standard texts for service specifications of building construction and ecological requirements | Leaflet – on filling-material with recycled, crushed material |
| Landfill Directive | ÖNORM B 3151 norm on deconstruction processes | Leaflet – recycled building materials for trenches |
| Classification Ordinance of hazardous waste | | Leaflet – working with contaminated soils and contaminated mineral construction waste |

Table 4: Political Framework

Figure 2: Figurative Conclusion of the Theoretical Part



4. Case Study of the Retirement Home Building 'House Döbling'

The following chapter constitutes the practical part of this thesis conducting a case study in regard to the dismantling of the building 'House Döbling' which served as a retirement home in Vienna in the 19th district until it was demolished in May 2012. In this thesis, it is assumed that building material can be used after demolition and therefore it entails a certain value. For this reason, it can be referred to secondary material or secondary resources. Hence, the first part of the chapter outlines the definition of secondary resources and continues with the importance of data acquisition on building material stocks. The aim is to outline which material streams can be retrieved in House Döbling to determine their quantity and eventually their value. The financial analysis is based on one recycling scenario of House Döbling which was assumed after talking to recycling experts and people involved in demolition and disposal issues. Subsequently, prices of primary and secondary material were juxtaposed in order to reveal the potential financial value of the building at the stage where it was built and after demolition. Finally, the most profitable material streams of House Döbling can be identified by taking their masses, their primary and secondary value into account. The information used in this chapter is based on several sources: on the one hand, research on secondary building materials and prices of construction materials was done. On the other hand, the data collection of quantities was used for choosing the main material fractions based on their major quantity. In addition, interviews were carried out with recycling and demolition experts who provided realistic assumptions on recycling rates and paths of building materials. Overall, it must be stated that the term 'building material' is referred to the 14 chosen material fractions in this chapter and that there is a permanent focus on these selected substances in terms of quantity and financial value.

4.1. Secondary Resources in the Building Stock

There are two sources of secondary resources to be distiguished. On the one hand, materials which are in anthropogenic use, such as buildings. They are considered as secondary resources in the building stock. These resources provide already installed and used materials which can be disassembled and subsequently sold via building components exchange. On the other hand, the second source of resources are outside the built environment and results from production processes, such as

residues from power plants including fly ash or slag. In the following chapter, the focus lies on the firstly mentioned secondary resources which can be regained directly from settlement areas. After the primary use of certain materials, they can be directly re-used and applied as secondary resources or they are used after a period of storage. In both cases, quality standards have to be met and preparation processes are required where it is necessary. The more the original primary resource keeps its natural composition, the easier it can be reapplied at high quality. However, nowadays production engineering offers numerous possibilities and a diverse and wide range of goods and material composition which complicates the concept of resource recovery. As a consequence, it can be assumed that the requirements for high quality recovery have to be similarily high as for production engineering (Lichtensteiger, 1998: 32).

4.1.1. Importance of Data Acquisition on Building Material Stocks

In order to support resource efficient management in the building industry the building stock and the infrastructure stock should be considered as important cultural, social and architectural resource of our future. In Germany, 210 million tons mineral CDW per year were recorded between 1995 and 2009, which corresponds to 60% of the total waste volume in Germany. Every year, about 44 million tons are processed to recycling materials and mainly applied in road construction (Petzet, 2012: 177). Hence, due to the fact that buildings and infrastructure are the main carriers of material stocks within the urban system, it is undeniable that there are indeed usable resources in the built environment which are to be considered as secondary resources resulting from waste materials flows.

However, in order to manage them properly and to identify valuable resources, their amounts and compositions have to be known. Secondary materials of buildings including concrete, gravel, sand, cement, bricks, tiles etc. are not of major importance today in terms of quantity because their easy availability is expected for the next decades (Liechtensteiger, Thomas, 2005: 5). Yet, the demand for primary resources is one decimal power higher than the demand for secondary resources. The reason lies in the fact that the existing potential of secondary resources is not yet available. That can only happen when renovation processes become more important than new construction processes in terms of quantity and material flows are taken into account in respect to spatial planning (Liechtensteiger, Thomas, 2005: 55).

For an efficient resource management and urban mining method, urban spatial planning institutions should be complemented with physiological indicators including data on the use of materials and energy in regard to the built environment. Furthermore, the establishment of a regional and national binding regulatory framework is a precondition to guarantee the exploration and record of urban building stock in order to use buildings as a source of resources. In this case, a wide range of political resorts have to integrate urban building and housing concepts in their agenda, such as economic policy, transport policy, energy policy, environmental policy and spatial planning. Urban mining only makes sense when it is part of a longterm strategy politically comprising a wide area (Liechtensteiger, Thomas, 2005: 54f).

4.1.2. Reasons for Lacking Data of Building Materials Stocks

The material composition as well as its amount of the built environment is not wellknown. There are two major reasons for the lack of data in terms of materials and their quantities. Firstly, developed countries operate with aerial cadastral plans in order to manage their spatial planning. Therefore, settlement growth is always connected and also illustrated with land use and not with material input. Hence, there is no data on the quantitative use of materials, but building insurances do have regional data bases for data on building volumes. The second reason for the lack of building stock data is of economic nature. Material costs only account for less than 20% of total construction costs and are therefore of minor concern compared to labour costs and costs for building grounds. So, since the economic means for building materials are available at the moment, there are also no resource boundaries and consequently no demand or interest for data on quantities in terms of building materials (Liechtensteiger, Thomas, 2005: 54). However, resource efficient planning requires knowledge on quantities and composition of urban material stocks is of major importance.

4.2. Presentation of House Döbling



Figure 3: Photo exterior view of House Döbling

The following figures show the building complex of House Döbling from different perspectives and illustrate the different sizes of the three main building blocks as well as their connecting parts.



Figure 4: Front View of House Döbling



Figure 5: Side-view of House Döbling



Figure 6: Aerial View of House Döbling

Concerning the technical information of the house, it is a reinforced concrete steel production and consists of three main buildings (1,2,3) which are supplied with dwellings for residents, the retired people. Yet, the building complex is provided with one large connection block (4), a marble hall (5) and garden facilities. In building (6), a a multi-purpose-hall and a kitchen were constructed for common activities and

events. Yet, an underground sauna was placed in the cellar of building (7). There is also an external construction part, a kiosk (8), which was rented out. However, building part 8 is not taken into account in the subsequent investigation of material quantities and following calculations because it is not physically linked to the seven construction parts and therefore considered to be an external element. The analysis of data regarding material quantities and their prices is done for the above mentioned seven building components in the following paragraphs.

According to definitions of ÖNORM B 1800 on the determination of areas and volumes of buildings, the cubic content or gross capacity of the building accounts for about 60 000m³ and the gross floor area for approximately 18 200m² (Kleemann F. et al., 2013). Considering the single building parts, following figures were identified according to the building's construction plan:

| BUILDING PART | GROSS CAPACITY [M ³] | GROSS FLOOR AREA [M ²] |
|----------------------------|-------------------------------------|---------------------------------------|
| Part 1 "A- Wing" | 18 450 m³ | 6 050 m² |
| Part 2 "B- Wing" | 18 300 m³ | 6 320 m² |
| Part 3 "Annex" | 14 400 m³ | 4 450 m² |
| Part 4 "Connection Part" | 780 m³ | 270 m² |
| Part 5 "Marble Hall" | 440 m³ | 130 m² |
| Part 6 "Multipurpose Hall" | 6 000 m³ | 560 m² |
| Part 7 "Cellar with Sauna" | 1 600 m³ | 440 m ² |
| TOTAL | 59 970 m³ | 18 180 m² |

Table 5: Allocation of Cubature and Gross Surface Area

(Kleemann F. et al., 2013)

4.3. Background Information on Building's Demolition

The retirement home 'Haus Döbling' was constructed in 1970 by the city of Vienna. In 1987, it was renovated. Even though the building was finding itself in good condition before demolition, it was considered not to meet the requirements of a modern retirement home anymore. Therefore it was decided to dismantle it in order to use the location for an appartment house. The roughly 160 elderly people were moved to a more modern retirement home in October and November 2012, which is situated a couple of streets further down the Grinzinger Allee.

When I visited the building with PhD students of the Christian Doppler Laboratory for 'Anthropogenic Resources' on December 12th (2012), furniture was still on site. The first stage of the deconstruction process had already begun with workers removing equipment and furniture from the house, which was not set into stone or cement²². Interior furniture, such as the cooking facilities in the kitchen and fridges in rooms were removed and subsequently put onto trucks. The workers said that the equipment of the kitchen is reused and freezers are transported to a recycling center. However, there is no officially available information on what finally happened to the left furniture or equipment, such as left hospital beds. On February 5th (2013), construction workers were about to remove the mineral rock wool panels from the facade and put them into containers. In addition, sinks were collected and put together in containers as well. Lamps were gathered in one room, wooden material and wires was removed from walls either by hand or by a mini-excavator. They were still at the first stage of deconstruction, in which unfixed material is removed. More information on deconstruction and demolition processes are to be found in the following paragraph.

Regarding background information on the wrecking company, 'Prajo OEG' is one of the largest demolition companies in Austria and a 20 year-old family-run company which undertakes all kinds of demolition works ranging from single-family houses to bridges, industrial installations and large-scale projects, such as the Central Station, 'Hauptbahnhof' in Vienna. Prajo is a company dealing demolition processes and subsequently with the transport and recycling of old building materials. At the recycling plant, bricks and concrete are mechanically treated and reintroduced into the economic cycle.

In order to reduce waste disposal costs which constitute the major part of demolition costs, Prajo follows a waste disposal plan for its demolition projects. This plan contains a threefold strategy in order to achieve environmentally sound demolition projects in terms of environment, economy and safety. The first step of the deconstruction process is the removal of interior and demolition of rising

²² German term for this stage: Entkernung

structures²³. The remaining material is then sorted and disposed. The next measure taken is the partial demolition. Hereby, only certain structural components, such as stairs or interior walls are removed²⁴. Finally, in the last stage, the building is totally removed²⁵ (PRAJO&CO, 2013). In the demolition case of House Döbling, the waste disposal plan was applied and the deconstruction and demolition processes were carried out according to ÖNORM В 2251 and ÖNORM В 2110 (Forschungsgesellschaft Technischer Umweltschutz GmbH, 2012: 41).

4.4. Approximated Amounts of Building's Material before Dismantling

The building's materials and their quantities were identified in December 2012 by taking measurements of the equipment left in the house before the deconstruction processes started. This was accomplished in the frame of the Christian Doppler Laboratory for 'Anthropogenic Resources'. Moreover, information of the building's construction plans was taken into account in order to find out approximate amounts of concrete or bricks etc.. During the investigation of the house, measurements were taken directly in the building to identify sizes of pipes, cables and types of doors etc. to learn more about how many kinds of materials are available and where to find them. Then, heaters, floors, pipes, cables, doors, windows, ventilation pipes and so on were weighed to determine the masses of single different objects made of a certain material. For instance, the weight of all doors, which were made of wood, was calculated by multiplying the weight of one door with the numbers of wood doors found in the constructions and the same was done for heaters and windows etc.

Nevertheless, the figures on the approximated masses imply assumptions and uncertainties. For instance, wires were cut out of the walls and samples were taken in regard to determine the cross section of the various kinds of wires. Furthermore, it was assumed, that the ratio between copper and PVC is 1:1, so 50% copper and 50% PVC for all cables. These measurements of cables of one room, for instance, were assumed to be found in the same building blocks and summed up according to the proportions of the building in the construction plan. However, it is not always easy to determine what objects or parts in a house consist of which exact materials,

 ²³ This first stage is called 'Entkernung' in German.
 ²⁴ The second stage is called 'Teilabbruch'

²⁵ The third stage is named 'Vollabbruch'

therefore the identified masses of materials are only approximated. All in all, 14 different major 'materials' were identified, namely concrete, sand/gravel, steel, bricks, wood, eternit panels, PVC, glass, polystyrene, aluminium, copper, mineral rock wool, bitumen, other metals and other synthetics. As a general remark, it should be noted that the material description 'eternit panels' is referred to cement bound asbestos. As far as the material designation 'bitumen' is concerned, it is related to building materials which mainly consist of bitumen, but also comprise asphalt and is applied as insulation material and roofing felt etc. Moreover, mineral rock wool refers to insulation material which may also correspond to glass wool and stone wool. Yet, samples of different materials were taken and analysed in the chemical laboratory at the Technical University of Vienna in order to find out where harmful substances are located. They were detected in pavements made out of PVC and lamps which contain heavy metals. Eternit panels containing asbestos fibres also count to harmful substances²⁶.

It is evident that more than 14 types of materials are contained in the building's material flows. For instance, smaller fractions, such as gypsum or single kinds of synthetics were not taken into account in the calculations. However, the main focus throughout this thesis lies on the above mentioned 14 material streams of which were assumed to represent the major quantities of the building material.

²⁶ These fibres are resistant to chemicals and stable in the environment. That is why they are not harmful in closed and built form. However, when breaking eternit panels, these harmful fibres may be suspended in the air and negatively influence human health if inhaled (United States Environmental Protection Agency, 2013).





The chart above provides an overview and comparison of the largest material streams which were identified in House Döbling. It is evident from the graph that concrete represents by far the biggest quantity of the building accounting for 22 000 tons which is still almost 26 times bigger than the second biggest material stream sand. Steel represents the third significant material flow accounting for less than half the quantity of sand. Bricks, wood and eternit panels appear in similar quantities around 100 tons, such as bitumen, PVC and glass account for 30 to 50 tons. Other metals include brass (30kg) and zinc (1000kg). Considering all metals including aluminium and copper but excluding steel, they represent sources of relative significance in terms of quantity and refer to 21 tons. They only represent 0,01% of the total mass of around 23 840 tons. All in all, it is evident that concrete is by far the most significant source when speaking of quantity.

| MATERIAL FRACTION | % OF TOTAL MASS |
|----------------------|--------------------|
| concrete | 92,292 |
| sand/gravel | 3,610 |
| steel | 1,710 |
| bricks | 0,868 |
| wood | 0,489 |
| eternit panels | 0,376 |
| bitumen | 0,209 |
| PVC | 0,145 |
| glass | 0,131 |
| polystyrene | 0,059 |
| aluminium | 0,053 |
| copper | 0,028 |
| other synthetics | 0,018 |
| mineral wool | 0,011 |
| other metals | 0,005 |

The table on the left illustrates the percentage distribution of the various materials. Again, it is obvious that concrete is the biggest mass flow with around 92%. Sand and steel, as the second and third biggest mass flow account for 3,6 and 1,7% respectively. All other materials represent less than 1% of the total building material of House Döbling. Thus, it can be stated that the difference in quantity from the three biggest streams differs dramatically from the masses of the other 11 remaining materials.

Table 6: Percentage of Material Amounts

(Kleemann F. et al., 2013)



Figure 8: Mass Percentage Rate of built-in Materials without Steel, Sand and Concrete

(Kleemann F. et al., 2013)

The pie chart about percentage rates highlights the distribution of quantities without the three biggest material streams concrete, sand and steel. It is evident that bricks, wood and eternit panels are of major importance with a mass proportion of about 70% altogheter, whereas the other materials such as bitumen, PVC and metals are of relatively small significance with accounting for less than 10% each.

4.4.1. Localisation of Materials

It is not only vital to know what quantity portions of materials are to be found in a building, but also where the single materials are located. The location has a great relevance for the recovery process. 'Underground material streams' are more difficult to recover and deconstruct than material which is finding itself above the surface. Therefore, following graphs point out the location of the chosen material fractions. According to the location, assumptions on the quality and composition of material can be made. For instance, the PVC used in flooring is different from the PVC applied in cables or window frames. Though, it shall be acknowledged that following figures contain uncertainties and estimations. Their information is elaborated based on Kleeman's data recorded at the in-house investigations.

| MATERIAL | LOCALISATION | | |
|--------------|------------------------|--------------------|--|
| concrete | 100% in dwellings | | |
| sand/ gravel | 100% in dwellings | | |
| bricks | 100% in dwellings | | |
| wood | 85% in dwellings | 15% in roof truss | |
| glass | 80% in windows | 20% in doors | |
| bitumen | 100% in roof | | |
| polystyrene | 97% in ceilings | 3% in dwellings | |
| copper | 94% in wires | 6% in roofing film | |
| mineral wool | 60% in pipe insulation | 40% in façade | |

Table 7: Localisation of Major Building Materials

The table on the localisation of building materials illustrates rough approximations where the material fractions can be found which are relatively easy to recover due to their rather homogeneous locations in the construction. However, it is noteworthy that the materials are often mixed together. For instance, steel is set into concrete in form of reinforcement bars. So at the time of deconstruction it has to be separated from concrete. At the end of deconstruction not all materials can be totally separated from each other and are finally landfilled or delivered to waste disposal contractors as bulky waste.

According to the table, concrete, sand and bricks only have one location to be found in the building. This reason is due to the fact that they are materials which are only used for the foundation of the construction. Because of their homogeneous allocation they are easy to find and revocer during deconstruction processes. Since wood is mostly situated in dwellings as furniture or doors, it can be assumed that these 85% of wood are material treated with plastic paint and varnish. This fraction has to be recycled differently from untreated wood which is used for foundation purposes, such as the wood bulks applied on the roof. The table shows that bitumen is only used at the roof because of its good insulation properties and to protect from moisture. In constrast to most materials in the table which have a main source of origin, 60% of mineral wool is applied as pipe insulation whereas 40% is built in facades.

The following charts illustrate the locations of steel, PVC, aluminium and eternit panels. These materials find more versatile applications in the house and are therefore placed in many different parts of the building.



Figure 9: Localisation of Steel

Steel is used for various applications and its major quantity is located in the reinforcement bar. The rest of steel is distributed rather equally and situated in heaters, pipes and frames for windows and doors. About 7% of steel is used in frames for windows and doors. Heaters and pipes represent a little bit less than 6% each. The fraction 'others' imply minor material masses in the loggia, bathrooms, handrails, lamps, suspension, lattice and sheet metal. All in all, it is a material applied almost everywhere inside and outside the construction complex being used in dwellings, the hallway and the roof. Yet, it is interesting to acknowledge that steel accounts for 5% of the volume of concrete.



Almost 70% of aluminium is found in windows and doors. Other 20% is applied in the façade. The rest of this light metal is located in roofing and the exterior part of the building, at the loggia.

Figure 10: Localisation of Aluminium



Figure 11: Localisation of PVC

Around 80% of PVC is applied in flooring which constitutes the major location. Wires account for the second biggest source of PVC. Toeboards, walls are of minor significance in terms of quantity. In the graph only information on soft PVC is revealed. Figures on the masses of hard PVC applied in pipes are not given.



The quantity of eternit panels is almost equally distributed on roof and façade accounting for 50% and 45% respectively. The rest of the panels is assumed to be found in dwelings, but its mass is of minor importance.

Figure 12: Localisation of Eternit Panels

4.4.2. Material Allocation in regard to Cubature and Gross Floor Area

Average values of material quantities related to cubature and gross floor area are of vital importance for the comparison of other buildings' mass allocation. The European norm, EN 15221-6 and the Austrian ÖNORM b 1800 regulate calculations on the determination of areas and volumes of buildings. Based on these standards, the definitions of cubature and gross floor area are defined as following:

The Cubature or cubic capacity corresponds to a building's gross volume. Hence, it is the volume inside the outer boundary surfaces of the building and the under surface floors of the construction's bottom plate. So, the cubature can also be determined without the knowledge on the subdivision of individual floors and is organised into net volume and construction volume which are not considered in the following illustration. The House Döbling's total volume was calculated according to construction plans and accounts for 60 000 m³.

The Gross Floor Area of a building is organised by the sum of all floor areas on all the floors of a building and breaks down into net floor area, usable floor area and construction area which are not considered hereby. The gross floor area corresponds to 18 200 m² in House Döbling (ÖNORM B 1800, 2010: 2-5).

| | MASS PER VOLUME | | MASS PER AREA | |
|------------------------------|-----------------|-------------------|---------------|-------------------|
| Concrete | 370 | kg/m³ | 1210 | kg/m² |
| Sand/Gravel | 14 | kg/m³ | 50 | kg/m² |
| Steel | 7 | kg/m³ | 22 | kg/m² |
| Bricks | 3 | kg/m³ | 11 | kg/m² |
| Wood | 2 | kg/m³ | 6 | kg/m² |
| Eternit Panels ²⁷ | 2 | kg/m³ | 5 | kg/m² |
| Bitumen ²⁸ | 1 | kg/m³ | 3 | kg/m² |
| PVC | 0,6 | kg/m³ | 2 | kg/m² |
| Glass | 0,5 | kg/m³ | 2 | kg/m² |
| Polystyrene | 0,2 | kg/m³ | 1 | kg/m² |
| Aluminium | 0,2 | kg/m³ | 1 | kg/m² |
| Copper | 0,1 | kg/m³ | 0,4 | kg/m² |
| Other Synthetics | 0,07 | kg/m³ | 0,2 | kg/m² |
| Mineral Rock Wool | 0,05 | kg/m³ | 0,2 | kg/m² |
| Other Metals | 0,02 | kg/m ³ | 0,1 | kg/m² |
| | | | | |
| TOTAL BUILDING MASS | 400 | kg/m ³ | 1300 | kg/m ² |

Table 8: Average Material Allocation in regrard to Gross Cubature and Gross Floor Area

The table illustrates average mass proportions of the chosen materials in regard to their gross volume and gross floor area. It is interesting to note how values differ by volume and mass as for example with steel which accounts to 7kg/m³ and 22kg/m². Certain materials are indicated with certain units, therefore both units for volume and area are specified in the table in order to pick the suitable measurement for comparement purposes. As for instance, concrete and sand are always related to m³ when considering prices and masses, the mass and prices of PVC and glass are always given in relation to m². Evidently, concrete corresponds to the largest

²⁷ Eternit Panels are only applied in roof facilites and are therefore not relevant in regard to cubature and gross floor capacity. If underground construction of the building, for instance, is expanded by a new basement, the quantity of eternit panels remains the same. In the table above, it is only mentioned in order to demonstrate the average total building mass per m³ and per m² in order not to ignore any material streams.

²⁸ See comment 27. Bitumen and Eternit Panels only are assumed to be placed in the roof. Therefore their average value in regard to cubature and gross surface area is only of little relevance.

quantity per volume as well as per area. Especially the total building mass is interesting to observe in relation to other buildings in order to gain an overview of how much material is available.

| | House Döbling | MULTI-FAMILY HOUSES | | DOUBLE-FAMILY HOUSE |
|----------------------------------|---------------|---------------------|-------------|------------------------|
| Construction Year | 1970 | 1972 | unknown | 1927 |
| Cubature | 60 000 m³ | 6 000 m³ | 22 600m³ | 500m³ |
| Building Mass per m ³ | 0,40 t/m³ | 0,49 t/m³ | 0,54 t/m³ | 0,47 t/m³ |
| Location | Austria | Germany | Switzerland | Switzerland |
| MATERIAL PORTION | | | | |
| Concrete | 92% | 46% | 73% | 9% |
| Bricks | 0,87% | 34% | 17% | 70% |
| Eternit | 0,38% | - | 0,8% | - |
| Glass | 0,13% | 0,2% | 0,1% | 0,1% |
| Metals | 0,09% | 2% | 3% | 2% |
| PVC | 0,15% | 0,4% | 0,3% | 0,1% |

4.4.3. Comparison of Data and Size to other Houses

Table 9: Relative Mass Portions of Buildings in Relation

(Lichtensteiger, 1998: 5)

The table on relative mass portions of houses does not only give an overview on material allocation of various houses, but it also shows clearly the lack of data available on material availabilites in buildings. Already by the comparison of the building mass, the dimensions of the diverse construction can be identified. So, the table makes it obvious, that House Döbling is by far the largest construction in terms of volume. However, the building mass of the Swiss multi-family-house is 15 tons bigger per m³. Considering the material portion, the percentage amounts of concrete and bricks varies greatly. It can be assumed that the swiss multi-family house is a concrete building as well as House Döbling. The German building is mainly comprised of concrete and bricks accounting for 46% and 34% respectively. The Swiss Double Family House is built from bricks which represent 70% of the

building's material. Interestingly, all buildings share a similar material portion of glass which corresponds to 0,1% to 0,2%.

All in all, it is obvious that the named buildings represent various construction types which makes a comparison rather challenging. However, it can be stated that apart from building style and age of a building, stone, glass, cement and inorganic fibres constitute 90% of the buildings' mass. The rest is a mixed composition of wood, metals and organic synthetics mainly applied in building services. The densities of the buildings are similar with around 500kg/m³. If a total volume of 215m³ buildings percapita is assumed, the total building stock in terms of mass accounts for around 110t per capita (Lichtensteiger, 1998: 5).

4.5. Analysis of Commodity and Recycling Value of Building Materials

The analysis of commodity and recycling prices is based on their juxtaposition per unit and in reference to House Döbling in order to illustrate the differences in value regarding primary and secondary building material. Moreover, its aim is to identify the most profitable material streams after demolition, specifically for House Döbling. Firstly, recycling and disposal paths of House Döbling's building materials are illustrated in order to show what happens to the materials right after demolition processes and which recycling routes they take. Yet, the scenario is complemented by research on general recyling paths of the selected materials. Secondly, average prices of primary and secondary materials are put into comparison to each other.

The prices of primary construction material are based on internet research. Thereby the intention was to indicate the original value of construction resources and to keep the price as close to the pure raw material value as possible trying not to imply processing costs. For the financial value of secondary building materials, one scenario was assumed based on telephone interviews with waste disposal contractors and the manager of the Austrian Construction Materials Recycling Association. Thirdly, the juxtaposition of prices, the value of House Döbling's primary construction material as well as the difference of primary and secondary value is presented in order to identify materials with 'positive' and 'negative' values. The aim is hereby to present the change and decrease of value regarding primary and recycled building substances based on the example of House Döbling.

4.5.1. Recycling and Disposal Scenario of House Döbling's Materials

The following table gives information on recycling and disposal routes of the 14 selected building substances of House Döbling. Its aim is to show what happens to the separated materials right after demolition processes in order to demonstrate which materials can be recycled and which ones cannot. Assumptions on recovery, recycling and landfill rates were taken with the intention to create a realistic scenario of what and how much of it can be recycled. These assumptions are based on telephone calls with the manager of the Austrian Construction Materials Recycling Associations, a recycling expert employed at Prajo, with employees of recycling plants, waste disposal contractors and general research on recycling material because waste disposal contractors determine both takeover or acceptance prices of demolition material and selling prices of secondary building material. However, the prices of recyclable building material differ at various stages after demolition. These variations as well as fluctuations of prices are not taken into consideration, but an approximated average value is indicated for the presented scenario.

| | RECYCLING RATE | RECYCLING PATH | DISPOSAL RATE |
|----------------------|---|---|---|
| Concrete | 95% | filling material, additive for concrete production | 5% landfilled |
| SAND/ GRAVEL | 90% | filling material | 10% landfilled |
| Steel | 95% | steel production | 5% landfilled |
| BRICKS | 60% | sand for tennis courts, additive | 40% landfilled |
| Wood | 15% | chipboard | 85% processed and burnt |
| ETERNIT PANELS | - | - | 100% landfilled |
| BITUMEN | - | - | 100% landfilled |
| PVC | 5% | reintroduction to PVC material cycle | 95% processed and burnt in waste incineration plant |
| GLASS | 70% | float glass production | 30% landfilled |
| POLYSTYRENE | - | - | 95% burnt 5% landfilled |
| ALUMINIUM | 85% recycled 15% scrap metal ²⁹ | aluminium production | - |
| Copper | 85% recycled 15% scrap metal | copper production | - |
| OTHER SYNTHETICS | 10% | synthetics production | 90% landfilled |
| MINERAL ROCK WOOL | - | - | 100% waste incineration plant |
| OTHER METALS | 90% | metal production | 10% landfilled |

Table 10: Recycling Scenario for House Döbling

²⁹ Losses of aluminium in steel industry

Table 10 shows the recycling and disposal scenario for House Döbling's selected building materials indicating recycling and disposal rates as well as recycling paths which outlines what further happens to the recyclable material. It shall give information on how many fractions can be reused and how many are not reusable after demolition. 100% of four out of 14 material streams are directly landfilled and cannot be reused at all. They comprise eternit panels, bitumen, polystyrene and mineral rock wool. They cannot be reused due to hazarardous substances in eternit panels, impurity of polystyrene and no local recycling options for mineral rock wool and bitumen. For House Döbling, it was assumed than 90% of PVC were burnt due to the high amount of heavy metal in PVC samples. On the other hand, 90% of each metal type can be recovered and reintroduced into the metal material cycle. The recycling rate of concrete and sand accounts for more than 90%, whereas brick's recycable rate corresponds to 60%. Similarily, 70% of float glass is recycled, the remaining 30% are either not separable or unusable broken fragments.

The recycling rate is directly linked to the recovery rate which indicates how much can be regained segregatedly from the building. Often, materials are mixed and therefore not easily separable. However, the demolition company Prajo follows a disposal concept proposing a three-fold policy of demolition processes on the stages of deconstruction and demolition. The three stages imply the total removal of all loose objects, deconstruction of building components and total demolition (PRAJO&CO, 2013). The reason behind these three steps is to remove single material streams step by step. Therefore, an optimistic recycling scenario can be assumed since the three-fold deconstruction and demolition method sets the stage for relatively pure material streams. However, it is not possible to separate 100% of each single material fraction, such as concrete, sand or bricks and therefore remaining building rubble containing mixed fractions ends up in a landfill or waste incineration plant. As far as House Döbling's building material is concerned, after deconstruction and demolition, it was put into containers in separated fractions and delivered to various waste collectors or waste disposers which subsequently either separate and process the waste collected or further transport it to a recycling plant or to a landfill.



Figure 13: Photo Deconstruction at House Döbling

4.5.2. Information on Common Recycling Paths of Selected Materials

Concrete, sand, gravel and bricks as well as asphalt, masonry and other sandstone belong to the *mineral fraction* of building materials. Concrete contains cement, concrete granulate, water and if necessary concrete admixtures. Additives and concrete admixtures might lead to contaminations in the form of nitrate, nitrite, chloride and heavy metals (Rentz et al., 1997: 25,28). These groups of substances contain similar properties and common characteristics because of their origin and their production processes. Therefore their recycling routes are rather similar after their primary use. Recycling options for mineral concstruction materials are mainly used in civil engineering as granulate additives. On the one hand, granulate of higher quality can be used as base layer and anti-freeze in road construction. On the other hand, remaining granulate of lower quality can be applied as filling material or in noise barriers.

After its primary use, *concrete* is shredded and processed to concrete granulate which can be used in noise barriers, in transport infrastructure, road construction, filling material, base layer and subsoil improvement or granulate for new concrete production. *Sand and gravel* can be reused for the same appliances. In regard to *bricks*, their additive mortar might hinder recycling. Due to the share of mortar, they

cannot be reused as bricks and fulfill their original function anymore. Hence, they are also further processed to granulate after their primary use. However, bricks granulate can be also used in noise barriers, road construction, civil engineering, as filling material and ground stabilisation (Rentz et al., 1997: 143). The prices of recycled mineral material strongly depend on their local availability and the natural stone market. Acceptance prices for mineral fractions, which are determined by disposal contractors, also depend on landfill fees. In case there is no landfill in the immediate proximity or even in the province, the acceptance prices are higher since the disposal contractor has to overtake transport costs to a landfill and the fees related to landfilling.

In practice, two kinds of *Metals* may be distinguished: first, ferrous metals including steel and cast iron, secondly non-ferrous metals implying aluminium, lead, zinc, copper and copper alloys. In multi-household buildings, ferrrous metals account for 3,5% and non-ferrous metals for 0,5% of the total building mass. In the construction sector, steel is mainly applied as reinforcement and iron dowel as well as in doors, windows, window boards, balconies, roofing, pipes for heating, water and ventilation appliances, such as sanitary fittings and fixing elements. Non-ferrous metals are mainly applied in alloys, apart from copper which plays a crucial role for electronic appliances in its pure form. Copper finds a wide range of appliances in electronic installations, such as cables, cooling coils and roofing facilities due to its thermal conductivity. Even though metals contain heavy metals, they are not considered as ecologically damaging because they are only eluated on the surface. Metals are remelted after use and can be reapplied without quality deficiencies endlessly which makes them more attractive in terms of recycling. Metal scrap is a popular raw material in metal production since it can be used as steel converter. Yet, steel scrap is delivered to shredder facilities right after deconstruction and subsequently to steelworks after which it follows its original function. Furthermore, non-ferrous scrap metal is collected, sorted and consequently further processed as unmixed and segregated fraction. For instance, aluminium scrap is used for the production of casting alloys through metallurgic processes and refining (Rentz et al., 1997: 153f).

Glass is a homogeneous non-crystallised solid body with low heat and electricity capacity as well as great resistance to air and liquids. It mainly consists of the raw materials sand, lime and sodium carbonate which are mixed together and melted at 1600 degrees. There are various types of glass, namely lead-glass, silica glass etc., but in general, glass products are distinguished by hollow glass (bottles) and flat

glass (windows). The difference between them are due to diverse production processes, chemical composition. However, flat glass has a higher melting point. In the construction industry, flat glass is used for windows and for room separation as well as for insulation purposes.

Float glass has a recycling rate almost up to 100%. Since it is a mineral substance it can be repeatedly recycled without quality deficiencies. Recyclate material of flat glass, called flat glass granulate, can be further proceeded to float glass, cast glass, container glass, mineral wool, reflective beads and glass fiber. In the main, all kinds of flat glass can be recycled under the precondition of being well segregated from other materials (Das Land Steiermark, 2006). A high recycling quota, however, is based on high quality requirements such as optical and colour criteria and the amount of foreign matter. Though, the recycling of flat glass demands higher quality requirements: used glass is not allowed to contain more than 15g/t of organic substances, such as mineral materials (Rentz et al., 1997: 150). The collection of flat glass is based on bulky waste collection. Acceptance prices of old glass correspond to around 120 t if not segregated. However, if the material is unmixed and free from other components, the bringer may get up to 5 (Das Land Steiermark, 2006).

Wood is the only building material which is gained from a living plant and therefore a 'pure' raw resource. Its material composition comprises 40-50% cellulose, 20-35% lignin, 15-35% hemicellulose (also known as Polyose) and extractable constituents such as resins, wax, terpenes, sugar, proteins, minerals etc. Since it is an organic material, it is biodegradable via oxygen. Thus, wood preserver is used in order to prevent organic depletion and protect the material from insects, decomposition and rot fungi. Wood preservers include a variety of products such as impregnation agents and wood preservation salts and can contain heavy metals. Hence, treated wood with preservation products is more difficult to recycle (Rentz et al., 1997: 33f). The actual quantity of wood as construction material crucially depends on the construction style. Used building wood comprises beams, wooden boards and pallettes, etc.. The main issues hindering the recycling of building wood are contaminations through wood preservers, metal parts and mineral fractions. However, old and unmixed wood offers a variety of recycling paths, such as raw material for the production of chipboards. In the 90's, already 80% of old wood was recycled to chipboards in Italy. However, the recycling rate varies greatly across different countries and can range from 10% to 80%. The second recycling route for old wood is thermal recovery for the production of energy, such as in waste incineration plants, biomass heating plants, but also in industrial furnaces. Even though there are many decent recycling routes for treated and untreated wood, its demand and the recycling rate strongly depend on the market and supply of the raw material (Rentz et al., 1997: 149f).

Synthetics are used in the construction sector since the mid 1950s due to their advantageous properties such as their low specific quantity, high resistance to corrosion and high insulation properties. More than half of plastic products in the construction sector are made of PVC (polyvinyl chloride), but also synthetics such PS (polystyrol or polystyrene), PP (polypropylene) and PUR (polyurethane) are widely applied. Since the focus of this thesis lies on selected material streams, only polystyrene and PVC are explained in more detail.

Polystyrene is marked by a high degree of mechanic strength with low inherent weight. Furthermore, it has a low thermal conductivity, high sound absorption, high resistance to temperatures and low water vapour permeability. It can be shredded and reused for its original purpose, but that rarely happens in the construction sector due to mineral contaminations. In the packaging sector it can reach a recycling rate up to almost 100%. However, in the construction sector it is usually contaminated with mineral material and is consequently burnt.

PVC or polyvinyl chloride is distinguished by hard PVC and soft PVC. Hard PVC does not contain any plasticiser and is applied in pipes for the supply of water and sewage, plastic plates, windows, doors, roller shutters, roof gutters and façade cladding. It is characterised by high mechanical resistance, good electrical properties and high resistance to chemicals. Soft PVC is mainly used in hoses, cables, sealing membranes, roof covering, floor coverings, cable insulation and plugs. Its properties compries adjustable flexibility, resistance to chemicals and good electrical properties in low voltage area and low frequency range (Rentz et al., 1997: 38-40). Both disposal and recycling of PVC require processing, even if it ends in a waste incineration plant in order to avoid heavy metals to be released in the air.

On the main, the weight percentage of synthetics in a building accounts for about 1%. However, in the 1980s already, plastic products in constructions represented 20% of total construction costs. In terms of recycling, synthetics may contain hazardous substances, such as PVC from the 1970s might contain heavy metals and can release dioxines when burnt. However, recycling paths for plastics exist,

such as for window profiles, floor coverings, façade cladding and efforts regarding the reuse of synthetics are taken. In 1990, an association for the recycling of PVC floorings was established in Germany. Processing steps for recycling include sorting, crushing, washing and conditioning. The recycling product eventually created is PVC powder which can be applied in the production of new floor coverings with a share of 50%. Another option is to process mixed synthetics from window profiles and façade claddings to recycling granulate by physical-chemical treatment, mechanical or chemical recycling. Cable waste consisting of about 45% of metals and 55% of synthetics, is usually treated and processed to regain the metals. Thereby the focus lies on copper recovery which can be up to 95 to 97% (Rentz et al., 1997: 152ff).

Mineral Rock Wool is an inorganic fibrous substance produced by steam basting and cooling molten glass. It is mainly used for acoustic insulation, fire protection, cement reinforcement, pipe insulation and can also be applied as synthetic soil for growing plants. Even though, it was not reused in this case study, rock wool offers recycling options. It can be used as a substitute for coarse and fine aggregates. Due to its composition, its waste is similar to pozzolanic materials, such as fly ash, ground granulated blast-furnace slag and silica fume. Hence, it can be considered as cementitious material. If recycled, it can replace natural aggregates and be used as coarse aggregates, fine aggregates, cementitous materials, or ultra fine fillers in concrete depending on their chemical composition and particle size (Cheng et al., 2011: 336).

Regarding unrecyclable material streams, *absestos* is the oldest unorganic fibre material. It is marked by high resistance to heat, insulation property and it is impossible to burn. Therefore it is applied as ceiling and wall finishing, as fire protectant, sound insulation, heat protection and as sealing. However, hazardous asbestos can be released into the environmnent through natural wear and tear and weathering which can cause cancerogenic diseases if inhaled. Since 1995, however, the production and installation of asbestos materials in building constructions is prohibited (Rentz et al., 1997: 30f).

Bituminous substances contain bitumen and tar or pitch to a certain extent. Bitumen is waterproof and insoluble and therefore used as insulation material and protection against moisture. Bitumen is derived from petroleum whereas tar is a coal product. Applications are mainly found in roof sealings and terrasses. Bitumen is not a

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hazardous substance itself, but it may contain tar which is partly soluble in water and may contain cancerogene polycyclic aromatic hydrocarbons. Overall, bitumen is not recyclable and therfore landfilled (Rentz et al., 1997: 44f).

4.5.3. Prices of Primary and Secondary Building Materials

Prices of primary building materials were researched online whereas the intention was to find the price which is closest to the original raw material. The aim is to present the resource value of selected materials and subsequently find out the potential resource value of House Döbling. However, the prices of all materials experience fluctuation to a greater or lesser extent and contain therefore uncertainties. As the prices for concrete, sand, bricks, mineral rock wool, polystyrene and eternit panels are rather stable, prices for metals, synthetics and wood fluctuate on a daily, monthly or yearly basis. The variations strongly depend on market conditions and availabilities or supply of certain materials. In this case, approximated average values based on research are indicated. Regarding sources for so-called primary prices, were found on webpages of forums for construction materials and companies selling construction materials, such as wood³⁰, sand³¹, steel³², concrete³³, bricks³⁴, bitumen³⁵, polystyrene³⁶, glass³⁷ and mineral rock wool³⁸. For the remaining metals³⁹ and synthetics⁴⁰, relevant homepages provided information on prices. However, the comparison of prices refers to two kinds of materials, primary and secondary. These materials are in a different state or

³⁰ <u>http://www.baustoffeehrlich.at/EhrlichList.aspx</u>

³¹ <u>http://www.klaghofer.com/webkatalog/baustoffe/sand-schotter-kies/bausand.html</u>

³² <u>http://www.gueteschutzverband.at/betonstahl-preise</u>

³³ <u>http://www.cemex.at/924_DE-Beton_strich-Preislisten_older.htm</u>

³⁴ <u>http://www.baustoffeehrlich.at/EhrlichList.aspx</u>

³⁵ <u>http://www.comprano.de/artikel/fluessigbitumen-wichtige-informationen</u>

³⁶ <u>http://www.bausep.de/BAU/Styropor-Preise/</u>

³⁷ <u>http://www.pilkington.com/europe/austria/german/default.htm</u>

³⁸ <u>http://www.frag-den-heimwerker.com/html/mineralwolle_preis.php</u>

³⁹ <u>http://www.finanzen.net/rohstoffe/</u>

⁴⁰ <u>http://plasticker.de/preise/marktbericht2.php?j=12&mt=3&quelle=bvse</u>

All homepages accessed on 12th September 2013

condition before and after use. Thus, the price of the new construction product brick is compared to the secondary price of brick rubble. The processing costs of brick rubble required to reuse bricks granulate are not considered in this thesis. Neither are labour and transport costs taken into considerations. However, as shown in chapter 3.5.1. transport costs are of crucial importance in regard to the profitability of the recycling of building materials.

Prices for secondary or recycling materials are lower than the value of raw materials and also vary according to their primary price fluctuations, especially in the case for metals. The value of recycled substances also varies strongly depending on the processing stage and how many steps are done along the way from a recycling material to a new product. Along that way, waste disposers and collectors as well as recycling plants and manufacturers are involved. In this thesis, the price for secondary material was chosen at the stage where the materials leave the recycling plant which is the sales price. Hence, the recycled material is still far from being a manufactured or specific item. However, the processing steps required for the primary reuse of material are taken into account. In the case of glass, the value of recycling glass is indicated which would be the step before a window is produced. For metals, the acceptance prices of metal recyclers are taken because the sales prices of recycled metals can be assumed to equal the primary prices. Obviously, the number of processing steps strongly depends on the material itself. Such as for sand or concrete granulate, less stages are required to reuse it than for synthetics. In addition to that, the prices of recycled material, especially for glass, are very sensitive according to employees of various recycling plants. Hence, the value of the waste product was assumed according to the value of the raw material. The remaining prices were indicated based on the price list ⁴¹ of the Austrian Construction Materials Recycling Association and information from telephone interviews. However, the name of the interviewers and their companies are not disclosed due to confidentiality reasons. So overall, the indicated prices for secondary materials are supposed to represent the values of the materials before a specifically manufactured item is poduced or before they are reintroduced into their original cycle if that is the case. The aim hereby is to find out the value related to secondary resources.

⁴¹ <u>http://www.brv.at/files/shop/Preisliste.pdf</u> accessed on 20 th September 2013


Figure 14 : Commodity Prices for Raw Materials and Waste Products in €/m³

Figure 14 gives information on the comparison of commodity and recycling values of concrete, sand, bricks, polystyrene and wood. The left bar of each material indicates the price of the primary material and the second bar the recycling value. Wood has diverse recycling paths and its negative price stands for disposal or processing costs. Especially treated wood containing wood preserver, which is applied in furniture, is required to be treated before being burnt. It is interesting to observe the loss in value between primary and secondary price. As for instance, the price of concrete and bricks decreases by a factor of around ten which means that the primary material is worth ten times more. However, the primary and secondary price for sand differ only by a factor of three. Regarding wood, there are various ways how to process and use it after demolition. These ways are strongly dependent on whether it was treated with wood preserver and on its condition. Therefore, there are many scenarios for wood after demolition, either it is easily recyclable, in case it is almost untreated without wood preserver or other chemicals. However, in case it is reusable there is a value loss of a factor of six between primary and secondary price. Yet, if it has to be processed or burnt its price decreases by around 270€ per ton. Overall, the steps between primary and secondary prices undergo significant changes for all mentioned materials. Though, the increase varies between materials according to their 're-application' and related processing steps.



Figure 15: Commodity Prices for Raw and Recycled Metals and Glass

According to figure 15, the commodity and recycling prices of metals and glass don't differ as dramatically as the prices for cement, sand, bricks and wood. Since nowadays the demand for metals is rising, the metal recycling business is flourishing. Except for glass, the prices indicated at the figure represent their value at the stage of deconstruction and are so-called acceptance prices. According to metal recyclers, not only information on these prices, but especially on selling prices of recylcers are very sensitive and not made public for business reasons. That means, that a demolition company is paid these values if it transports the metals to a metal recycler. Even for scrap metal, which is a mix of different kinds of metals, the receiving price is 130€ per ton. Glass is usually transported to a waste collector who delivers it to a glass recycler. The acceptance price of glass lies between 0-5€ per ton at the stage of waste collection after demolition, but depends on its purity. However, it is assumed, that the price of glass before reintroduction into the float glass production lies around 150€ per ton if well separated from other material. But this value is only guessed because nobody from the recycling glass industry wanted to share information on recycled float glass prices. The figure shows that the price difference of primary and secondary value of steel is the largest accounting for a factor of 6 respectively. However, the recycling price of 100€/t represents a rather pessimistic scenario. Usually it is around 150€t. In terms of aluminium, zinc and

brass, the secondary metal price is approximately half of the value of the raw material. All in all, copper is the most expensive material which undergos the smallest price decrease out of all other metals. Overall, the scrap price of all metals is closely linked to the market price and experiences daily fluctuations based on market conditions, supply and demand.

Materials, which require disposal fees after demolition and cannot be recycled due to hazardous contaminants or no local recycling options, entail disposal costs. They represent the biggest financial burden to the demolition company as well as to disposal contractors. They comprise eternit panels, bitumen, polystyrene, mineral rock wool and PVC. It was assumed that these materials are disposed on landfills or burnt in waste incineration plants. Landfill fees account for about 30€/t and costs for waste incineration for about 100€/t. Eternit contains hazardous asbestos fibres and is therefore landfilled. Otherwise asbestos could enter the atmosphere and release harmful substances, if burnt. Bitumen is also very likey to be landfilled, whereas mineral rock wool is usually burnt. Synthetic material and PVC are usually processed after collection and often recycled. Nevertheless, depending on its composition and purity, some quantities are subsequently burnt in a waste incineration plant.



Figure 16: Commodity Prices for Remaining Materials

In order to approximate the value of the raw materials which cannot be recycled and require appropriate disposal fees after demolition, figure 16 shall indicate approximations on primary prices. It gives information on values of eternit, bitumen, synthetics, PVC and mineral rock wool. In regard to costs of eternit panels, it was assumed that they cost about double the price of concrete due to the fact that they are made of concrete and contain additional fibres. Regarding mineral rock wool, it is usually indicated in the unit m³ or m² and not in tons because its density is very small accounting for 0,025t/m³. Hence, its price is around 70€/m³.

Especially the values for synthetics and PVC are only approximated figures because the materials have numerous applications and various compositions. For the fraction of synthetics, it was assumed that 10% of House Döbling's masses are recycled and can be recyceled with the revenue of 240 €/t. In fact, it is not representative to assume this case on a general basis because the variations of prices and composition of synthetic materials are too big so that a general assumption on a recycling price would not give any representative information. However, according to information of a synthetics recycling plant, hard PVC, which comprises façades and pipes, has an average recycling value of 100 €/t and soft PVC including cable sheathing has a negative value of around minus 50 €/t. All in all, the average prices are not representative only to a certain extent because, recyclable PVC pipes can have a value between 20 to 350 € per ton depending on quality and composition status.

All in all, it can be stated that the price difference between primary and secondary materials varies by a factor of 10 to 2 depending on the specific material, its use, reuse, primary and secondary function and recycling application. On the whole, metals and glass have the smallest difference between primary and secondary value representing a price increase of around a half except for steel whose price variation between commodity and recycling value lies between 100 to 200 ¢/t depending on purity and level of separation. What is worth to acknowledge is that not 100% of metals can be recovered from a building. Often, around 85% to 90% can be regained and the rest either ends up as scrap metal or goes to a landfill as mixed building rubble because it is inseparable from other materials, such as mineral materials.

4.5.4. Value of House Döbling's Primary and Secondary Building Materials In this chapter, the recycling scenario from chapter 4.5.1. and prices from chapter 4.5.3. are linked to House Döbling's material streams with the aim of disclosing the potential primary and secondary resource value. Firstly, figure 16 shows the original value of the 14 selected materials before construction. Figure 17 illustrates the secondary value of House Döbling by showing the same materials with either a positive or a negative value. Due to the fact that there is no material stream of which 100% can be recovered, there is always a quantity remaining as building rubble which cannot be regained or separated from other materials and has to be disposed in the form of mixed demolition waste. Materials representing a 'positive value' are materials whose recycling value exceeds their disposal fee. So, the revenue gained from the quantity being recycled is higher than the disposal fee of the quantity which requires disposal. On the other hand, materials with a 'negative value' can be substances which are either completely unrecyclable or materials whose disposal fees are higher than their revenue gained from recycling. Unrecyclable materials of House Döbling comprise eternit panels, bitumen, mineral rock wool and polystyrene. It was assumed that these materials are disposed on landfills or burnt in waste incineration plants. The disposal costs were assumed to be 30€/t for landfilling and 100€/t for waste incineration. Overall, it shall be acknowledged that only the value of

building materials is taken into account without processing, labour or transport costs.



Figure 17: Value of Raw Materials built-in House Döbling

Figure 17 illustrates the value of primary resources in House Döbling taking into account the masses of each of the selected substance. Even though the materials are listed according their quantity starting with the biggest, it is obvious that there is no connection of quantity and financial value of materials except for concrete. However, concrete is the biggest material stream accounting for 92% of total quantity which is 22 000 tons. So, before construction, most money was spent on concrete and steel, which both account for around 1,2 million Euro together. The total sum of all materials corresponds to 1.43 million Euro. On wood and PVC about 63 000 Euro and 50 000 Euro respectively were invested. Most materials correspond to a financial value between 10 000 and 37 000 Euro, such as bricks, glass, polystyrene, aluminium and copper. The financially less significant material streams comprise sand, eternit panels, bitumen, other synthetics, mineral rock wool and other metals. Interestingly, metals except for steel do not play an extraordinarily financial role in terms of total material investment in the house. In the main, most money was invested for concrete and steel. Even though sand accounts for the second biggest material stream, its value accounts for not even 10 000 Euro which indicates that money spent on materials does not necessarily correspond with their masses.



Figure 18: Value of House Döbling's Waste Products derived after Demolition

Figure 18 indicates the financial value of the selected material streams after demolition. The positive values represent material streams whose recycling value exceeds their disposal value, such as concrete, steel, glass, aluminium, copper and scrap metal. Material streams with negative values are either not assumed to be recycled at all, or their disposal fees exceed their recycling value. Eternit panels, bitumen, polystyrene and mineral rock wool are disposed to 100% either at a landfill or waste incineration plant and therefore automatically have a negative value. Even though, a certain percentage of sand, bricks, wood, PVC and other synthetics is recycled, the revenue gained from recycling does not outweigh the disposal costs and therefore the material streams only entail costs. It is interesting to note that 95% of sand can be reused, but it still entails a negative value because the disposal price of 30 Euro per ton is much higher than its recycling value of 2,6 Euo per ton. Evidently, the most profitable secondary materials are concrete, steel and copper, followed by glass, aluminium and lastly, scrap metal.

If all positive and negative values of the material streams are summed up, a value of about plus 82 000 Euro results excluding processing costs of recycling material. That means that the demolition company Prajo gets a price of 82 000 Euro for the secondary builling materials in addition to the salary of the conctracting entity ordering the demolition. However, in this case, it is taken into account that Prajo has a recycling plant processing the mineral fractions of House Döbling which means the processing costs for concrete, bricks and sand are not taken into account because they stay within the demolition company. Moreover, the costs related to the separation and processing of glass are not within the calculations. Neither comprise the calculations the acceptance prices of mixed building rubble which is delivered to a waste collector company. Overall, only the 14 material streams were investigated in terms of their quantity and financial primary and secondary value. In order to compare the primary (1 430 000€) and secondary value (82 000€) of House Döbling, the building material loses a value of factor 17 during its primary use and the secondary value accounts for about 5,7% of the primary value. However, these figures are referred to House Döbling and do not have a representative function for general assumptions.

5. Results and Discussion

The study on composition, quantity and financial value of House Döbling's construction materials shows that the major material streams are of mineral nature. So do concrete, sand and bricks account for 96,80% of the building presented in the case study. Wood corresponds to 0,60%, synthetics to 0,20%, metals to 1,80% of the total mass of House Döbling. Other material streams, such as eternit panels, bitumen and mineral rock wool account for around 0,60% in terms of total mass quantity. Even though metals represent less than 1% of the total mass, they are identified as being among the most profitable material streams of House Döbling after demolition as well as concrete and glass. The assumed recycling scenario of House Döbling's material streams shows that the sum of building materials after demolition entail a so-called positive secondary value, even when disposal costs are taken into account. However, processing costs for recycling are not taken into consideration, because the prices of recycling materials are assumed at an early stage before an actual recycled item is manufactured. Moreover, transport and labour costs as well as financial efforts linked to the deconstruction and recycling of the material are not considered. Therefore, it cannot be firmly asserted that the secondary value of building materials can be considered as additional revenue for the demolition company. Nevertheless, if the primary and secondary resources themselves are considered without associated charges, the secondary value is still positive. For this reason, the hypothesis of this thesis is veryfied. This positive value of secondary resources is referred to around 80 000€ and strongly depends on recycling routes, purity of the material and the actual market conditions determining prices. If the secondary value of recycled building material is compared to the primary raw material value of House Döbling's mass quantities, it is evident that the primary materials' value decreases by a factor of 17 in the presented case study. However, it is not possible to generalise this result to other cases, therefore the decrease in value has to be determined in each individual demolition project.



Figure 19: Most Profitable Material Streams

Figure 19 illustrates the most profitable material streams after demolition which are steel, concrete, copper, aluminium, glass and scrap metals. Even though concrete accounts for 92% of the whole building mass, it is only the second most profitable material stream after steel. The financial sum of the mentioned fractions is referred to around 125% because material streams with negative values are also taken into consideration. Negative values correspond to substances which entail disposal costs. However, it is vital to mention that not all recyclable materials have a positive value because it is not possible to recycle 100% of each recovered material fraction. Often, regained material is mixed and contaminated with disturbing components and therefore requires disposal, such as landfilling or thermal recovery. As for instance, a certain part of sand, bricks, wood and synthetics is recyclable, but the disposal costs of the recyclable fraction exceed the revenue gained from recycling. Therefore these substances entail a negative value. On the whole, a realistic recycling scenario was assumed based on information gathered from interviews with experts. Regarding polystyrene and mineral rock wool, it was assumed that these material streams were disposed and thermally recovered. However, it is technically feasible to reuse both of them, but not a general practice in Austria. In terms of polystyrene, it may have an almost 100% recycling rate when it comes to packaging material. Though, it is not recycled if taken from the construction sector. It is unclear why there is no recycling option for mineral rock wool in Vienna even though the technical optoin is available. For the future, the recycling potential of both mineral rock wool and polystyrene should be exploited in order to increase the recycling quota and the recovery of secondary resources in the construction sector.

6. Conclusion

This thesis outlined the recycling of building materials in regard of composition and financial value of construction and demolition waste. Thereby, the aim was to contribute particular knowledge on the political, legal and economic preconditions for the recycling of CDW and providing specific information on composition and value of resources in the building stock.

The first and theoretical section of the thesis gave an overview on the current situation of CDW management in Austria elaborating relevant definitions and data on use and consumption of CDW. Consequently, the state of the art regarding management of CDW-derived recycling products was shown by outlining the legal and political situation in Austria and Europe. Thereby norms, regulations and guidelines linked to the practice of CDW management were consulted to set the foundation of economic aspects concerning the reuse of building materials. Strategies and obstacles of secondary markets for dismantled building substances were identified. The aim was to illustrate how the legal and political preconditions may favour the establishment of secondary markets. The finding of the theoretical part showed that the political framework can have positive influences on quality improvement of recycling products and hence, the establishment of a secondary market by enhancing a binding definition of end-of-waste status and a product status declaration.

The second and practical section was based on a case study where a retirement home building of 60 000m³ cubature was investigated in terms of materials, composition and financial value. The hypothesis that building materials entail a financial value was confirmed by answering the research questions: Firstly, the analysis of material composition and quantity was based on the selection of 14 material streams based on major quantity. Secondly, the 14 major material streams concrete, sand, steel, bricks, wood, eternit panels, bitumen, PVC, glass, polystyrene, aluminium, copper, mineral wool and scrap metal were localised in order to find out their location in the building which is relevant for their recovery rate. Thirdly, a recycling scenario for House Döbling was created with the aim of illustrating recycling and disposal paths of the 14 materials. Then, prices of primary and recycled materials were investigated by research and consultation of experts and compared to each other to approximate the value of primary and secondary resources in general. After the juxtaposition of primary and secondary value; quantity, primary and secondary prices of the single materials were related to each other in order to find out the total primary and secondary value of resources put in House Döbling. Thereby, costs related to processing, labour and transport were not taken into consideration. Solely the prices of the materials themselves and disposal costs were used in the calculations. Still, the outcome showed that the primary value was about 17 times higher than the secondary. For the investigation of the secondary value, the recycling scenario was taken into consideration as well as disposal costs were taken into account. The result showed that even with disposal costs of materials, the total value of all secondary materials after demolition is positive without related labour, processing and transport costs. On balance, quantities and profitability of materials were only related to each other in the case of concrete accounting for 92% of the total building mass. Moreover, steel, copper, aluminium, glass and scrap metal were identified as the most valuable secondary resources after demolition even though they accounted for less than 3% of the total building mass.

6.1. Limitations and Strengths

Even though the recycling scenario is based on a realistic assumption on recovery rates and prices, more scenarios with varying recycling rates and prices could be developed in order to evaluate different scenarios of use or disposal. Differently assumed set-ups could also capture price fluctuations according to market development which is especially relevant in the case of metals. Regarding financial value, the difference in prices at various recycling stages might also be interesting to investigate. Furthermore, transport, processing and labour costs are of crucial importance when determining the profitability of recycling building materials. In order to find out if the demolition company could expect a positive revenue from material streams after demolition, financial efforts related to recycling scenarios should be taken into account.

Yet, it has to be noted, that the amounts of the material quantities are based on inhouse investigations and are the result of approximations. Originally it was planned to juxtapose the approximated amounts to the de-facto amounts given from the demolition company Prajo. The comparison between approximated and de-facto amounts could show how far it is possible to estimate on waste streams before a house is wrecked. This is relevant for prior determining material fractions in order to make the demolition process more predictable and to plan better ahead. Unfortunately, the data was not sent out in time, therefore the comparison could not be made.

Even though the thesis comprises strengths as well as limitations, its significance is expressed by its actuality. Furthermore, there is almost no scientific research on financial values of recyclable building materials. Research efficiency is a major concern as well as an important target in world politics and economy. Relatedly, the European Commission launched the project 'DRAGON – development of resourceefficient and advanced underground technologies' from 2012 to 2015 which deals with the efficient reuse of underground construction materials. The project's objective is to find ways of substituting large amounts of primary mineral resources with underground construction materials, such as excavated tunnel material. That would result in reducing environmental problems and CO2 emissions involved in landfilling and transport. The applied methods include life-cycle analysis and material flow analysis to compare different scenarios of the use and disposal of excavated material (Dragon, 2012). Thus, also an analysis on the financial value of excavated material would be of great interest. This project proves the relevance of the topic on reuse of construction and excavated material which certainly will continue to have a vital environmental and economic significance in the future.

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