Urban Mining Cadastre – a Geospatial Data Challenge

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Key words: urban mining, resources, SDI, cadastre, data management, renewable land management, urban facility management, city lifecycle management

SUMMARY

Regarding the worldwide demand on resources like minerals and metal the need of improving the mining of secondary raw material becomes clear. One of the biggest warehouses unlocked is the building stock. The approach of recovering resources from the anthropogenic stock is called 'Urban Mining'. Unfortunately, the effective potential is unknown yet, neither in a spatial nor in a temporal comprehension. The availability depends on the type of building and this leads to two main categories which have to be taken into account: On the one hand side space matters, since there is a specific spatial distribution of types of buildings. Concerning the industrial buildings for instance, an urban region with a high density of automotive industry will show a different potential than a rural area with less industry. On the other hand, the remaining life of buildings is based on both the constructional conditions and the specific use.This information could be merged by an urban mining cadaster. Thus, in a research project atTechnische Universität Darmstadt a resource cadasterinthe metropolitan region Frankfurt/Rhine-Main will be provided, comprising the industrial and commercial buildings of the region. Based on single samples of building types, a projection of the spatial distribution as well as the temporal availability for the whole region will be given.

Due to the variety of data sources – most of them in a spatial context – geoinformatic approaches can be used to combine and analyze these data. Different spatial data warehouses are providing information on building types in the research area, combined in a centralized data model can be the key element to calculate a secondary resource inventory.

This paper shows the methodical approach of gaining acadaster of secondary resources using private, OpenData, and official geo- and building meta-data as well as modeling the resource inventory. The complex study is initially focused on the city region Darmstadt.

SUMMARY
Die weltweite Nachfrage nach mineralischen und metallischen Rohstoffen macht eine Nutzung von Sekundärrohstoffen unumgänglich. Eines der größten, bisher unerschlossenen Rohstofflager ist der Gebäudebestand. Bisher sind jedoch weder die räumliche Verteilung noch die zeitliche Verfügbarkeit solcher Rohstoffe bekannt. Beide sind abhängig vom Gebäudetyp, weshalb eine Erfassung des Potenzials insbesondere zwei Untersuchungsgegenstände in den Fokus stellen muss: Einerseits muss die Verteilung von Gebäudetypen im Raum erfasst werden. So wird sich das Rohstoffpotenzial einer urbanen Region mit hoher Dichte an Automobilbetrieben deutlich von dem einer ländlichen Region mit einem kleinen Anteil an Industrie unterscheiden. Andererseits interessiert die Restnutzungsdauer eines Gebäudes, die abhängt vom baulichen Zustand und der Nachfrage nach der spezifischen Nutzung. Diese Informationen können in einem Geodatenbank-basierten Urban-Mining-Kataster zusammengeführt werden. Dazu wird derzeit an der TU Darmstadt ein Forschungsprojekt durchgeführt, in dem für die Metropolregion Frankfurt/ Rhein-Main ein Ressourcenkataster aufgebaut werden soll, das die Gewerbe- und Industriebauten der Region umfasst. Anhand der detaillierten Erfassung einzelner Gebäude werden Gebäudetypen aggregiert, wodurch eine regionsweite Hochrechnung ermöglicht werden soll. Anhand der Schätzung der Restnutzungsdauern sollen außerdem die raum-zeitlichen Verfügbarkeiten von Rohstoffen ablesbar werden.
Der vorliegende Beitrag zeigt die methodische Herangehensweise an den Aufbau des Katasters anhand von privaten, OpenData- und amtlichen (Geo-)Daten, der Modellierung der räumlichen Verteilung und der Einbeziehung von Veränderungen über die Zeit. Die Untersuchung beschränkt sich dafür zunächst auf Darmstadt.

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1. CONTEXT: URBAN MINING IN BUILDING ENVIRONMENTS

The foreseeable resource shortage and the increase of commodity prices necessitate new concepts, technologies, and services of a sustainable flow material management and value chains. The smart and efficient use of raw material, the improvement of all three components 'reduce, reuse, recycling' of the waste hierarchyleads to a reduction of costs and in environmentally damaging mining activityas well as to an improvement of security of supply [Satterthwaite 2011]. A long term goal is to decouple resource consumption and economic growth to enable a development independent of availability of primary resources.One approach is 'Urban Mining', the recovery of resources from anthropogenic stock [Klinglmair/Fellner 2010]. The reuse and recycling of resources from the building stock in particular is coherent, since the buildings 'accumulate' a vital contingent of resources. In Germany, the mineral material demand of the economy is about 150 mil tons per year. The residential buildings are made of about 10.5 bn. tons [UBA 2010] and 106 mil tons of metal [UBA 2010, Angerer et al. 2009]. In a state facing a declining growth, this potential is an option. In addition, the globalization, the development of technology, and the financial crisis cause a change in the stock of commercial buildings (table 1).

Changes in the stock of commercial buildings in 2020 (1,000 buildings/year)			
	Germany	Western Germany	Eastern Germany
New buildings	36,0	31,0	5,0
Demolished buildings	16,2	13,9	2,2
New/demolished	2,2		

Changes in the stock of commercial buildings in 2050 (1,000 buildings/year)			
	Germany	Western Germany	Eastern Germany
New buildings	26,0	23,0	3,1
Demolished buildings	11,9	10,5	1,4
New/demolished	2,2		

Table 1: Assumption for the building stock of commercial buildings, [UBA 2010]

The use of secondary resources from the building stock is of interest of both, economy and ecology since it is likely to improve the reduction of the emission of carbon dioxide. However, the re- and upcycling of metal from the building stock is still poor, because the information of kind, quantity and spatial distribution are missing. In addition, the processes of demolishing have to be adapted to possessthe resources in an efficient way (see chapter 3).This regards especially the commercial buildings: The residential buildings could be divided into building types containing an indication of the used material (see chapter 3.3). In contrast, commercial buildings are very different in structure, use and construction. However, the information of the available resources could affect the decision, if a building is

demolished – and gets part of the urban mining – or stays vacant when it is not used any longer. This decision is important for the possibilities of a sustainable urban development in terms of a circular flow land use management [DIfU 2013].
In addition, planning authorities themselves could benefit from the information since the strategic waste management could be based on the data.Thus, estimations of the specific resource quantity of a region could improve the sustainable development of a region and the building stock.

2. PURPOSE

The purpose of the research project ‘Potential of Urban Mining in the Industrial and Commercial Building Sector: the Case of the Rhine-Main-Area– PRRIG’ is to provide a cadaster of secondary resources in commercial buildings integrating a temporal component in addition of the spatial. Therefore, the entirecommercial buildingstock of the study area has to be analyzed, comprising quantity and quality of the material. The building stock includes production halls, warehouses, office buildings, educational, research and health care facilities, and community services. The technical facilities of these buildings are the main part of the urban mining approach.
The region to be analyzed is the European metropolitan area Frankfurt/ Rhine-Main. However, the polycentric regioncovers an area of roughly 13,000 square kilometers and the industrial structure varies. To develop a scheme of analysis and data-modeling first, the spatial level was scaled down to the city of Darmstadt. Darmstadt is located in the south of the metropolitan area and the industry (especially chemicals) as well as electronics and information technology sectors are a major part of the city's economy. Darmstadt also has a large tertiary education sector, with three major universities and numerous associated institutions. Their buildings are spread over the city, so the data capturing is complex and is supported by the use of a geo-information system (see chapter 4).Different external partners are supporting the research activities, supplying data about their building stock or detailed information about used material and inventory in the building. The detailed data of selected single buildings (resource reference buildings)are recorded in the project, some with direct access, and others with building literature. Information about the buildings is stored in a ‘component database’ to infer building resource values (see chapter 4.1).
The analysis is paralleled by the development of a building typology in order to classify the entire industrial and commercial buildings in the study area.
Based on the reference buildings representing different building types and their specific resource values, an estimation of resource stock of Darmstadt is to be extrapolated. Therefore, all buildings of interest are assigned to one building type. Using the gross volume in terms of a coefficient the relative resource value could be extrapolated. Afterwards, the appraisal of the temporal availability will be done based on the remaining useful life estimation (see chapter 4.2). Commercial buildings often show shorter life-cycles than residential due to the dynamics of the economic sector and technical advances.
In result, the cadaster addressing both private building owners and planning authorities should provide a decision-making support for demolishment and use of secondary resources.

3. STATE OF THE ART

Different studies concerning the resourcescaptured in the building stock have been conducted.

3.1 Urban Mining and Resource Cadastre

The idea of resource recycling from the anthropogenic stock is not a new one, but it is not systematic yet. Previous research focuses on conceptual and theoretical analysis [Prytula 2010, Weisz 2010] without a spatial relation. Only [Kohler 1999] describes a study for the German building stock on behalf of the Enquête-Commission 'Schutz des Menschen und der Umwelt' which developed a dynamic model of minerals and biological resources based on assumptions of new buildings and demolishment. Cadaster of secondary resources do not exist [Lucas 2010].
In the last years new spatial-related studies were done. [Müller 2006] developed a material flow model predicting the resource quantity of the residential buildings of the Netherlands. Based on this study, [Bergsdal et al. 2007] analyzes resources ofthe housing stock of Norway, also considering refurbishment [Bergsdal et al. 2008]. [Havranek 2010] forms an estimation of raw material of the city of Prague, including buildings and infrastructure. This estimation is based on statistical data and does not differentiate commercial and residential buildings. [Tanikawa, Hiroki et al. 2009] are estimating the building stock in Wakayama Citycenter (Japan) and Salford (UK) based on a 4D GIS-database. Their systematic approach of analyzing old paper maps and aerial photos to (manually) collect all necessarydata is applicably for specific regions, it does not fulfill the need of an automatic approach collection building informations specific for urban mining purposes.
In Germany, [UBA 2010] figures out, how elements of construction waste could be recycled more efficiently. The estimate was done for the residential building stock of Germany and comprises a model predicting changes. Refurbishment is not taken into account, although [Bergsdal et al. 2008] prove the significance (about 44 % of the secondary resources from buildings in 2004).
Since the flow balances of regions are different due to the 'typical' construction [UBA 2010: 36], neither the Norwegian, Japanese nor the Prague results could be used directly for the Rhine-Main region.

3.2 Resource Inventory of Buildings Based on Specific Values

The extrapolation of resources of a whole region could be based on specific values regarding the construction material. Data of commercial buildings are available only for isolated cases regarding new and demolished buildings without redevelopment measures. Most of the existing inventories pick the mineral waste products and contaminants accumulating during the demolition of buildings [Rentz et al. 2001].Metals and materials in terms of resources are content of newer research projects like [Wittmer 2006] showing the copper resources in buildings of Zurich. Empirical data of non-residential buildings were collected for three office buildings. Based on these samples, a model of average copper resources of virtual buildings regarding roof, IT-, heating-, electricity-, and sanitary facilities was established.
[UBA 2010] aggregates specific values of metals in building material based on the construction activity statistics of Germany. The statistic includes information on frame structure so the aggregation comprises mainly steel and ferroconcrete. Additionally, the copper in- and outflow was balanced based on the research of Wittmer including residential and non-residential buildings.
In the research project PRRIG, demolition companies' data of completed demolitions are tobe analyzed like [Raess et al. 2002],[Seemann/ Rentz 2001], and [Hassler et al. 2003].

3.3 Building Typology

To extrapolate the resources of a city based on the specific values of single reference buildings, a building typology has to be established. Today's approaches for building typologies are primarily concerned withresidential buildings [IEE 2012; Diefenbach/ Enseling 2007; IWU 2005] and focus on climate and energy efficiency improvement [IWU 2011; Wischermann et al. 2011].Although there are activities extend beyond residential houses [IEE 2012], a system of non-residential buildings is still missing.
The National Institute of Building Science provides a list of non-residential building types categorized by use[1].
Other building typologies exist in standardized spatial data models. One of themis comprised in the ALKIS (German authoritative real estate information data) data model [OK ALKIS® - HE V3]. Newer research topics focus on the modeling of cities as a system [Kolbe et al. 2005;Lee/ Zlatanova 2008]. Semantic approaches are taken into account here. Recent initiatives are promising, like the newer cityGML standardization [OGC cityGML 2.0]. The main goal is to generate a cost-effective sustainable 3D city model, allowing the reuse of the same data in different application fields. 3D citymodels are a cost intensive investment for the municipality; therefore even more use cases based on this data are necessary. Examples like the energy atlas Berlin[2] already show how to use city models for heat demand calculations. For future urban resource calculation such data models can be used, especially because they are more detailed than standard cadaster data models. Within cityGML roofs, walls (even with their material), doors, windows,etc. modeled. As they are currently under development, and no comprehensive area-wide datasets exist, theseapproachesare to be considered in the project. More than example calculations are not feasible right now, as it will take some time to integrate detailed city models in the specific Rhine-Main area. Afterwards, a mapping between own building topologies and the definitions made by cityGML [SIG] and standardization groups are promising (figure 1).

[1]http://www.wbdg.org/design/buildingtypes.php
[2] http://energyatlas.energie.tu-berlin.de

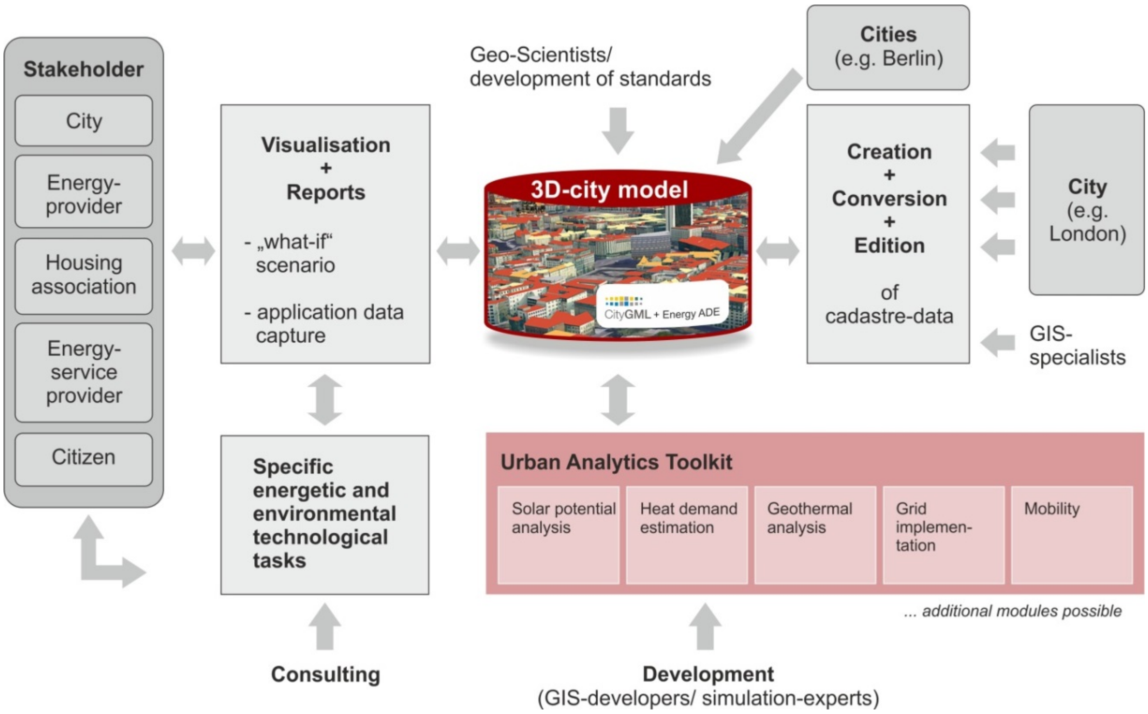

Figure 1: Concept of energy-atlas Berlin, based on cityGML,
Source: http://energyatlas.energie.tu-berlin.de/wp-content/uploads/2013/05/EA_Struktur_neu.jpg (15.11.2013)

4. METHODOLOGY AND RESEARCH DESIGN

As a geo-spatial data challenge, the PRRIG project showsmultiple research topics being intertwined. The research design – regarding the spatially related part of the project – is divided in the following steps (figure 2):

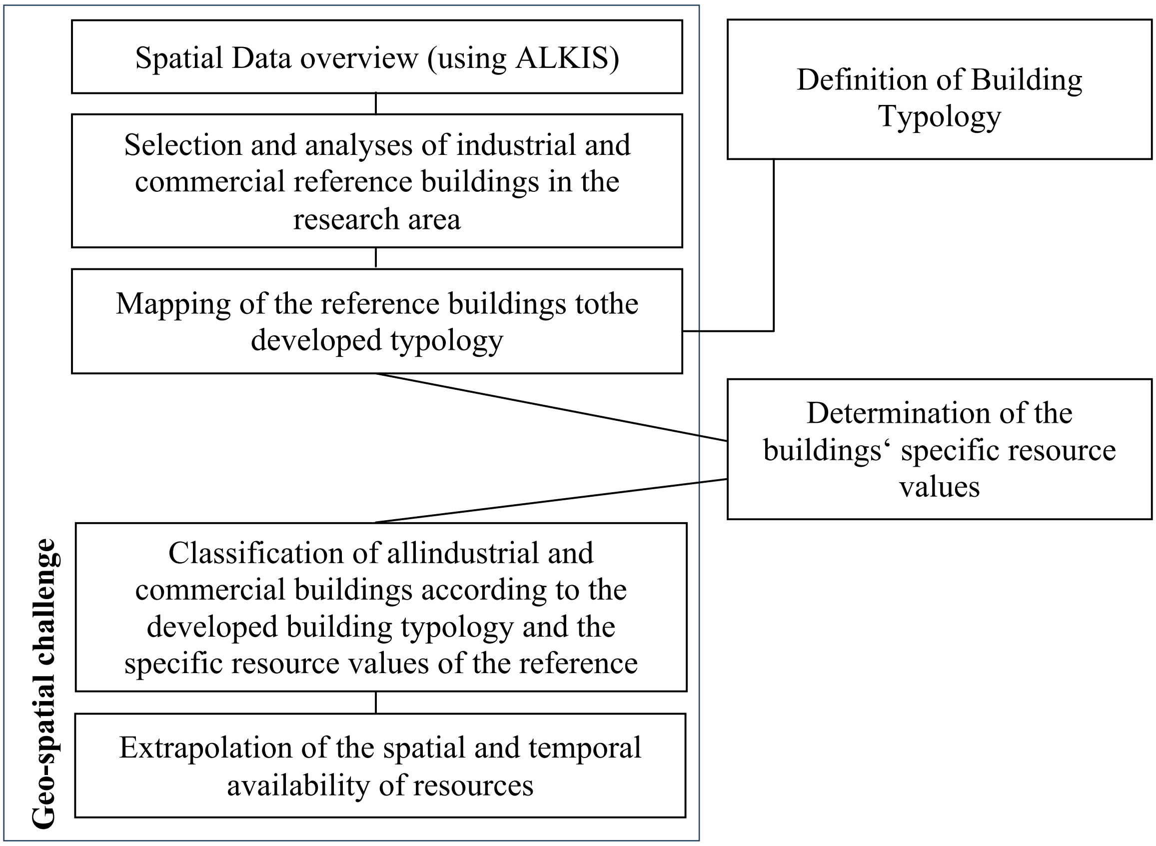

Figure 2: Research steps as a flow diagram

To gain a first overview, an integrated (spatial-)database using ALKIS is to be prepared. The authoritative data are provided for the entire area and facilitate information of the building useowing to the official building use characteristic of the authoritative real estate information data [OK ALKIS® - HE V3.0].Simultaneously, a building typology suitable for the project is to be developed[3]. Unfortunately, this first overview is not suited for the link betweenbuildings and building type or even of specific resource values and the extrapolation. Thus, further information of the actual situation is needed. This data is not provided by public authority agencies in a standardized way. Thereforesome reference buildings haveto beanalyzed more detailed. Thus, in the next step data like use, age, geometry and construction have to be collected using laserscanning, private, commercial and OpenData. This information is stored in a geo information system (GIS) and allows classifying the reference buildings according to the developed building typology. By assigning the specific resource value to the reference buildings, each building type gets a transferable resource value. Using the gross volume and the building surface in ratio, a transformation factor is gained to analyze the remaining buildings.

For a later extrapolation of resource values within the area, building data like use, typology, year of build etc. are crucial, but not suitable and valid for a region where not every building can be analyzed directly. Thus, informationof the building use and characteristics are the key parameter. Therefore, a combination of different datasets, resulting fromcase-studies, the

[3] This is not a geodetic challenge and is not part of the paper.

private sector or Volunteered Geographic Information (VGI) data, all being spatially related, is appropriate to fill this gab. After collection and aggregation of all building information, even more subject-specific analyses can be done. With data about used materials, building age and building type, material-flow-models and building live cycle considerations can be developed.

Figure Nr. 3 gives a brief overview of the methodology and overall design behind the PRRIG resource cadaster. Not every possible data source is named, but the idea of aggregating different parameters together is represented.

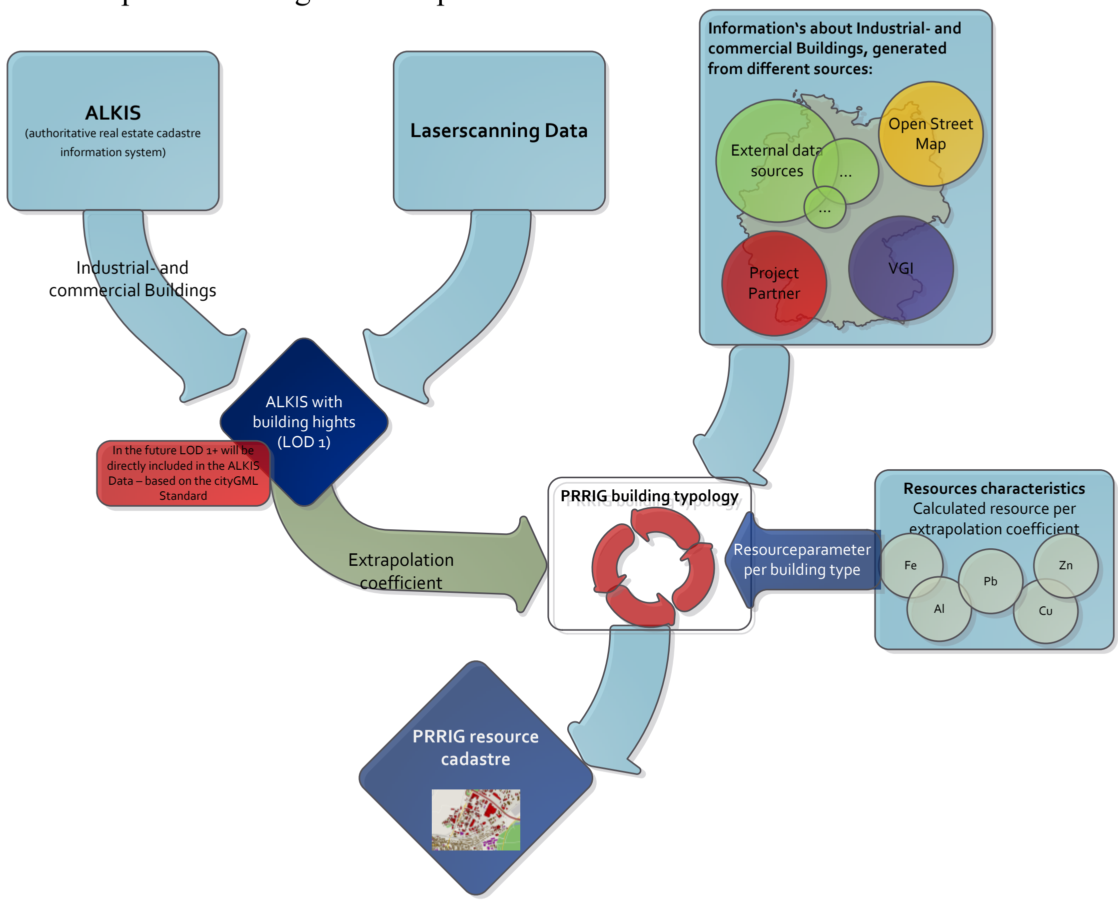

Figure 3: PRRIG cadaster – methodology and overall design structure

4.1 Building Typology

Industrial- and commercial buildings in the Rhine-Main area are differing in many aspects, in terms of use, building age, used materials, the technical building systems or the construction type. Detailed descriptions of the listed parameters for every building are not accessible, since a database like this does not exist and cannot be easily generated for the whole area. Therefore, a typology needs to be developed covering the described parameters as well as trying to model them in a comparable way. This topology will be used to logical classify all industrial- and commercial buildings into categories. One of the main difficulties of defining a comparable building typology is to balance the complexity with the accuracy of discrimination. An 'easy' model needs to be defined, but still the typology has to gather and bundle all necessary building information. It needs to focus on available datasets and

typologies as source, but still model the need of the described project.
Then, being able to map all buildings of interest to the defined typology a calculation for bigger areas is possible.
The building typology has two main functions, on the one side it is the reference system for all buildings in the defined region, on the other side frequency rates are helping to choose types which have to be analyzed more detailed and need be chosen as reference buildings for the collection of specific resource parameters.

4.2 Building Resource Values

The determination of specific resource values for each building type, case studies are conducted including reference documentation and surveys. One data source can be the project partners, who monitor building demolitions over time. This data including resource specific values can be analyzed and mapped to the typology.
As well the case studies of reference buildings can help to verify the defined typology, and expose missing types or the need of more detailed definitions. The calculation and mapping between 'building resource values' and specific 'building typologies' are a iterativemethod, and may change over time when more reference buildings are evaluated. One of the main challenges in the definitions process is how to map or generalize building conversations over time or structural alterations. The raw building by itself can have a specific age, but not necessarily the age is connected to the interiors and building system units like heating, power grids or thermal insulations.

4.3 Extrapolation

Since the buildings in the study area are not comparable directly, a quantity has to be found suitable as a coefficient. Using this coefficient the specific resource value of a reference building representing one building type could be transformed to the other buildings assigned to the same building type. In the PRRIG-project the gross volume (specified by DIN-277-1[4]) in relation to the surface has been chosen as factor. Both quantities could be derived from the geometry: the base of the building is part of the cadastre and the height could be taken from the 3D building model Level of Detail LOD 1). Future geographic data in the German federal state Hesse will for example comprise the comprehensive 3D-model.
The temporal component of the extrapolation includes the availability of resources over time. The determining quantity is the remaining useful life of the buildings depending on use, construction, quality, etc. In the PRRIG-project the assumptions are based on [Kleiber/ Simon 2006: 1423 ff.]. During the later project, results of calculations based on the extrapolation coefficient will be validated with on-side reviews. Small adjustments can be applied depending on the results.

5. PROJECT STATUS

5.1 Building Typology

[4] www.messdat.de/310-DIN277.pdf (15.11.2013)

Firstly, a project-specific building typology, taking the existing classifications [BMVBS 2011]into account, was defined. Table 2 shows the classification.

Main category type (use)	**Subcategory (describing)**
Office buildings	Government buildings, office, banks
Industrial buildings	Factory, power plant, barracks, mill
Commercial buildings	Food and non-food-markets, shopping mall
Storages	Storages, hangar, garages
Hotels and restaurants	Hotels, restaurants, fast food restaurant, roadhouses
Educational buildings	Daycare centers, schools, universities, college
Transport buildings	Airport, stations, park decks
Health care facilities	Hospitals, special-care-facilities

Table 2: Building typology defined in the PRRIG-project

In a second step, the building stock of a selected area are to be analysed and assigned to the building types. For the development of a model, the inital research focus on the city of Darmstadt.

5.2 Area specific values

The GIS-analysis of the ALKIS data offered about 8.000 buildings (or building parts according the ALKIS definitions) in the city of Darmstadtwith the attribute 'industrial or commercial use' (figure 4). All these buildings or building parts are likely to be relevant for the PRRIG-project.

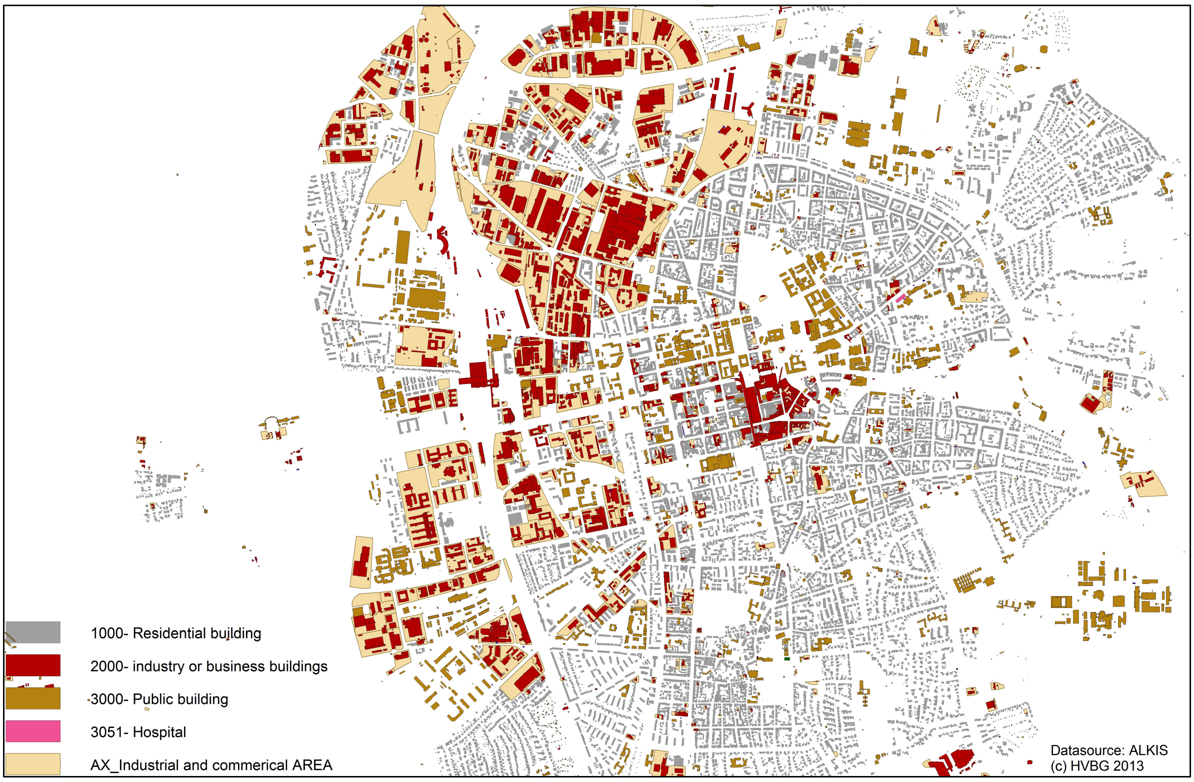

Figure 4: Overview over the Darmstadt city region (all colored buildings are of interest in the context of an urban resource cadaster for commercial and industrial buildings) spatial data source: HLBG 2013

As already described this data source can only be used as a reference and overview data set. To collect the necessary more comprehensive data, different information sources are being evaluated and integrated.

5.3 Building cadaster

Building Information Source 1 – individual datastores and integration of building information sources from the project partners

The parties involved (Fraport AG, Adam Opel AG, municipalities etc.) have building data available due to economic issues (asset valuation owing to the German GAAP (Doppik)) or logistic and strategic planning concerning the availability of production space and storage areas. These data have to be integrated in the data model and help to assign the building or building part to a corresponding building type. The comprehensive model requires the link between the spatial and numeric data of the partners with the ALKIS data in the GIS.

The specified buildings might be divided into single building parts depending on the typology. Since the PRRIG-typology also defines mixed uses, e.g. government building, the differentiation is not distinguishing single rooms, but entire floors or wings.In result, single rooms with special functions could be noted; however, they will not be part of the extrapolation.

This described overview (section 5.2.) has been used to identify possible data owners, e.g. industrial park operators in the area of interest, public authority agencies or commercial building operators. Based on this research detailed description of the buildings has been asked and the following dataset-parameters have been or are to be analyzed:

Information categories:

- Building-Geometry
  - of their GIS, CAD, or CAFM (Computer aided facility management system)
  - or the indirect location (address)
- Building type
- Building height (absolute or number of floors)
- Year of construction
- Building specialties
- Bearing structure
- Structural alteration
- Additional information

The data collection of the within-case-studies is aligned to the geometry (coordinates or at least addresses).

Building Information Source 2 –Combination with VGI & OpenData

Over and above the private dataexternal sources could be used in terms of lists of construction permits (applications) and information of OpenStreetMap (OSM). With the Volunteered Geographic Information (VGI) system for example, OSM offers a comprehensive database of building information. Although the information are not detailed yet and varying between different regions, the OSM-projects are promising, since they are improving and getting more detailed over time. The collection of data like georeferenced building permits from local authorities, by the publication within OpenData initiatives are another way of improving the data.

Furthermore,the data could be improved by people using impulsion like gamification[5], as well investors and building owners could commit informations to the database themselves.

Building Information Source 3 – Integration of thematic data stores

The third data pool are thematic data stores supported by the economy. The company IndustrialPort for example stores detailed geometries of 7.000 halls in Germany[6]. These data should be mapped to the PRRIG reference area and integrated in order to improve the dataset. Additionally, the professional registers (from public or private sources) should be integrated.

To harmonize all different datasources two approaches are currently established. One is to gather all datasets in an easy for the project calculation sufficed datastructure. In this case the various date stores are connected and integrated with GIS and finally stored in a harmonized geospatial database. The second approach is to orientate on the cityGML standardization. In this case, further research is required to collect more information about timetables when city wide cityGML datamodels provided by the authorities. As cityGML provides an open

[5]e.g. an OSM based game like - http://www.kort.ch/

[6] http://industrialport.de/

architecture it could be constructive to define anApplication Domain Extension (ADE) similar to noise or solar calculations.[7]

6. CONCLUSION

The establishment of a secondary-resource-cadaster for industrial and commercial buildings is a very complex project since there are no comprehensive and valid data of building typology or specific resource values. Even the official geographical data sets are still lacking information on height, the specific use of a building or reconstruction. This data need to be collected and integrated with the use of various thematic specific data sources. Here the interoperability comes into play. One of the main goals of the project is to generate and collect the necessary data without the need of manual collections and data integrations. As well further outstanding issues are the semantic transformation of the data. Even the relatively open defined building typology needs to be described in more detail to be able for semi-automatic matching of different external data stores describing commercial and industrial buildings.

Some future research will be on the harmonizationof data models, especially like the one of INSPIRE (INSPIRE-Directive (Directive 2007/2/EC[8])). Only if it is possible to set up a calculation for urban resources on structured data models, it will be also achievable to provide a PRRIG secondary-resource-cadaster for the whole Rhine-Main metropolitan area. This, as well, can strengthen and support the need of harmonized spatial data infrastructures (SDI) and motivate different authorities to transform and open up their data to initiatives like INSPIRE. The lack of motivation, especially at the local level, is already discussed in different studies like [Hickel/ Schnitzer 2013a and 2013b] and [Deutscher Landkreistag 2012]. Sample workflows according to the one described in this paper can be a key added value to harmonize spatial data.

Another model has to be taken into account: Nowadays the development of 3D city models is a step ahead of even visualizing the city in three dimensions. Newer approaches are trying to model the whole city in a 3D context resulting in the fact that the future will bring detailed 3D models of city areas. To adopt the described method for harmonizing 3D models with information about the building structure of every single building will open up possibilities for even more accurate resource extrapolations. Therefore, CityGML is suitable, which will be established as international 3D standard in INSPIRE.

Thus, the results of the project could be transformed to other regions not until a guideline regarding the data migration has been developed. In addition, the extrapolation of the spatial and temporal availability of resources will be a challenge of the project in an advanced status.Future demographical and economic development will vary and will be spatially dispersed. Some industries will change faster due to the technical advances or the missing succession. This is to be considered when extrapolating the spatial and temporal availability. However, the knowledge of the secondary resource mining especially in regions with declining growth is important since the decision of demolition or vacancy is based on.

[7] Overview of currently available cityGML ADE's http://www.citygmlwiki.org/index.php/CityGML-ADEs (15.11.2013)

[8]http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:0014:en:PDF

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