Surveying the building stock of Graz with regard to a circular economy in the construction sector

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Abstract. Construction consumes about 40% of resources globally. The switch to a circular economy model in the building industry can contribute to the reduction of use of resources, and lower the environmental impact by extending the life cycle of building components and materials. However, circular economy principles in building industry are not yet established, while at the same time the complexity and consequences of such a transition require further research. The objective of the exploratory study “City Remixed”, whose first results are discussed in this paper, is to identify re-use and recycling potentials of Graz's building stock for the city of Graz, in order to initiate the transformation of the building sector of the city towards the circular economy. Considering the city of Graz and its surroundings in a reasonably short transport distance as a closed system, we started by quantifying the existing building stock in form of a digital 3D model as shown in this paper. In addition to the recording of the materials or construction elements present in buildings and infrastructure (networks) and quasi bound in them with regard to type of building material, quantity, condition and position in a geo-information system (“urban cadastre”), the expected future time of availability of the material or construction element is also to be recorded digitally. In the future we will enrich the model with metadata, in order to enable the investigation of re-use and recycling potential of the components and materials as well as to determine companies, manufacturers testing and certification institutes that are necessary for these processes. Finally, we will develop renewal scenarios based on the existing building stock, as a result of possible component and material flows. From this process, we identify the fields of action, we settle decision-making bases and provide recommendations with regard to the transformation to a circular economy for different stakeholders, including the citizens. In this context digital technologies allow the storage, retrieve, management and update of large amounts of information, support the development of circular economy scenarios, which in turn offer a simple way towards the re-use and recycle of materials in the building industry.

Keywords: city, scenario analysis, circular economy, sustainable construction, data analysis
1. Introduction

1.1. On the need for a circular construction in Austria

With about 40% worldwide[1] and in Austria even more than 50% of the total resource demand (in mass) and more than 70% of the total waste (in volume), the construction sector has a major impact on the overall waste management and CO₂ balance.[2] About one third of the total anthropogenic CO₂ emissions are due to the construction industry.[1] The production of cement alone currently accounts for about 8% of global greenhouse gas emissions and 3.2% of Austria's CO₂ emissions.[4] Given the growing world population and the already reached planetary boundaries, a scarcity of resources is to be expected, which will lead to an increase in the price of building materials and especially mineral building materials. The resource needs of the world's population are expected to double by 2050[5] and thus the energy required to produce them will also increase.

One indicator of resource consumption is the land use, which is increasing by an average of 11.8 hectares per day in Austria. This is understood to mean the permanent loss of biologically productive soil due to building development for settlement, transport and leisure purposes or quarrying areas. Of this, 41.2% is sealed, meaning it becomes impermeable to water and air [6]. Land consumption is also addressed in the EU's 7th Environmental Action Program [7], which calls for no more land to be taken up by 2050 at the latest.

Another indicator of resource consumption is new construction. It is expected that in Austria, about half of the existing buildings will be replaced by new buildings by 2050. Therefore, the building stock of around 3.700 million tons (475t per inhabitant per year) is growing by 2.4% annually. [11] This is due, among other things, to the average life cycle of a building. Although a standard life cycle of a building is conceived to be 50 years [9], in Vienna the life cycle is reduced to approximately 35 years. [8] Office buildings are sometimes even demolished after 20 years [10]. The cause for this phenomenon is often the increases in land prices, which forces a higher utilization of Individual building components are thus designed to have much longer lifetimes and have great potential for reuse. [8] Currently, a large proportion of materials derived from buildings are either downcycled (e.g., as road aggregate or fill) or end up in landfills. Recycling of materials for use in new buildings or reuse of building components is rarely practiced. In the past, building materials and products were typically reused more often in other construction. However, the application of these practices has been declining over the last 70 years [13]. There are several reasons for this; among others, the increasing complexity in recycling and reuse plays a major role [1]. Furthermore, high costs for dismantling are a major issue; on the other hand, there is often a lack of information and expertise to carry it out profitably nevertheless. In addition, legal restrictions pose a hurdle to the establishment of circular construction. In the "City Remixed" research project, possible fields of action are being developed and solutions sought.

Nevertheless around 60% of the construction waste generated in building construction is landfilled in Graz. [11] In order to counteract the resource and associated waste problems, the development of proposed solutions is essential. Closing linear material flows into closed circles. This opportunity has not only been recognized by the European Commission and cited in its Action Plan for Circular Economy [1], but also in Austria it is already included in the Federal Waste Management Plan [2]. In Graz, the circular economy is not yet part the Stadtentwicklungskonzept 2020 (city development concept) but CO₂ emissions are to be reduced and, despite a growing population, only one fifth of the resources are to be consumed by 2050. In order to achieve those goals, there is a need to make adaption in the spatial, urban, transport and energy planning with the help of new information and communication technologies, though intelligent system integration and though networking. [12]
1.2. Circular economy in the construction industry

In principle, materials in a circular economy are kept in use for as long as possible. The key is to keep the value of materials, products or components constant. Materials are valuable when they are accessible, functional and attractive. This requires that materials and building products can be removed from a building at the end of their life cycle with minimal effort, without contaminating the environment and without losing their qualities and properties. [1]

A circular economy in the construction industry follows a clear waste hierarchy (simplified in Fig. 1). This hierarchy forms the principles to be followed in a functioning circular economy. In the first place is refuse, and should indicate to reconsider demolition or deconstruction of a structure, to find another use for it, or to expand or rehabilitate the existing structure. Early demolitions are usually due to a financial reason. If a demolition is certain, then a deconstruction is to be aimed at, which is to be accomplished as non-destructive as possible around whole building components again to use (reuse components). The terms recycling and reuse are combined together, but there is a strong hierarchy in a material cycle. In this sense, reuse is seen as a reuse of building component that has been reprocessed without much effort. In recycling, energy must be applied again to return resources to their original form. [1] The last step for reclaimed material is to consider it as worthless waste and landfill it, which is considered to be the worst option. Thus, it is imperative to increase resource efficiency by extending the life cycle of structures and introducing them into a cycle of reuse or recycling. In contrast, moving to circular economies can increase jobs and reduce carbon emissions by 66%. [15]

1.3. Aim and objectives of the research

The aim of the project is to identify the potential and the obstacles that need to be overcome in order to facilitate a shift towards a circular economy model for the building industry for the city of Graz. The objective of the research is to identify the reuse and recycling potentials of components and materials, by investigating companies, manufacturers or laboratories and testing institutes that are necessary for these processes. The findings and effects on the building industry resulting from this process are prepared as fields of action, set the base for decision-making and for recommendations with regard to a "Green Transformation" that can be used by the actors of sustainable building (the city of Graz, investors, planners and residents).

2. Methodology

2.1. Literature research

Based on relevant literature review which includes specialized books and study of regulations and norms, we formed the fields of action for the shift towards the circular economy for the city of Graz.
2.2. **Technical discussions**

In order to obtain the necessary knowledge, we included qualitative research based on discussions with experts from fields related to economy and building industry.

2.3. **Data collection**

Furthermore, an attempt is made to collect metadata about Graz. In addition, areas of the city have been identified and analyzed according to defined criteria that include the use of building, the construction period and the construction method. The metadata and information extracted by this inventory analysis was used to generate a material map of the existing building stock in Graz. Through this inventory, the potential and feasibility of a circular construction industry in Graz is being demonstrated.

The research project City Remixed is fundamentally concerned with the conservation and associated reuse of the anthropogenic building stock of the city of Graz. Leftovers of building materials are highlighted and transferred from a building-level perspective to an overall urban context. The study considers all 17 districts of the city Graz and ends at the city’s borders. Building construction and infrastructures are included in this analysis.

Between 1951 and 2011, the population of Styria increased by approximately 9% from 1.1 to 1.2 million inhabitants. In contrast, the development of the building and housing stock in Styria shows a different dynamic. In the same period of time, it increased by 234%. There were 176,000 buildings in 1951 and 350,000 in 2011. The fact that the housing stock only doubled (+202%) in the same period of time shows that this isn’t only caused by the demographic development in the second half of the 20th century.[11] According to the last publicly accessible building census, there is a building stock of 39,984 buildings in Graz.[22] In view of the retrograde development, we state that this number increases by about 11% in a decade and comprises an estimated 44,400 buildings in 2021.

The anthropogenic stock in buildings comprises 186 million tons in Styria in 2011. [11] An estimation based on this number and the inference from the building stock Styria - Graz, results in an estimated anthropogenic stock in buildings in Graz of about 26 million tons. Infrastructures and networks are not considered. A case study of a demarcated district in Graz Eggenberg has shown that the embodied stock in mass in buildings to networks is in the ratio 70 to 30. [11]

The study is based on the development and analysis of a 3D model of the entire city. The model includes all the building volumes in low level of geometry. This was generated using Python, a scripting module for the 3D modeling program Rhinoceros, which accesses the open source data of OpenStreetMap. Additional information has been assigned to the building geometry in order to create an inventory prototype. That includes Geographic Information System (GIS) data, publicly viewable databases, and previously analyzed results from projects. Buildings under monument protection are deducted from the mass determination. Information about it one in the AGIS (AltstadtGrazInformationsSystem). [21]. OpenStreetMap was used because it’s freely-reusable geospatial data.

![Figure 2. Overview Building Stock Graz](Institute of Architecture Technology (IAT), TU Graz)
For an efficient circular economy, specific data or tools for monitoring are needed, whereas a lot of (meta-)data are in the property of the Urban Planning office. The problem often lies in the accessibility and linkage of the data. Basic data is often located in different offices, with the surveying office of the city of Graz being the key office. Most of the existing data is not intended to be publicly accessible due to personal data protection. In 2015, the research project Urban Mining Kataster (UMKAT), which have been developed in collaboration of the Environmental Office and Surveying Office of the City of Graz the City and Ressourcen Management Agentur (RMA), was a first attempt to document the building stock in the city of Graz and therefore to introduce the circular economy in the building sector of the city. In a selected project area in Graz-Eggenberg, the material composition of the existing construction and networks (road, canal, rail, etc.) was determined, quantified, evaluated and visualized with the help of the urban GIS. A temporal component was neglected in this project. [11]

Although there is information related to the period of the building construction, it requires a lot of manual work, since the information is not digitized. A temporal assignment can be achieved by photogrammetric evaluations or local inspections. This in turn makes a categorization possible, which was conducted according to Seiser [3] and is based on the type of construction/building, the use/execution and period of time. This also indicates the expected service life of a building and therefore its end.

Analogous to created categories, areas in the urban fabric of the city will be selected and analyzed as precisely as possible regarding the existing building and infrastructure. The quantities then are determined and shaped in form of tables. Those include the total volumes, the construction volumes and the material and component quantities. Those average values which in turn are determined based on the amount and characteristics of the buildings that have been analysed. Due to time limitations, this project considers only a minimum amount of buildings taken into analysis in order to extract the average values.

The results from the analysis of the categories will then be raised to an urban level by multiplying the average values by the mass of the structures assigned to a category and quantifying them. The targeted result is a prototypical inventory and is intended to illustrate a time estimate of the release of resources, with the inventory being determined in [t/m²]. Unfortunately, the developed urban mining cadastre does not contain any information about the time in the future when certain materials or building elements will have to be renewed or will probably be available in order to be recycled.

3. Identified fields of action for a circular economy in the construction sector Graz

From discussions with experts and literature research, it became clear that the reuse of components and resources is currently insufficient for a number of reasons. These include technological, planning, economic and also cultural reasons. In summary, the following predominant fields of action emerged as an interim result:

- Circular planning
- Demountable construction, planning for reuse
- Increasing the service life and value of materials and products
- Digital documentation of buildings and infrastructure networks in a uniform, comprehensive, cross-linking and digital format, which also contains information on the expected availability (time dimension).
- The lack of new circular-enabling business models and subsidies
- Framework conditions and incentives for high-quality recycling

3.1. Circular Planning

The early designs stages show the highest impact of the recycle-reuse potential of a building. During the circular economy decision making of materiality, construction methods and others, architects need to show higher responsibility on the one hand, while on the other, they need special knowledge and tools.
Integral design, ideally supported by Building Information Modeling (BIM), captures and documents the relevant information throughout the life cycle. End-of-life and circular economy parameters must be included in an overall LCA (life cycle assessment), which is intended to serve as an important decision-making aid. Smart management of material flows on the construction site can reduce waste. Thus, building in modules is considered to have great potential. [16]

3.2. **Increase the service life and value of materials and products**

The way a product or system is designed and manufactured has a critical impact on its effects and future fate. This can include impacts on the environment or human health at all stages of the lifecycle and beyond - from the sourcing of raw materials required for the manufacturing process to the final decommissioning or second life of a product. The design phase, in particular, offers a great opportunity for the circular economy. Designing a product or building so that it can be easily disassembled, recommissioned, remanufactured or refurbished is a central pillar of a functioning circular economy. This includes the concept of design for disassembly, design for recycling or similar concepts. Another aspect is the selection of materials. Decisions about material use are made during the design and production phases, including responsible sourcing (e.g., resource criticality) or consideration of recycling aspects (e.g., recycled content). [1]

Often neglected aspects are the high resource and energy input, the so-called grey energy, which is necessary for the extraction of the used materials, as well as the effort for the construction of the infrastructure itself. [6] Also, the connection technology has to be considered in order to avoid a disproportionately high effort of reclamation. Among other factors, the potential for reuse is highly dependent on the building's construction method, age, and type of use. Structures built up to about 1920 have the greatest potential for reuse of building components. This is due to the fact that the existing connections of these buildings often allow for a non-destructive deconstruction of components and the materials used are usually of high quality and are additionally in high demand due to their special appearance. [9]

Nowadays, many products contain a large number of different types of materials that are bonded together in different ways to achieve the mechanical and physical properties relevant to a product's application. On the one hand, this often leaves products to perform only one specific task, but on the other hand, this also makes it difficult to recycle them by type. In addition, there is an information gap in material and product information. Wood, aluminum or steel count as completely recyclable. As long as they can be recycled by type, there is nothing to stop them from being reused. When used correctly, they produce no waste. Furthermore, a trend towards timber construction can be observed and it is assumed that load-bearing elements will be made of wood and metal instead of reinforced concrete in the future. If reinforced concrete is not returned to a cycle as recycled concrete, then its fractions often end up as gravel substitutes and are thus no longer in the sense of a circular economy, since neither the gray water stored in the concrete nor the gray energy of the cement or the increasingly scarce resource sand can be recovered. [9] The reuse of entire concrete components is only conceivable in a modular construction method, since the continuous reinforcing steel must be interrupted during dismantling.

3.3. **Documentation of structures and of infrastructure networks**

Often, the composition and properties of materials and products are not known or are not communicated to the relevant actors in the building value chain at the required time. Therefore, standardized methods of data collection for materials and products in buildings throughout the life cycle of a building are urgently needed. In addition, there is a need for a uniform, comprehensive, cross-linking and digital format, which also contains information on the expected availability (time dimension). In order to evaluate and promote a circular economy, a wide range of information is needed from different actors along the value chain and thus a continuous documentation of the buildings has to take place in order to have information about the resources used and also pollutants. This could work via so-called Materials Passports (MP). A MP is a tool that provides a platform and repository for storing, linking and providing relevant information about materials in buildings (e.g. building products) to relevant actors along the
value chain. They are (digital) data sets that describe specific properties of materials and components in products and systems that give them value for current use, recovery and reuse. They are an informational and educational tool that describe properties that are often not covered by other documents or certifications of building products. In particular, the focus is on the recyclability of products. MPs do not evaluate the data output and are not data evaluators. Instead, they provide information that supports evaluation and certification by other parties and allow existing evaluations and certifications to be entered into the passport (as uploaded documents). In short, an MP is a digital report that contains data relevant to the circular economy that is entered into a central database and then extracted from it in the form of reports. For a material, for example, an MP can define the value of its recycling, whereas for whole products and systems, for example, decomposability can define the value and potential of a deconstruction. An important aspect of material passports is the traceability of materials and products throughout their life cycle and beyond. [1]

3.4. Circular business models and subsidies
The reuse of building components is currently still a niche market. However, as the demand for it is expected to increase in the future, this market segment is predicted to have great potential. [17] New economic sectors are to be developed to provide access to used construction resources. The market segment offers great potential for new business models and for job creation. In other countries, such exchanges are already happening through online used construction parts exchanges and similar initiatives. [18] This shift could also bring the formation of new jobs and roles, such as recycling managers, auctioneers and used goods dealers for material stock.

3.5. Legal framework conditions conducive to the circular economy
In order to harmonize the building regulations in Austria, the Austrian Institute for Building Technology (OIB) issues the OIB guidelines. They are issued following a decision in the General Assembly (which is composed of representatives of the federal states) and are thus available to the federal states. To a large extent, the federal states have declared the OIB guidelines to be binding in their building codes. This has led to a nationwide standardization of building technology (although it is the responsibility of the federal states). The OIB-RL are structured analogously to the basic requirements for construction works of the Construction Products Regulation (The Regulation 305/2011) of the European Parliament [19]:
- OIB-RL 1 Mechanische Festigkeit und Standsicherheit (Mechanical strength and stability)
- OIB-RL 2 Brandschutz (Fire protection)
- OIB-RL 3 Hygiene, Gesundheit und Umweltschutz (Hygiene, Gesundheit und Umweltschutz)
- OIB-RL 4 Nutzungssicherheit und Barrierefreiheit (Nutzungssicherheit und Barrierefreiheit)
- OIB-RL 5 Schallschutz (Sound insulation)
- OIB-RL 6 Energieeinsparung und Wärmeschutz (Energy saving and thermal protection)

For the basic requirements 1-7 have been implemented in the OIB, only for the 7th basic requirement "Sustainable use of natural resources" from the BPV there is no OIB-RL" (OIB, 2020d). Based on the project "WHITE PAPER KreislaufBAUwirtschaft - Standards for resource-saving construction", a proposal for an OIB-RL 7 was created in the cooperation of the Federal Environment Agency, the Building Materials Recycling Association and the architect Thomas Romm. It contains a concept for the promotion of a successful implementation of a circular economy in the building industry in Austria and describes its prerequisites. A central element is the integral planning, which sets the course for a later deconstruction with the choice of building materials.

Furthermore, the inclusion of circular economy parameters in subsidy regulations for residential construction (e.g., by formulating a "disposal indicator") could provide a further incentive for resource conservation. [20] A binding quota for the use of secondary raw materials in construction projects, e.g., in tenders, would promote the use of secondary raw materials. The specifications could be defined for specific projects (e.g. excavation, renovation, demolition) and set individually depending on the material
or components. They should not be too complex in design and should also specifically address reuse. [1] Another point of discussion is that the renewal cycles of a building (mostly in the private sector or away from traffic routes) differ from those of the infrastructure networks (in the public sector, mostly in traffic routes). Here it would have to be questioned how a coordination and a good resource management is made possible. Last but not least, it could be integrated in the existing Energy Building Certificate a scale that considers the capacity of the building materials and building components to be recycled or reusable.

4. Conclusion
With the overall goal of establishing a circular economy in the city of Graz by identifying potentials and obstacles, these fields of action were encountered and defined:

- Circular planning
- Demountable construction, planning for reuse
- Increasing the service life and value of materials and products
- Digital documentation of buildings and infrastructure networks in a uniform, comprehensive, cross-linking and digital format, which also contains information on the expected availability (time dimension).
- The lack of new circular-enabling business models and subsidies
- Framework conditions and incentives for high-quality recycling

In order to cause a rethinking and a turnaround in the building sector, a cooperation of all actors is necessary. The city of Graz has to cooperate specifically with research, provide data and make political decisions. A common goal requires working together. In the procurement of data, for example, one encounters such an addressed problem. Although some meta-data is already collected and available, it is often not accessible (for reasons of data protection or clearance from an office). Furthermore, the inclusion of circular economy parameters in housing subsidy regulations could provide another incentive for resource conservation. A binding quota for the use of secondary raw materials in construction projects, e.g. in tenders, would encourage the use of secondary raw materials. It is not only the city that can set the course for a functioning circular economy at an early stage, but also the product producers and planners, because key decisions that influence the life cycle of a building are already made in the planning stage.

Further steps include the completion of the data analysis based on the analysis of the sub-areas and quantification. The following evaluation will illustrate the basic potentials of a circular economy in the building sector in the city of Graz and show a temporal estimation of the freeing of resources, whereby this is given in masses. Subsequently, scenarios for certain resources will be created to show possible cycles. Furthermore, expert discussions will be held with all stakeholders in order to develop further fields of action.

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